A PSYCHO-ACOUSTIC MODEL OF THE PLEASANTNESS FOR HEARING IMPAIRED PERSONS (MCHI)

Georg Schmalfuß, Jörg Haubold

ciAD® - competence in AudioDesign, D-44287 Dortmund, Witthausstr. 42, Germany

ciAD® competence in Audio Design

www.audioquality.de

schmalfuss@audioquality.de
haubold@audioquality.de

BACKGROUND

A successful hearing aid fitting is generally described by the patients with improved SPEECH INTELLIGIBILITY and a PLEASANT SOUND PERCEPTION in different everyday life situations. In the practice of hearing aid fitting often a compromise between a good SPEECH UNDERSTANDING, a PLEASANT HEARING and a NORMALIZATION of the impaired hearing is required. A loudness normalization only is often not satisfying the patient. Also an improvement of speech understanding is not a sufficient criteria for a successful hearing aid fitting. The same is valid for the pleasantness of the hearing impression without a sufficient speech understanding.

An important conclusion is to include a direct assessment of complex hearing impressions by the patient as a measurement category in the fitting process additional to loudness scalings and speech intelligibility tests. Especially for modern hearing aids with complex signal processing such assessments are essential for individual fitting optimizations in consideration of an acceptable expenditure.

OBJECTIVES

Since the sensed pleasantness of the hearing impaired person is an important attribute of the hearing aid fitting success an objective pleasantness measurement procedure is desirable. With such a procedure the auditive pleasantness of

- Individual hearing aid settings,
- Effects of settings changes,
- Effects of specific signal processings,
- An objective assessment for the reached fitting quality and
- As a design value for optimisation criterias

can be determined.

For normal hearing people psycho-acoustic models to predict the auditive pleasantness are existing. However hearing impaired persons are rating the pleasantness of natural sounds qualitatively different than normal hearing people. Therefor it is inadequately to adapt these models to hearing impaired persons under consideration of the affected loudness perception.

To develop a psycho-acoustic model of the pleasantness for hearing impaired persons (MCHI) it was necessary to:

- Select the applicable scaling method,
- Combine and arrange the hearing dimension inventory,
- Signal analyse natural sounds,
- Model the main dimensions,
- Design the entire calculation model and
- Develop the application

The results of the model of the prediction of the pleasantness should be valuesindicated on a categorial unit scale and verbal categories of the pleasantness sensation of hearing impaired persons with hearing aids and for natural sounds. The needed inputs are

1. The individual hearing loss of the patient,
2. The time function of the interested sound and
3. Normal hearing reference data.

MODEL

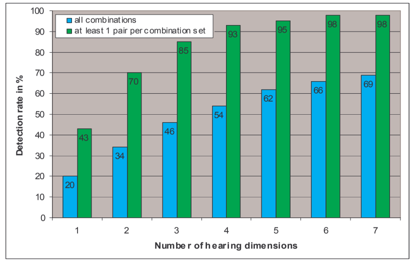
HEARING DIMENSIONS

Number of hearing dimensions	H_{LUV}	H_{LSV}	H_{HM}	H_R	H_V	H_{ND}	H_{NST}
1						x	
2					x	x	
3					x	x	x
4		x			x	x	x
5	x	x		x		x	x
6	x	x	x	x		x	x
7	x	x	x	x	x	x	x

Optimal combinations of 7 hearing dimensions for the differentiation of natural sound pairs

- **uncompressed and 2 different compressions**
- **66 sounds:** $n = 66 * \binom{3}{2} = 198$ **combinations**

  minus 39 sound pairs with significant loudness differences
- $\alpha = 0{,}05$

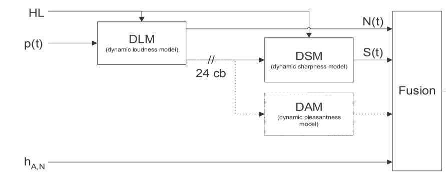


Detection rate for invested sound pairs depending on the number of hearing dimensions (α = 0,05)

- **Blue: Specified sound pairs for all combinations.**
- **Green: At least one sound pair specified for each set of combination.**

