CONCLUSION

In this paper we presented a new algorithm of acoustic simulation of CI hearing. Physiological phenomena like current spread, loudness perception and frequency perception were included in the model. In contrast to the vocoder approach of Shannon *et al.* (1995) and Dorman *et al.* (1997) we developed a more general algorithm using CI stimulation patterns as input. Therefore, the new acoustic simulation can be used to compare different CI strategies without modifying the algorithm or its parameterization. At the same time, the simulation can be configured to mimic individual capabilities of CI users. Consequently, investigating specific influencing factors of speech intelligibility like current spread or phase locking ability is possible.

The results of this study indicate that the acoustic simulation algorithm can be used to estimate the amount of useful information in a CI stimulation pattern. Hence, it might help evaluating speech processing strategies. However, the acoustic simulation is only intended to measure trends in speech recognition performance and pitch discrimination. Exact predictions of performance regarding speech perception of a CI user are currently not possible. Further work should compare results of normal-hearing listeners using the acoustic simulation with actual CI user performance to asses the validity of the algorithm.

ACKNOWLEDGMENT

The underlying research reported in the paper was funded by the grant B514-09020 of the Thuringian Ministry of Education, Science and Culture.

REFERENCES

Bingabr, M., Espinoza-Varas, B., and Loizou, P. C. (**2008**). “Simulating the effect of spread of excitation in cochlear implants“ Hearing Research, **241**, 73-79.

Black, R. C., Clark, G. M., Tong, Y. C., and Patrick, J. F. (**1983**). “Current distributions in cochlear stimulation” Ann. N.Y. Acad. Sci., **405**, 137-145.

Dorman, M.F., Loizou, P.C., and Rainey, D. (**1997**) “Speech intelligibility as a function of the number of channels of stimulation for signal processors using sine-wave and noise-band outputs“ J. Acoust. Soc. Am., **102**, 2403-2411.

Fu, Q. J. and Shannon, R. V. (**1998**). “Simulating effects of amplitude nonlinearity on phoneme recognition by cochlear implant users and normal-hearing listeners“ J. Acoust. Soc. Am., **104**, 2570-2577.

Greenwood, D. D. (**1990**). “A cochlear frequency-position function for several species - 29 years later“ J. Acoust. Soc. Am., **87**, 2592-2605.

Kral, A., Hartmann, R., Mortazavi, D., and Klinke, R. (**1998**). “Spatial resolution of cochlear implants : The electrical field and excitation of auditory afferents” Hearing Research, **121**, 11-28.

Shannon, R.V., Zeng, F.G., Kamath, V., Wygonski, J., and Ekelid, M. (**1995**). “Speech recognition with primarily temporal cues” Science, **270**, 303-304.

de la Torre Vega, Á., Martí, M. B., de la Torre Vega, R., and Quevedo, M. S. (**2004**). “Cochlear implant simulation version 2.0 : Description and usage of the program“ University of Granada, Spain.

Benefits of common vocabulary in hearing aid fitting

Carsten Daugaard[1], Søren L. Jørgensen[1] and Lone Elmelund[2]

[1] *DELTA, Technical-Audiological Laboratory, DK-5000 Odense C, Denmark*

[2] *Institute of Biology, University of Southern Denmark, Campusvej 55 DK 5230 Odense M*

BACKGROUND

Modern hearing aids are very sophisticated devices and through the fitting process they can be adjusted to fit the hearing loss of a large variety of people. However in order to set the fitting parameters right, the communication between the hearing aid professional and the user has to be successful. The challenge here is to understand and map the experience of the user in order to transfer it to the fitting software.

Today, hearing aid manufacturers has taken up the challenge by designing software handles whose function is less technical and more related to commonly experienced hearing aid problems. They have also added expert assistants to the software, mapping common user complaints into the traditional technical software handles. When it comes to perceived sound quality, however, the challenge lies first and foremost in understanding the user’s perception, to decode the sound experience of the user so to speak. For this challenge the hearing aid professional must be experienced enough to understand the user’s language of sound perception. Hearing aid professionals know that this can prove to be a complicated problem. As with many other perceptual experiences we are not used to express sound experiences in many more words than soft, loud, annoying or pleasant.

