Auditory training

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The mapping of a sound pattern to a linguistic context is the base of acoustical communication. This process is taking place whenever language skills are acquired. However, sound cues might be changed or lost in amplification, thereby changing the sound pattern. Adaptation is required to reconnect sound with context. Focused training on this connection will speed up and improve the process. The necessity of this training is evident where hearing is restored from deafness, but a training effect is also expected in rehabilitation of gradually emerging hearing loss. Programs training speech recognition and cognitive skills exist for English speakers. They are used with some success, however the criteria for who will benefit from training are unclear. From sensory perception evaluation, training the attention to sound details and developing a language about sound attributes is well known, but the use of non-speech stimuli in auditory training has not yet been given much attention. Looking at the hearing-aid fitting process, an improved fitting could be expected if sound description ability is improved within the framework of specialized training. Music as a part of an auditory training program may increase sound property awareness to the benefit of cognitive skills also related to speech perception. Adding music improves the fun and thus the motivation of the training sessions.

BACKGROUND

Auditory training links naturally to hearing rehabilitation. The attention to the field grew in the USA around World War II, where better diagnostic capabilities and means of rehabilitation of hearing casualties from military service were severely needed. Skills such as lip-reading and ‘listening practice’ would accompany the prescription of hearing aids to minimize the perceived handicap of the hearing loss. As hearing aids were improved during the eighties, the auditory training as a unique part of the rehabilitation disappeared. In the late nineties, however, auditory training in the USA had a revival based on computer-controlled learning programs and new scientific results.

Auditory training has traditionally been focusing on enhancing speech understanding. However, with the complexity of modern hearing aids another training opportunity is the vocabulary of words describing sound. The link between the impression of sound and a word expressing it could be important in the process

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of adjusting the hearing aid to the user. Sound impressions could be created by music samples supplementing the speech stimuli, adding diversity and amusement to the speech training sessions.

The basic concept which makes the training of hearing possible is the auditory plasticity – reorganizing neural connections in the brain on the basis of input – and behavioral changes (Musiek, 2002). The argument is that a ski-sloping hearing loss, for example, deprives the stimulation of sound at high frequencies thus causing the neurons to reorganize based on a bass-dominated input. Restoring the treble by means of a hearing aid will not find the right path in the brain until the connections regarding treble input are restored. Training might improve the speed of these changes.

COMMUNICATION MODEL

Sweetow and Sabes (2006) have introduced a hierarchical communication model illustrating that the basis for acoustical communication is hearing, i.e., that there is access to the information on the acoustical level (Fig. 1). Next step is to pay attention to the acoustic signal, to listen with the purpose of understanding the signal. If - when listening concentrated - the acoustical signal bears any meaning, comprehension is the third step. Comprehension can be aided by increased listening and by request of repeating part of the acoustic signal with the purpose of more critical listening. Finally when comprehension reaches a state where meaningful information can be derived from the acoustic signal, answers or rephrasing of information can be formulated and communication has been established. Taking this hierarchy into account, it is fair to propose that auditory training with speech signals aims at promoting the understanding at the higher levels in the hierarchy, while music training probably will enhance the ability to listen when introduced in the communication model.

AUDITORY TRAINING METHODS

In the theory four different learning concepts to approach the understanding of spoken language are described (Blamey and Alcántara, 1994). These are:

Bottom-up: Identification of all cues individually, come together as a meaningful sentence.

Top-down: Identification of a still increasing number of cues in an informational stream are compared with similar meaningful structures until one correct meaning is chosen.

Pragmatic: Introduction to different hearing strategies, also including distance to speaker, reformulate questions, etc.

Eclectic: A combination of the three concepts mentioned above, fitted to target group and to the purpose of the training. The American auditory training program LACE is an example of this concept.

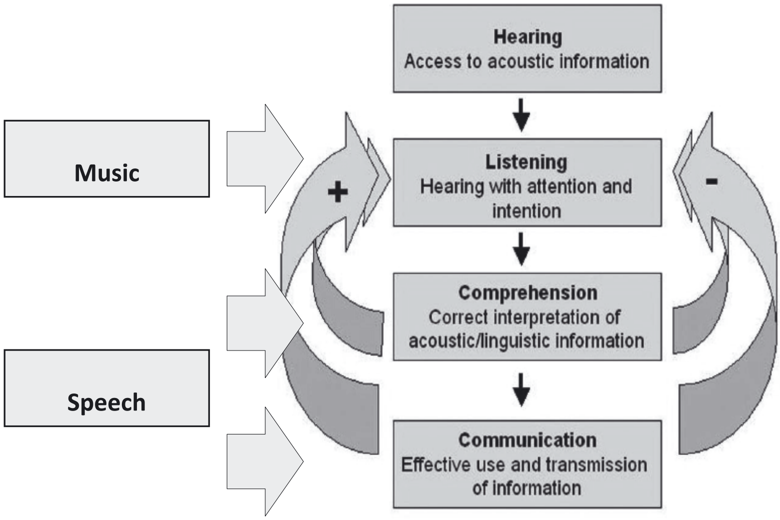

Fig. 1: Communication model modified from Sweetow and Sabes (2004).