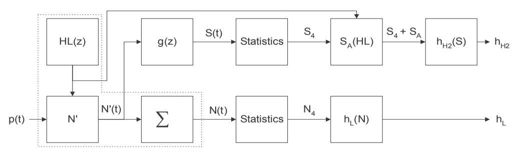
H_{ND}	Liveness
H_R	Noise
H_{LUV}	Loudness difference of the foreground sound
H_{NST}	Reverberation intensity
H_{HM}	Background modulation
H_{LSV}	Loudness fluctuation of the foreground sound
H_V	Distorsions

STRUCTURE

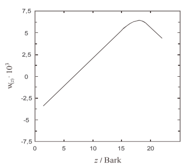


p(t)	sound pressure time function of the processed sound
$h_{A,N}$	pleasantness assessment of the original sound by normal hearing persons
$h_{A,H}$	pleasantness assessment of the processed sound by hearing impaired person
S_A	acclimatisation sharpness
S_4	4% exeedance sharpness
N_4	4% exeedance loudness
h_L	loudness [CU]
h_{H2}	timbre [CU]

LOUDNESS / SHARPNESS

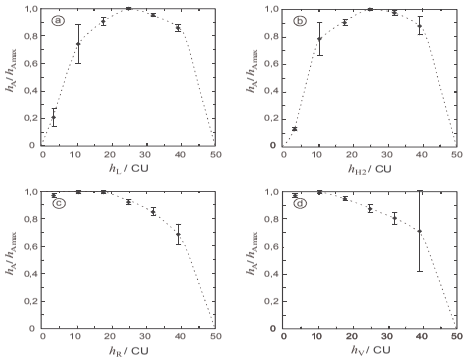


$$\frac{S_A}{\text{acum}} = \frac{1}{z_1 - z_0} \int_{z_0}^{z_1} w(z) \cdot \frac{HV_{(z)}}{\text{dB(HL)}}\, dz$$



Mathematical Description

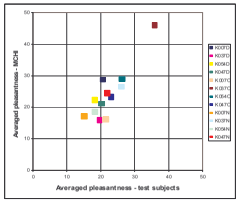
$$\frac{h_A}{CU} = 50 \cdot \left\{ \left[g_1(h_L) \right]^{C1} \cdot \left[g_2(h_{H2}) \right]^{C2} \cdot \left[g_3(h_R) \right]^{C3} \cdot \left[g_4(h_V) \right]^{C4} \right\}^{g_5(h_{A,N})}$$

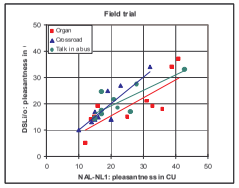


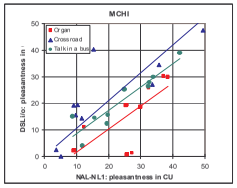
Results

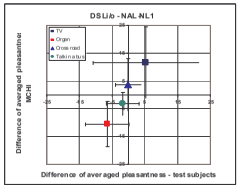
Evaluation & Verification

Model	Investigation	Test persons	Scalings	Sounds
loudness	estimation quantity and transformation to categorial judgements	8..14 normal hearing persons	8..144 for each sound	77 natural sounds + 132 different compression versions
		17 hearing impaired persons	60	2 representatives for home sphere and traffic noise with 60 individual hearing aid settings
timbre	transformation to categorial judgements in dual wise a reference system adaptation for hearing impaired persons	8..12 normal hearing persons	8..144 for each sound	255 natural sounds (93 basic sounds + 132 compression versions + 114 linear filtered versions)
	influence of compression	17 hearing impaired persons	60	2 representatives for home sphere and traffic noise with 60 individual hearing aid settings
		8..12 normal hearing persons	8..12 for each pair	28 pairs of natural sounds with significant differences of timbre caused by dynamic compression
comfort	combination of loudness, timbre, noise impression and distortion detection	about 1000 hearing impaired persons	3470 for each hearing dimension	48 natural sounds, predominantly with speech
speech	estimation of speech understanding and easiness of speech understanding	23 normal hearing persons and 16 hearing impaired persons	separate 2-level ratings for understanding and easiness + 6 hearing dimensions	19 selected natural sounds









Conclusion

Results from multiple field trials are demonstrating the usability of the selected inventory of hearing dimensions to describe the hearing impression of hearing impaired persons. Improvements of loudness, pleasantness and speech understanding could be proved.