A common vocabulary between the user and hearing aid professional would probably make the task easier so rather than relying on the hearing aid professional’s skills to understand the user’s desire, the user’s vocabulary of sound perception could be trained. Inspiration for this alternative approach can be found in the sensory evaluation discipline, where selected panels train their ability to express differences in selected sound attributes (Bech and Zacharov, 2006).

Attributes in sensory evaluation

Sensory evaluation is a systematic approach to assess the sensory impression of a given object, i.e. food products, perfumes, sound. The goal of sensory evaluation is to have a panel of trained assessors, known as a listening panel, which is able to consistently and repeatable evaluate objects in a range of attributes, describing the object. In other words, to establish a “sense-o meter” to evaluate how humans experience the object to be tested.

A central part of the descriptive analysis process of sensory evaluation is to establish specific traits of the object that can be explained and evaluated on a scale. Every

Proceedings of ISAAR 2011: Speech perception and auditory disorders. 3rd International Symposium on Auditory and Audiological Research. August 2011, Nyborg, Denmark. Edited by T. Dau, M. L. Jepsen, J. Cristensen-Dalsgaard, and T. Poulsen. ISBN 87-990013-3-0. EAN 9788799001330. The Danavox Jubilee Foundation, 2012.

sensory exposure, regardless whether that is food, sound, smell or a picture, stimulates our senses in a number of ways. We can experience complex sensory stimulation, but also break it down into more one-dimensional experiences, i.e. "Were the potatoes salty?", "Did you hear that bass?", "Was there a touch of strawberry in that smell?" Each of these characteristics objectively describes an impression of the object, as opposed to preference statements such as "It tastes good" or "Something in here smells funny". A sensory experience is comprised of a number of these characteristics, - often called attributes. As they are objective descriptors they will typically be scalable, and the quantity of each attribute will influence the sensory experience. Often the scale of the attribute is defined with one or more so-called "anchor points", explained using text and sometimes practical examples.

Basic attributes in the sensory evaluation of sound are not very well defined, therefore sound evaluation panels are typically trained in developing attributes. This can be done individually or in a group oriented word elicitation process. In the word elicitation process descriptors for a set of sound stimuli are generated. The process starts by generating all the descriptive words a given set of stimuli gives rise to. Then in a consensus meeting the generated words are grouped into attributes, and a scale and anchor points is defined. DELTA prefers to explain anchor points in text and exemplify them with - sometimes manipulated - sound examples. After the word elicitation the panel is often given the opportunity to train on the assessment of the attributes on a number of sound examples exercising the scales. Then the panel will be ready to evaluate the actual sound stimuli. Such a process will naturally be much too time consuming in hearing aid fitting. However some of the thoughts behind describing sounds with words might be applicable also in the real world hearing aid fitting situation.

A central part of the sensory process that could be applied in hearing aid fitting is the training. Working with sensory evaluation emphasizes the challenge of mapping sound impressions to descriptive words and scales consistently. This is not so different from the fitting situation, where the user must describe in objective terms the sound experience through the hearing aids. If the user was provided with a tool: 'Descriptive words and scales', perhaps the task would be easier.

The sensory evaluation process is a well-controlled "laboratory" process in principle only valid for the family of stimuli evaluated in the process. That is, a change in stimuli could give rise to a change in the set of attributes. The number of attributes describing a given stimulus, is only limited to the vocabulary and imagination of the listening panel.

The Danish vocabulary describing sound is quite rich. In 2005 DELTA established "The semantic space of sounds" - a lexicon of words describing sound (Pedersen and Zacharov, 2008). This volume comprise 450 words (in Danish and in English), collected from literature in the field as well as the dictionary of synonyms and the

thesaurus. The words in the lexicon are sorted in seven classes and after a so-called semantic space (the Euclidian distance of the words described by 17 descriptors).