SPEECH PERCEPTION TRAINING

Based upon the principle of the brain's plasticity, the purpose of speech perception training is to exercise the neural pathways related to decode the acoustical structure of speech into comprehensive information as it is modeled in Fig. 1. This can be obtained by listening to speech material with different degrees of degradation, enabling a correlation of speech cues with the information of the acoustic presentation. This probably also exercises the cognitive abilities, and thus the fundamental task of figuring out the meaning of an acoustical message. The three most commonly used degradations are masking the speech, speeding up the speech, and distorting the speech. Adding a masker corresponds, depending on the nature of the masker, to the real-life situation of noisy places or competing speech, e.g., at a cocktail party. Time compression is another type of degradation, which represents fast-talking speech signals in real life. Degradation could also be harmonic distortion representing real-life situations where the speech signal is unclear due to transmission through electrical circuits (phone, etc.). Also other types of degradation could be imagined: frequency shaping, amplitude variations, etc. Most speech training programs also employ the knowledge of different communication strategies to help reach the goal of a better speech understanding (eclectic training).

MUSIC AND THE BRAIN

There is no tradition of using music as a part of computer-based auditory training for hearing rehabilitation. In the music industry, however, auditory training with the purpose of producing and reproducing sound has been practiced for many decades

(Letowski, 1985; Brixen, 1993). In the later years some projects direct attention towards the perception of music and development of language and communication (Holst, 2009; Petersen *et al.*, 2012). Petersen *et al.* apply traditional musical training to cochlear implant (CI) users, in order to investigate the effect especially on speech understanding ability. They find that musical training speeds up the process of learning speech understanding for the CI users, but more striking is the fact that there is a large interest in participation in the music-oriented tasks. This enthusiasm of music might be explained by investigations of music and the brain, acknowledging music as a rewarding stimulus triggering dopamine in the brain (Salimpoor and Zatorre, 2011). This study also shows that music causes brain activity in the frontal lobe, indicating that music also creates intellectual stimuli (such as pattern recognition). This finding might support an idea of music tasks also supporting higher order processes used in speech understanding. Williamson *et al.* (2010) investigate the short term memory of verbal and musical sounds and find some correspondence in the way these two are processed in memory. This again supports the combination of music and speech stimuli in auditory training. In the last few decades sensory evaluation of sound has been investigated. In this field a vocabulary of sound-describing words is established enabling communication about sensory experiences. Although this does not directly enhance the ability to understand speech, the opportunity to express the acoustical experiences through a hearing aid might lead to a better fitting and thus better sound quality (Daugaard *et al.*, 2011).

WORDS FOR SOUND

Describing the subjective impression of a sound might be difficult, especially if the description should be consistent and useful in changing the sound. In sensory evaluation, development of the right attributes describing the sensation and covering all aspects of the sound impressions is an important issue. Several approaches are possible. 'Word elicitation', leaving the creation, grouping, and description of attributes to a focus group of assessors; this is not a useful approach in the context of a fitting situation. Using pre-selected attributes based on earlier investigations is the obvious short-cut. Several investigations have suggested sets of attributes; comparing those leaves us with a handful of common sound characteristics relevant to different kinds of listening situations (mobile phones, stereo reproduction, hearing aids, etc.) (Pedersen and Zacharov, 2008). From sensory evaluation of food, comprehensive groupings of taste attributes are used for the evaluation of products. Best known is perhaps the wine wheel, describing the nuanced taste of red wine. DELTA is in the process of developing corresponding 'sound wheels' for different listening situations.

In the dictionary 'semantic space of sound' (Pedersen, 2008), 17 profiles or primary descriptors of classes of words describing sound are defined (Table 1). These attributes are emerged from the words in the dictionary and are scalable values. These could also be used as a base for training of word description, or as inspiration, as it is done in this project.

Sound profiles (Pedersen, 2008):		
Loudness	Tempo	Pitch strength
Amplitude variation	Regularity	Pitch
Impulse prominence	Roughness	Tone prominence
Duration	Sharpness	Polyphony
Decay	Presence	Harmony
Frequency variation	Localised in space	

Table 1: The list of sound profiles described in 'semantic space of sound'.

IMPLEMENTATION

A Power-Point based training program was developed, focusing on the inclusion of the right combination of tasks rather than the computer implementation. The program included adaptive training, post-trial re-hearing, variation, and immediate feedback on tasks. The implementation is easy to distribute and install, easy to use, fairly interactive and cost effective (development time and money). The program is based upon a top-down learning strategy, as this approach seems to be the most straight-forward to implement and use, as it does not require special knowledge or interest in linguistics from the user.

Speech exercises

The speech exercises in the Danish material are played with a competing noise consisting of one or two other talkers. The purpose of the exercises is to improve the users' ability to extract the speech information in the noise. The sentences are from the Danish DAT material developed at CAHR, DTU: "Dagmar tænkte på et skind og en lynlås i går" ("Dagmar thought of a hide and a zipper yesterday") (Nielsen *et al.*, 2011). This material is the best available sentence-based Danish word material. The speech exercises consist of seven simple tasks containing two simultaneously played speech tracks, the target sentence (i.e., Dagmar) and the masker (i.e., Asta), and four difficult tasks containing three simultaneously played speech tracks, one the target sentence (i.e., Dagmar) and the other two maskers (i.e., Asta and Tine).