The presented model / algorithm to predict the pleasantness impression of hearing impaired persons (MCHI) is using a minimum set of input data. The calculation variance is comparable with the variance of subjective field trials. MCHI is applicable for a widespread area:

- Preparation and examination of hearing aids without the presence of the patient,
- Measurement of detectable effects of parameter changes of the hearing aids,
- Computation of common change criteria and values for optimisations
- Computation of user and patient interpretable and comparable quality values
- Objective quality description and tracking for quality assessment and measurements

References

[Aur84] Aures, W.: Berechnungsverfahren für den Wohlklang beliebiger Schallsignale. Dissertation TU München 1984.

[Aur85] Aures, W.: Berechnungsverfahren für den sensorischen Wohlklang beliebiger Schallsignale. In: Int J Acoust – Acustica 59 (1985), p 130ff

[Ben78] Benedini, K.: Psychoakustische Messung der Klangfarben-Ähnlichkeit harmonischer Klänge. Dissertation TU München 1978.

[Ber96] Berglund, B./ Soames Job, R. F.: Theory and method in perceptural evaluation of complex sound. In: Fastl H., Kuwano S., Schick A. (Hrsg.): Recent Trends in Hearing Research. Festschrift for Seichiro Namba. Oldenburg: BIS 1996, p 215ff

[Bis72] v. Bismarck, G.: Extraktion und Messung von Merkmalen der Klangfarbenwahrnehmung stationärer Schalle. Dissertation TU München 1972.

[Bjö85] Björk, E. A.: The Perceived Quality of Natural Sounds. In: Int J Acoust – Acustica (1985) H. 57, p 185ff

[Bor81] Borg, I.: Anwendungsorientierte Multidimensionale Skalierung. Berlin/ Heidelberg/ New York: Springer Verlag, 1981

[Bor97a] Boretzki, M./ Knoblach, E./ Pietzsch, T./ Haubold, J./ Heller, O.: Skalierung phänomenaler Eigenschaften von hörgerätetechnischen Manipulationen. In Wille, P. (Hrsg.): Fortschritte der Akustik - DAGA' 97, Oldenburg: DEGA e.V. 1997, p 87f

[Bor97b] Boretzki, M./ Knoblach, E./ Pietzsch, T./ Haubold, J./ Heller, O.: Analyse der psychologischen Dimensionen von Hörgerätetechnischen Signalmanipulationen. In Wille, P. (Hrsg.): Fortschritte der Akustik - DAGA' 97, Oldenburg: DEGA e.V. 1997, p 85f

[Bra98] Brand, T./ Hohmann V./ Kollmeier, B.: Krümmung der Lautheitsfunktion in Abhängigkeit von der Bandbreite des Signals bei Normal- und Schwerhörenden. In Sill, A. (Hrsg.): Fortschritte der Akustik - DAGA'98, Oldenburg: DEGA e.V. 1998, P 324f

[Cha02] Chalupper J.,: Perzeptive Folgen von Innenohrschwerhörigkeit, Dissertation München 2002.

[Ebe91] Eberhard, M./ Kotterba, B.: Der Wohlklang kurzzeitiger Klänge. In: Fortschritte der Akustik - DAGA'91, Bad Honnef: DPG-GmbH 1991, P 485f

[Fas02] Fastl, H.: Psychoacoustics and sound quality. In A. Sill (Hrsg.): Fortschritte der Akustik – DAGA'02, Oldenburg: DEGA e.V. 2002

[Fic00] Fichtl, E.: Untersuchungen zur Zuverlässigkeit und Präzision der Hörfeldaudiometrie. Studien reihe Psychologische Forschungsergebnisse, Bd. 61, Hamburg: Verlag Dr. Kovač 2000

[Fud95] Fuder, G./ Haubold, J.: Hörgeräteanpassung mit natürlichen Klangbildern. In Arnold, W./ Hirsekorn, S. (Hrsg.): Fortschritte der Akustik – DAGA'95, Oldenburg: DEGA e.V. 1995, p 939f