The seven classes are:

1) Direct sound descriptors (e.g. loud, bassy, shrill)
2) Words relating to perceptions from other senses than hearing (e.g. bright, dark, colorless.)
3) References to events and sound sources (e.g. howling, roaring, rattling)
4) Changes or differences in perceptions (e.g. colored, compressed, muffled)
5) Affective responses to sounds (e.g. pleasant, annoying, boring)
6) Connotative associations (e.g. sporty, luxurious, powerful)
7) Onomatopoeia (e.g. woof-woof, yap-yap)

The classes 1-4 are words related to perception, classes 5-6 are affective words and class 7 is imitating words.

In the lexicon more than 30 % of the words are of class 3, followed by almost 25 % of class 6, and 20 % of class 1. Looking at the descriptions from hearing aid users from the test which is described later it is seen that also here class 3 words are frequently used. As we are dealing with hearing impairment, it is fair to assume that some attributes will be more prominent due to the hearing aid amplification, and that some words will represent characteristics of the sound, which are basically inaudible. In fact, recent work in sound sensory evaluation shows that a few basic attributes are often prominent descriptors.

Attributes in sound evaluation

When comparing the attributes of a number of studies of sound reproduction a certain pattern of "native" attributes seems to emerge. Although the names of the attributes naturally vary between studies the dimension they are describing seem to be the same. In a comparison of attributes from five different studies, dimensions like "clarity", "width", "tone colour", "distance" and "noise/distortion" seem to emerge ´(Pedersen and Zacharov, 2008). It is interesting to note that also "naturalness" is a dimension selected in two of the studies, as it is one of the parameters the un-trained hearing aid users in the study which is described later, often refer to.

Two other studies performed by the main author on hearing aids and active noise cancelling(ANC) headphones reveal attributes fairly comparable to the earlier five studies although the attributes "loudness" and "dynamic range", both of which are related to amplification, only make sense in the case of the hearing aid, because they are important factors of the hearing aids' functionality.

From the comparison of studies in table 1, it seems plausible that a handful of attributes are dominating, although the naming of these is not always identical. The attributes listed in the rightmost column of the table are from one of the first papers published on the subject, Gabrielson and Sjögren (1979). These attributes are also included in the five studies in Pedersen and Zacharov (2008). Using slightly different words, it seems to align well to the other studies. The attributes from Gabrielsson and Sjögren have been used as the basis of the training in the hearing aid fitting experiment described later in this article.

Pedersen and Zacharov	Hearing aids	ANC headphones	Gabrielsson and Sjögren
Clarity	Details	Precision	Clearness
Width/broadness			
	Resonance/Tin Can	Can sound	Fullness-Thinness
Naturalness	Distortion/overload	Linearity	
Tone colour/ brightness	Treble	Treble	Brightness-darkness
		Bass	Sharpness-softness
		Treble range	
Nearness/distance			Nearness
Space	Reverberation	Stereo Room	Feeling of space
Noise/distortion	Background noise	Background noise	Disturbing sound
	Background noise tone colour		
Localisation/direction			
	Dynamic range		
	Loudness		Loudness
	Speech reproduction		

Table 1: Attributes from several experiments listed to align similar attributes. The alignment is based upon the authors subjective impression of the sound describing words.

HEARING AID EVALUATION BASED ON SOUND ATTRIBUTES

Based upon the knowledge from the descriptive analysis process of word generation and training, a project was defined with the goals of selecting sound-descriptive words usable in a fitting situation and test if training using these words would be beneficial during the fitting process. As it is important that the describing words are meaningful to the user, an attempt was made to establish a word list on the basis of a kind of word elicitation where each user was asked to describe a number of sounds presented to him or her. The sound examples used were taken from the Acta Acoustica real life sound examples (Johannsen and Prante, 2001). The aim was to select sound examples with peaks in different frequency areas, as it would be helpful in the fitting process to be able to map certain expressions to certain frequency areas. Another selection criterion was that the sound would carry as little information as possible. The aim is to describe the nature of the sound, not derive information from the sound. However, all sounds are based upon one or more natural sound source(s), and a common reaction when asked to evaluate these sounds is to determine their origin and evaluate their fidelity. The results from the word generation indicated that a more controlled approach with basis in familiar attributes from the sensory work might be a better approach.

