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Automated hearing loss assessment based on objective audiological measurements

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Abstract: The reliable assessment of hearing loss, even in patients who are unable to cooperate, and the associated optimized provision of individually adapted, efficient hearing system solutions is a major challenge in modern audiology. Automated assessment of hearing loss based on objective audiological measurements offers a solution to this problem. The presented study shows first steps in this direction and discusses the achieved successes. In particular, the 89.9 % correct differentiation of normal hearing and moderate hearing loss (Grade 2 WHO) allows an objective assessment of the need for treatment without the patient's involvement in the provision of medical aids.

I. Introduction

According to the German epidemiological study "HÖRSTAT" from 2017, approximately 16.2 % (11.1 million) of adults in Germany are affected by hearing loss, and beyond that, a 1 % increase per five-year period is expected as demographics change [1]. It is assumed that over 90 % of hearing loss in all cases is due to sensorineural hearing loss [2]. To date, pure tone audiometry has been considered the gold standard in audiological diagnostics, which, however, has its limitations in patients who are unwilling or unable to cooperate in the performance of a tone audiogram. However precise audiological diagnostics is needed as a prerequisite for valid treatment recommendations, such as, e.g. the provision with a hearing aid (HA) or a cochlear implant (CI).

Some attempts to support and improve this process with tools for interfacing machine learning with empirical diagnostic data in an optimum way were already suggested. Buhl et al. [3] for example suggested the Common Audiological Functional Parameters (CAFPAs) as a common data structure to assist automated clinical decision support systems. Until now some realizations of approaches for this kind of system already exist. For example, Taylor et al. [4] showed that their algorithm AudioGene is able to predict genetic causes of hearing loss based on audiogram data with an accuracy of 68%.

This contribution strives to support this process by suggesting and evaluating an approach to combine audiological standard tests and using their outcome for automated hearing loss grading. In audiology, the combination of subjective tonal audiogram and objective distortion product otoacoustic emissions (DPOAE) is a current and important approach to improve standard diagnostics. However one major challenge in this context is, that the complexity of the linear and nonlinear mechanisms generating DPOAEs and confounders as age, middle ear status and noise exposure as well as physical phenomena (e.g., interference between different otoacoustic components, acoustical resonances and transmission in the outer and middle ear) introduce a large inter-subject variability in the measured levels.

A further problem in the limitation of grouping ability in diagnostics and additionally in the evaluation for research purposes is that gradients of DPOAE growth functions in their application have a large indifferent range s > 0.2 dB/dB to ≤ 0.7 dB/dB [5], in consequence the majority of patients may not be able to be assigned. The aim of the presented research was to minimize the influence of this large indifferent range using DPOAE I/O gradients without the need of active contribution of the patient and to perform automated hearing loss grading based on the test outcome.

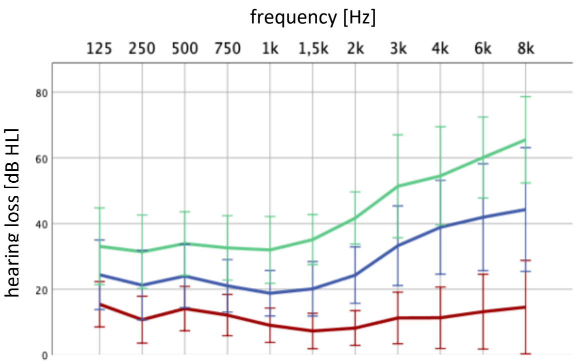

Figure 1: Audiometric mean hearing loss for grades of hearing loss (WHO) with standard deviations. Hearing loss was plotted against frequency (red: grade 0, blue: grade 1; green: grade 2).

II. Material and methods

In the present study, the tone audiogram and up to six DPOAE growth functions at audiometric frequencies were measured in 127 patients per ear at UKGM Giessen; the sample size was overall 225 ears.

The subdivision of the patient groups was made into patients with normacusis (59.1%) and patients with sensorineural hearing loss (40.9%). In assessing the severity for hearing loss (HL), the 2021 World Health Organization classification was used (WHO 2021):

Grade 0 - Normal hearing	< 20 dB HL
Grade 1 - Mild hearing loss	20 - 34 dB HL
Grade 2 - Moderate hearing loss	35 - 49 dB HL

In the present study, 44.4% of the patients had hearing loss WHO grade 0 (normal hearing), 36.9% of the study participants were assigned grade 1 (mild hearing loss), and 16.4% were assigned grade 2 (moderate hearing loss; minimum requirement for hearing aid prescription).