[Fud96] Fuder, G./ Haubold, J.: Psychoakustische Hörgeräteanpassung mit natürlichen Klangbildern. In Portele, T./ Hess, W. (Hrsg.): Fortschritte der Akustik - DAGA'96, Oldenburg: DEGA e.V. 1996, p 161f

[Gab91] Gabrielsson, A./ Lindström, B./ Till, O.: Loudspeaker frequency response and perceived sound quality. In: J Acoust Soc Am 90 (2) (1991), p 707ff

[Gee93] Geers, W./ Haubold, J.: Anpassung von Hörgeräten mit natürlichen Klangbildern. In: Fortschritte der Akustik - DAGA'93, Bad Honnef: DPG-GmbH 1993, p 756ff

[Han95] Handel, S.: Timbre perception and auditory object identification. In B. C. J. Moore (Hrsg.): Hearing (Handbook of Perception and Cognition, 2nd Edition), p 425

[Han00] Hansen, M./ Kollmeier, B.: Objective Modeling of Speech Quality with a Psychoacoustically Validated Auditory Model. In: J Aud Eng Soc (2000) H. 48 (5), p 395ff

[Hau88] Haubold, J.: Grundlagen für die Dimensionierung von Hörgeräten zur optimalen Verbesserung des Sprachverständnisses. Dissertation TU Dresden 1988.

[Hau96] Haubold, J.: A-life 9000 - individuelle Optimierung von Hörsystemen unter Berücksichtigung der akustischen Umwelt. In: Geers Hörbericht 60 (1996) H. 60, p 1ff

[Hau98] Haubold, J./ Fuder, G.: Psychoakustische Verfahren und deren Anwendungsmöglichkeiten bei zukünftigen Hörgeräteanpassungen. In Sill, A. (Hrsg.): Fortschritte der Akustik - DAGA'98, Oldenburg: DEGA e.V. 1998, p 130f

[Hei85] Heller, O.: Hörfeldaudiometrie mit dem Verfahren der Kategorienunterteilung (KU). In: Psychologische Beiträge 27 (1985)

[Hel91] Heller O.: Oriented category scaling of loudness and speechaudiometric validation. In Schick, A./ Hellbrück, J./ Weber, R. (Hrsg.): Contribution to psychological acoustics. Results of the fifth Oldenburg symposium on psychobgocal acoustics, Oldenburg: BIS 1991, p 135ff

[Hoh91] Hohmann, V./ Preissig, J./ Kollmeier, B.: Beurteilung und Anpassung von digitalen Echtzeit-Hörgeräte-Algorithmen. In: Fortschritte der Akustik - DAGA'91, Bad Honnef: DPG-GmbH 1991, p 597ff

[Joh98] Johannsen, K./ Prante, H.: Erforschung von Hördimensionen mit Umweltgeräuschen. In Sill, A. (Hrsg.): Fortschritte der Akustik - DAGA'98, Oldenburg: DEGA e.V. 1998, p 122f

[Kab93] Kabot, E./ Weber, R.: Kategorial beurteilte Schärfe von künstlichen und natürlichen Schallen. In: Fortschritte der Akustik - DAGA'93, Bad Honnef: DPG-GmbH 1993, p 840ff

[Kin94] Kinkel, M.: Subjektive Bewertung von Hörgeräte-Versorgungen. In: Fortschritte der Akustik - DAGA'94, Bad Honnef: DPG-GmbH 1994, p 1397ff

[Koh92] Kohler, M./ Kotterba, B.: Die Fusion gemessener Empfindungsgrößen zur objektiven Bestimmung des Wohlklanges. In: Fortschritte der Akustik – DAGA'92, Bad Honnef: DPG-GmbH 1992, p 905ff

[Kuw89] Kuwano, S./ Fastl, H.: Loudness evaluation of various kinds of nonsteady sound using the method of continuous judgement by category. In Pravica, P./ Drahulic, G. (Hrsg.): Proceedings of the 13th International Congress on Acoustics 1, Sava Centar/ Belgrad: ICA 1989, p 365ff

[Mca95] McAdams, S./ Winsberg, S./ Donnadieu, S./ De Soete, G./ Krimphoff, J.: Perceptual scaling of sythesized musical timbres: common dimensions, specifities, and latent subject classes. In: Psych Res 58 (1995), p 177ff

[Mül87] Müller, F.: Skalierung und Bezugssystem der Tonheit. Dissertation Universität Würzburg 1987.