Training of non-experienced listeners

14 different sounds were created on the basis of the two anchor points of the 7 attributes listed below. The selection of these attributes was based upon the investigations of Daugaard *et al*. (2009).

Attribute	Anchor point	Anchor point
Softness (Blødhed)	Soft (Blød)	Sharp (Skarp)
Fullness (Fyldighed)	Full (Fyldig)	Thin (Spinkel)
Loudness (Hørestyrke)	High (Kraftig)	Low (Svag)
Tone Balance (Klangbalance)	Light (Lys)	Dark (Mørk)
Clarity (Klarhed)	Clear (Klar)	Muddled (Rodet)
Distance (Nærhed)	Far (Fjern)	Near (Nær)
Spaciousness (Rummelighed)	Enclosed (Indelukket)	Spacious (Rummelig)

Table 2: Attributes preselected for the test (adapted from Gabrielsson & Sjögren). The Danish translation is given in parenthesis.

Loudness is of course easily adjustable in the reproduction of the stimuli and in the hearing aid, but is important for perceived quality and thus included. During the training of the test persons it was clear that some attributes were more understandable than other. The characteristics of “softness” and “fullness” were much easier to relate to, than “distance”, which during training seemed to be less obvious. Curiously enough, in the after-training evaluation the words “near” and “distant” were often used.

Effect of training

The effect of training of non-experienced listeners was investigated. The participants were first presented for a set of 11 stimuli and asked for a description of what they heard. Then they were trained with the set of 14 sound stimuli generated from the anchor points seen in table 2. Then they were asked to evaluate the set of the first 11 stimuli again. During the second evaluation there was no encouragement to use the training and there was no connection between the 11 stimuli of the evaluation and the 14 stimuli of the training. In the second sound evaluation all 7 test persons choose to use their new vocabulary to describe the characteristics of the sound, rather than the interpretation of the sound source.

	User 1		User 2	
Sound	**Before training**	**After training**	**Before training**	**After training**
2 Children	Happy sounds (glade lyde)	Light, distant, sharp (lys, fjern, skarp)	Whining (hvinende)	Sharp (skarp)
3 Church bells	Church, christmas (kirke, jul)	Loud, sharp, clear, distant (kraftig, skarp, klar, fjern)	Sonorous, spacious, comfortable (klangfuldt, rummeligt, behagelig)	Full, spacious (fyldig, rummelig)
4 Circular saw	Sawing (savende)	Sharp, light, near (skarp, lys, nær)	Shrill, noise, unpleasant, metallic (skinger, støj, ubehagelig, metallisk)	Light, near (lys, nær)
5 Compr. Air	Quiet, thin (stille, spinkel)	Weak, muddled, enclosed (svag, rodet, indelukket)	Swooshing, hissing (susende, hvæsende)	Thin, distant,weak (Spinkel, fjern, svag)
7 Dentist's drill	Indeterminable (ubestemmelig)	Muddled, weak near (rodet, svag, nær)	Blowing (blæsende)	Enclosed (indelukket)
9 Hooves	Hard , clear (hård, klar)	Clear, sharp, near (klar, skarp, nær)	Rattling (Klaprende)	Near, enclosed (nær, indelukket)
10 Howling wind	Swooshing, weak (susen, svag)	Weak, soft, distant (svag, blød, fjern)	Swooshing, blowing (susende,blæsende)	Distant, weak, thin (fjern, svag, spinkel)
13 Ringing glass	Clear, sonorous, thin, clean (klar, klangfuld, spinkel, ren)	Sharp, clear, light, near (skarp, klar, lys, nær)	Tone (klang)	Sharp, near (skarp, nær)
15 Scotch Tape	Not nice (ikke rart)	Soft, thin, muddled, near (blød, spinkel, rodet, nær)	Jarring (skurrende)	Near (nær)
20 Tincan	Low (lav)	Weak, muddled, enclosed (svag, rodet, indelukket)	Hammering, noise (bankende, støj)	Spacious, near (rummelig, nær)
24 Tyre on gravel	Chrushing, Chrispy (knasende, sprød)	Soft, muddeled, weak (blød, rodet, svag)	Crackling (fire), chrunching Knitrende (ild), knasende	Weak, distant (svag, fjern)

Table 3: Examples of the user evaluation vocabulary before and after training (sound stimuli number refer to the Acta Acoustica numbering) The original Danish words are given in parenthesis.