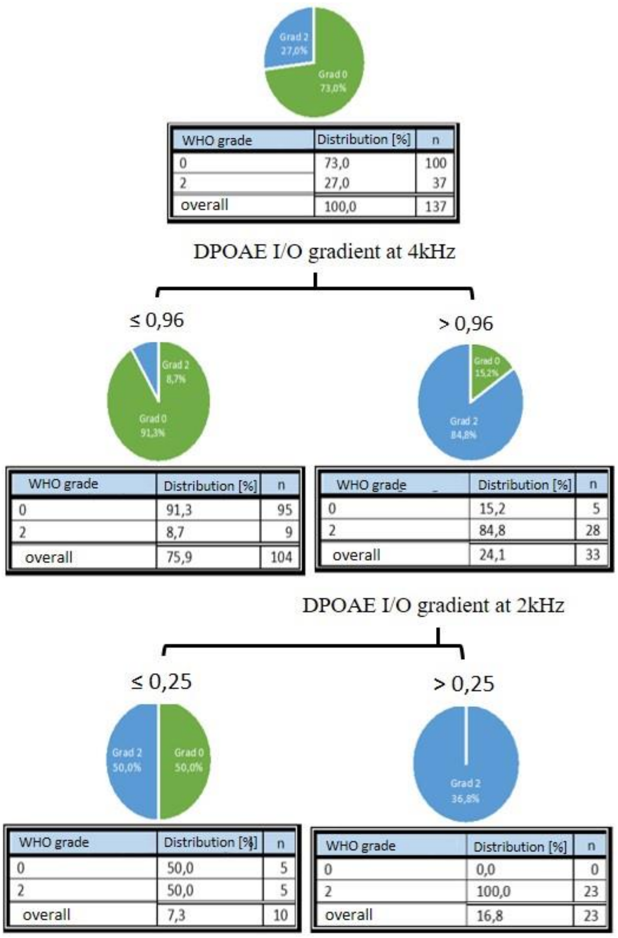

Figure 2: Classification tree (grade 0 vs. grade 2). The differentiation factors are the slope of the DPOAE I/O functions at 4 and 2 kHz. The cutoff value of the slope at the first node (4 kHz) for differentiation into degree 0 and 2 (WHO) is 0.96. The second node (2 kHz) sets the cutoff value at 0.25. Pie charts show distribution of nodes (grade 0: green, grade 2: blue).

III. Results and discussion

To test the suitability of the data obtained as a basis for an automatic classifier, a classification tree was created which differentiates between degree 0 and degree 2 hearing loss according to the WHO classification (Fig. 2) based solely on the DPOAE growth function gradient. The decision tree was calculated using the CHAID method with a maximum tree depth of five nodes, for which at least 50 cases in a parental note and at least ten cases in the child nodes were needed.

As evaluation, a cross-validation with a sample split of 10 was carried out. The final result was therefore the averaged risk of misclassification.

A subdivision was made at the first node using the 4kHz gradient at the slope value 0.96 ($p<0.000$; $\chi2=70.5$; df=1), with normal hearing (grade 0) predominating in the left final distribution and second-degree hearing loss predominating in the right final distribution. Starting from the right final distribution, a second nodal point is set with a cutoff value of 0.25 ($p=0.001$; $\chi2=14.2$; df=1) for the gradient at 2 kHz. The majority of cases exceeded this cutoff and could be assigned 100% grade 2. The remaining portion fell below or corresponded to the limit value and could be assigned in equal parts to grade 0 and grade 2. The subsequent trial run showed that 100.0% of the normal hearing cases were correctly predicted to be grade 0. Grade 2 moderate hearing cases achieved a correct percentage of 62.2%. The overall percentage of correct predictions was 89.8%. Thus, a reliable identification of the normal-hearing persons could be achieved. Furthermore, for all detected grade 2 hearing losses, the indication for hearing instrument fitting is unquestionable.

IV. Conclusions

The indifferent range of gradients of DPOAE growth functions was eliminated with the help of classification trees utilizing measurements at 4 and 2 kHz, differentiating between Grad 0 and Grade 2. Up to 89.9 % of all cases were correctly diagnosed, thus this classifier could prove to be a useful tool in everyday clinical practice for patients who are unable or unwilling to cooperate. In particular, the classification of Grade 2 allows an objective assessment of the need for treatment without the patient's involvement in the provision of medical aids.

Author's statement

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