Music exercises

The spectrum and amplitude of several music recordings was modified to represent different degrees of the three attributes roughness, tone, and vibration. At total of 12 exercises with one or more manipulated music recordings was produced. The purpose of the music exercises is training the recognition of the three attributes and associating them with their describing name. Furthermore the goal is to exercise the ability to rank each of the attributes according to the applied signal processing (degree of degradation). The three musical attributes included in the distributed program are roughness, tone, and vibration. The words are from the category 1 (direct descriptions) or 2 (words borrowed from other sensory domains) in the 'semantic space of sounds' (Pedersen, 2008). These attributes were selected as realistic effects experienced by hearing-aid users, as well as characteristics related to a psychoacoustic description. Signal processing was applied to music pieces corresponding to the impression of each attribute. The appropriate signal processing was determined by judgment of one of the authors.

Roughness: Distortion of the sound. Represented by the psychoacoustic attributes *roughness* and *sharpness*. The attribute is made by choosing the VST effect 'BJ overdrive' in the sound editor 'Audacity' software for PC.

Tone: A raise in the midrange of the soundstage (bandpass filtering around 1 kHz with bandwidths from 0.4 to 4.5 kHz) represented by the psychoacoustic attributes *tone prominence* and (possibly) *sharpness*. The effect is achieved by manual adjustment of an equalizer in the sound-editor 'Audacity' software for PC.

Vibration: Amplitude variation, changes in frequency and modulation depth, represented by the psychoacoustic attribute *amplitude variation*. The attribute is made by choosing the effect 'tremolo' in the sound-editor 'Audacity' software for PC.

The music exercises are based upon instrumental classical pieces (with one rhythmic music exception). This is thought of as a neutral choice of music focusing the attention on sound quality and the altered characteristics.

PILOT STUDY

To evaluate the effect of auditory training, a small group of three hearing-aid users and one CI user was selected to go through the 23 exercises in four weeks. They were presented with a test battery prior to the exercises, and again after a month, when the exercises were expected to be completed. The test battery consisted of a speech test, a test in musical vocabulary, and the Abbreviated Profile of Hearing Aid Performance (APHAP; Purdy and Jerram, 1998) questionnaire.

The speech test was the DAT test in Danish developed at DTU, presented (as the exercises) with one or two competing speakers as masking noise. The result for one-speaker masking noise shows improvement for three of four participants, while the two-speaker masking noise was either too difficult to perform or showed no improvement. Due to the limited data material no statistics were calculated. And thus the significance of the results is not determined.

The attribute recognition was tested by ranking tests and description of sound examples. Results show improved skills in both tasks after the exercises were completed.

The APHAP profile did not show improvement after the training, which indicates that the test subjects do not experience any improvement in their communication situation due to the training, or at least the APHAP questionnaire is not able to register that change.

	Tasks	Set-up
1-4	Find the reference, attribute name not mentioned	Double blind triple stimulus with hidden reference
5-7	Rank the changes, attribute name is presented	Ranking method
8-10	Rank the changes, compare/differentiate attributes	Ranking method
11-12	Rank + match sound and attribute	Ranking method + naming the right attribute

Table 1: Overview of the 12 music exercises.

As a part of the pilot test the participants were interviewed on the experience of the tests and their test activity. In general they were positive, and the majority had repeated each of the tests from one up to eight times in order to experience an improvement in their listening skills.

The distribution of the tests via computer, and thus the possibility to access the exercises at any given time, was approved, as well as the music tests, which all users reported added to the motivation.

DISCUSSION

The purpose of this project was first and foremost to establish a Danish auditory training program, also including music exercises. An evaluation of the program was preferable, but time limitations, as well as challenges finding the right parameters to evaluate, made it difficult to make a thorough evaluation. Under the heading 'Pilot study' the outcomes of the limited evaluation are summarized. Results are not that encouraging, but still indicate that some benefits could be obtained. It is possible that some groups of hearing-aid users could benefit more from auditory training than others. An obvious question then becomes: How to select the right candidates? One criterion for selecting candidates is their motivation, of course. Another one is prior knowledge of music and linguistics. Also it could be speculated that, for first time users of hearing aids, the training would help in the fitting process as well as in the general acclimatization to hearing-aid use.

PERSPECTIVES

The current project introduces the concept of computer-based auditory training in Danish language. It is modeled on the principles of English auditory training programs and their speech-focused training. The current project also introduces training of a vocabulary for auditory events, aiming at increasing the user's ability to express the experience of the sound through his hearing aids and thus making the fitting process easier. In the project a program for self-training of auditory awareness is implemented, focusing on learning concepts introduced in the English training programs. To establish the effect of the auditory training further investigation is needed. It is possible that some people (first time users) gain more effect of the training and it would be a subject of further investigations to show whether that is the case.

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