It might seem a pretty straight-forward result (presenting a list of words makes it natural to use them as descriptors afterwards), but an interesting point is that presenting the test persons with a selection of descriptive words immediately

sharpens their attention towards the nature of the sound instead of it's origin. Examples of this are given in table 3 for two users.

This could indicate that when evaluating the sound quality of their hearing aids, the untrained users in general do not focus on the sound characteristics but rather the ability of their hearing aids to reveal the naturalness of a sound source or a soundscape. Introducing the user to another set of words, and thus refining the scope of the task for the user, might help to put the communication between the user and the hearing aid professional on the same mindset.

Providing a few attributes and some training will probably not make the fitting process a walk in the park, but in the answers displayed above it is evident that after the training the users are utilizing their new vocabulary to express their experience. The feeling of a better understanding of the task is very prominent in the comments from the test persons in the evaluation after the test. Of course this is a very simple set-up only indicating a small progress. Larger studies have to be conducted in order to fully explore the effect of training.

Naturalness

Quite a number of the test persons evaluated the sound stimuli by assessing the sound source and relating it to normality/fidelity. Therefore another experiment was conducted where hearing aid users were asked to evaluate sound recordings in terms of naturalness/normality.

Twelve sounds were selected for their natural reproduction of a sound event commonly occurring. Three of them were from the Acta Acoustica, the rest were DELTAs own recordings and from other sound compilations. The test participants were selected from "well fitted" hearing aid users, this means that the fitting process is concluded and the users are satisfied with their hearing aids. They have been daily hearing aid users between 0 and more than 10 years, and they were all from the audiological department of University Hospital of Odense (OUH), Denmark. Of the 30 invited test persons 13 participated in the test. Their task was to evaluate the stimuli on a 7 point scale where the end points were labeled "normal" and "not normal". The sound stimuli were presented via loudspeakers at a realistic sound level.

RESULTS

As to be expected some sounds were evaluated more normal/natural than others. On the basis of the current test, however, it is difficult to establish any pattern in the relationship between sound stimuli and test persons in terms of judging normality. Contrary to normal scaling it might be expected that – provided good recording quality, hearing aid quality, familiarity of sound event etc. – the sound stimuli would generally be rated as normal.

The test shows that one of the participants seems to experience ‘normal’ differently from the others or using the scale differently. Disregarding test person 13, a few of the sound stimuli are judged generally as normal (2, horse hooves and 10, hand washing), while all other stimuli have one or sometimes two test persons evaluating them as non-natural. Looking at the test persons three of them are judging all natural or close to normal, while the majority have one or two stimuli that they don’t experience as normal. A low judgment on the normal-scale could of course be due to a bad recording quality or poor choice of sound stimuli, but the non-systematical distribution of judgments low on the scale indicates that this is not the real problem. Basically this test underlines the problem of establishing a common ground of reference. Although the term “normal” often shows up in the fitting situation the reference for this parameter seems to have large individual variations and therefore cannot be used as a shortcut in evaluating sound quality or hearing aid performance.

DISCUSSION

The knowledge of sensory practice along with the experiments described here has indicated that obtaining a vocabulary for sound impressions might be a good idea in hearing aid fitting. It is, however, a time consuming and quite difficult task if it is to be done properly with the tools we know today. The most challenging problem might be to establish the right scale for the evaluation. To use a judgment of normality as a fast obtained reference, is not possible, since this parameter has shown to have considerable individual variances.