[Nam96] Namba, S.: Noise quality. In: Fastl, H./ Kuwano, S./ Schick, A. (Hrsg.): Recent Trends in Hearing Research. Festschrift for Seiichiro Namba, Oldenburg: BIS 1996, p 1ff

[Nie95] Nielsen, L. B.: Objectiv Scaling of Sound Quality for Normal-Hearing and Hearing-Impaired Listeners. AES 98th Convention Paris, AES Preprint 4017, New York: AES 1995

[Neu98a] Neuman, A. C. et al.: The effect of compression ratio and release time on the categorical rating of sound quality. In: J Acoust Soc Am 5 (1998), p 2273ff

[Pra01] Prante, H. U.: Modeling Judgements of Environmental Sounds by means of Artificial Neuronal Networks. Dissertation TU Berlin 2001.

[Sch96] Schmalfuß, G.: Skalierung natürlicher Klangbilder durch Normalhörende und Hörgeschädigte. In: Portele, T./ Hess, W. (Hrsg.): Fortschritte der Akustik – DAGA'96, Oldenburg: DEGA e.V. 1996, p 138f

[Sch97a] Schmalfuß, G./ Fuder, G./ Haubold, J.: Untersuchungen zur Klangfarbenwahrnehmung bei der Anpassung von Hörgeräten mit natürlichen Klangbildern. In Wille, P. (Hrsg.): Fortschritte der Akustik - DAGA' 97, Oldenburg: DEGA e.V. 1997, p 238f

[Sch97b] Schmalfuß, G./ Haubold, J.: Psychoacoustic based hearing aid fitting with complex acoustic signals. NIH Hearing Aid Research Conference, Bethesda (Maryland), 1997

[Sch97c] Schmidt, M./ Hochmaier-Desoyer, E./ Schulz, E./ Moser, L.: Der HSM-Satztest. In Wille, P. (Hrsg.): Fortschritte der Akustik - DAGA' 97, Oldenburg: DEGA e.V. 1997, p 93f

[Sch98] Schmalfuß, G.: Algorithmische Optimierung bei der Feinanpassung von Hörgeräten mit natürlichen Klangbildern. In Sill, A. (Hrsg.): Fortschritte der Akustik - DAGA'98, Oldenburg: DEGA e.V. 1998, p 124f

[Sch04a] Schmalfuß, G.: Psychoakustische Methoden und Modelle zur Feinanpassung von Hörgeräten mit natürlichen Schallen, Dissertation München 2004

[Sch04b] Schmalfuß, G.; Fröhlich, M.; Haubold, J.: Validierung eines psychoakustischen Modells zum Höreindruck „Angenehmheit" für Schwerhörende (MCHI), Presentation DGA 2004, Leipzig, Germany

[Sei96] Seidler, H.: Signalanalyse natürlicher Klangbilder für die Hörgeräteanpassung. In: Portele, T./ Hess, W. (Hrsg.): Fortschritte der Akustik - DAGA'96, Oldenburg: DEGA e.V. 1996, p 140f

[Sei98] Seidler, H./ Pietzsch, T.: Analyse von Zeitstrukturen natürlicher Schalle. In Sill, A. (Hrsg.): Fortschritte der Akustik - DAGA'98, Oldenburg: DEGA e.V. 1998, p 126f

[Sei00] Seidler, H.: Meßtechnische Untersuchungen zur Analyse nichtstationärer Signale für die Anpassung mehrkanaliger Hörgeräte. Dissertation TU Dresden 2000.

[Sol58] Solomon, L. N.: Search for Physical Correlates to Psychological Dimensions of Sounds. In: J Acoust Soc Am 30 (4) (1958), p 492ff

[Ter81] Terhardt, E./ Stoll G.: Skalierung des Wohlklanges (der sensorischen Konsonanz) von 17 Umweltschallen und Untersuchung der beteiligten Hörparameter. In: Int J Acoust – Acustica 48 (1981), p 247ff