REFERENCES

Bech, S. and Zacharov, N. V. (**2006**). *Perceptual Audio Evaluation*, Wiley.

Daugaard, C., Jørgensen, S. L., Jørgensen, C. V., Legarth, S. V., and Zacharov, N.V. (**2010**). “Evaluating sound quality in hearing aids with reference test audiograms” in proceedings of ISAAR 2009: *Binaural Processing and Spatial hearing* 2nd International Symposium on Auditory and Audiological Research. Elsinore, Denmark. Edited by J.M. Buchholz, T. Dau, J. Christensen-Dalsgaard, and T. Poulsen. ISBN 87-990013-2-2 (The Danavox Jubilee Foundation, Copenhagen), pp. 453-462.

Gabrielsson, A. and Sjögren, H. (**1979**). “Perceived sound quality of sound-reproduction systems” Journal of the Acoustical Society of America, **65**, 1019-1033

Johannsen, K. and Prante, H. U. (**2001**). “Environmental Sounds for Psychoacoustic Testing” Acta acustica-ACUSTICA, **87**, 290-293

Pedersen, T. H. and Zacharov, N.V. (**2008**). “How many Psycho-acoustic attributes are needed?” Proceedings of Euronoise, Paris.

Spatial cue reproduction in modern receiver-in-the-ear hearing instruments

FREDRIK GRAN, JESPER RYE BØNNELYKKE, ASTRID HAARSTRUP, JESPER UDESEN, TODD FORTUNE, TOBIAS PIECHOWIAK AND ANDREW DITTBERNER

Global Research and Global Audiology, GN ReSound A/S

This study investigates the ability to preserve spatial cues in receiver-in-the-ear (RIE) instruments for six different hearing aid manufacturers. In this particular study, the instruments were fitted bilaterally assuming a symmetric hearing loss profile. In cases where the manufacturer recommended a specific programming option to maximize spatial awareness, this option was chosen. Otherwise, the default mode was applied. S2 and N4 audiograms were used to mimic hearing-loss and testing was performed in an anechoic chamber on a KEMAR head. In order to mimic the peripheral filtering of the auditory system the left and right signals were filtered using a gammatone-filterbank. ILD's were estimated at the output of each band across angles from 0-360 degrees and compared to the corresponding values of the open-ear-response. ITDs were determined by low-pass filtering the left and right input signals and using a cross-correlation technique in order to find their respective time shift. Distortions of ILDs were as large as 10 – 15 dB for certain manufacturers whereas ITD distortions lay between 20-100 µs.

INTRODUCTION

A key element in hearing and interpreting the acoustic wave field is binaural processing in the brain (Hartmann, 1999). The two signals at the ears contain a multitude of information about the spatial nature of any of the sources in the acoustic wave field. The spatial information is encoded in Interaural-Time-Differences (ITD), Interaural-Level-Difference (ILD), spectral cues and reverberation cues. Binaural processing by the brain, when interpreting the spatially encoded information, results in several positive effects; better speech-perception; direction of arrival (DOA) estimation; depth/distance perception and synergy between the visual and auditory systems (Bronckhorst *et al*., 1988; Bronckhorst *et al*., 1989; Hawley *et al*., 2004). Furthermore, even if DOA is an important aspect of spatial perception, and the most commonly investigated property of spatial hearing, preserving DOA estimation does not automatically give a natural sound impression. A sound field might contain all spatial cues needed for DOA estimation, but still will sound artificial or "inside the head". The field is said to be internalized rather than being externalized (Hartmann *et al*., 1996).Hearing aid solutions affect the audio signal adaptively and constantly interfere with the integrity of the sound. The end users have been reported to have poorer ability to localize sounds and determine

Proceedings of ISAAR 2011: Speech perception and auditory disorders. 3rd International Symposium on Auditory and Audiological Research. August 2011, Nyborg, Denmark. Edited by T. Dau, M. L. Jepsen, J. Cristensen-Dalsgaard, and T. Poulsen. ISBN 87-990013-3-0. EAN 9788799001330. The Danavox Jubilee Foundation, 2012.