International Journal of Audiology

ISSN: 1499-2027 (Print) 1708-8186 (Online) Journal homepage: www.tandfonline.com/journals/iija20

An open-access dataset of unaided and hearing aid-assisted auditory perception measures in complex virtual acoustic scenes

Tahereh Afghah, Jan Heeren, Laura Hartog, Pascal Biermann, Antje Wulff, Anna Warzybok & Kirsten C. Wagener

To cite this article: Tahereh Afghah, Jan Heeren, Laura Hartog, Pascal Biermann, Antje Wulff, Anna Warzybok & Kirsten C. Wagener (28 Dec 2025): An open-access dataset of unaided and hearing aid-assisted auditory perception measures in complex virtual acoustic scenes, International Journal of Audiology, DOI: 10.1080/14992027.2025.2601653

To link to this article: https://doi.org/10.1080/14992027.2025.2601653

INTERNATIONAL JOURNAL OF AUDIOLOGY
https://doi.org/10.1080/14992027.2025.2601653

TECHNICAL REPORT

OPEN ACCESS Check for updates

An open-access dataset of unaided and hearing aid-assisted auditory perception measures in complex virtual acoustic scenes

Tahereh Afghah[a,b], Jan Heeren[a,b], Laura Hartog[a,b], Pascal Biermann[c], Antje Wulff[b,c], Anna Warzybok[b,d] and Kirsten C. Wagener[a,b]

[a]Hörzentrum Oldenburg gGmbH, Oldenburg, Germany; [b]Cluster of Excellence Hearing4all, Oldenburg, Germany; [c]Big Data in Medicine Department, Carl von Ossietzky University Oldenburg, Oldenburg, Germany; [d]Medizinische Physik, Carl von Ossietzky University Oldenburg, Oldenburg, Germany

ABSTRACT

Objective: This paper presents the design and structure of an open-access audiological dataset created to support hearing aid algorithm development and model-based audiology. It provides comprehensive perceptual measures for individuals with normal hearing and hearing loss, with and without hearing aids.

Design: The dataset includes pure-tone audiometry, otoscopy, coupler measurements, the Loudness Validation Method (LVM), tone-in-noise detection, categorical loudness scaling, speech recognition tests (Göttingen Sentence Test, GÖSA; Oldenburg Sentence Test, OLSA), listening effort (Adaptive Categorical Listening Effort Scaling, ACALES), and self-reported hearing and functioning (HEAR-COMMAND Tool). OLSA and ACALES were conducted in both common spatial setups and four virtual acoustic scenes, with aided and unaided conditions for hearing aid users. Data are organised according to the FAIR principles (Findable, Accessible, Interoperable, Reusable).

Study sample: Seventy-six participants.

Results: The release includes database documentation, measurement details, raw data, metadata, and structured SQL files. Sample outcomes for individuals with moderate hearing loss are reported here for the OLSA, ACALES, GÖSA, LVM, and audiometry.

Conclusions: This dataset enables cross-methodological analysis and provides simulated acoustic scenes for evaluating hearing loss. By combining standardised and novel measures, it offers a baseline resource for model-based audiology research and hearing aid benefit assessment.

ARTICLE HISTORY
Received 10 September 2025
Revised 25 November 2025
Accepted 3 December 2025

KEYWORDS
Hearing aids; hearing loss; auditory dataset; speech intelligibility; listening effort; FAIR principles

Introduction

Improving hearing aid (HA) effectiveness in noisy environments and enhancing overall user satisfaction are among the primary goals in advancing HA Digital Signal Processing (DSP) algorithms. These algorithms have continuously evolved with a focus on speech enhancement, which involves separating target speech signals from other masker sounds. Multiple approaches have been applied to HA software and hardware components to segregate and amplify target signals while suppressing distracting sounds and background noises, ultimately improving speech intelligibility (Fiedler et al. 2021; Gannot et al. 2017).

Speech enhancement techniques have recently improved significantly through the application of Machine Learning (ML) techniques, including Deep Learning (DL) and Deep Neural Networks (DNN). Several potential applications of DL and DNN in HA design have been proposed, demonstrating high potential for enhancing speech intelligibility (Andersen et al. 2021; Diehl et al. 2023; Nossier et al. 2019). These approaches rely on large and well-structured data sets to develop and validate model-based audiology methods.

When examining the real-world effectiveness of these advanced methods in enhancing user satisfaction and quality of life, subjective evaluation is also essential for evaluating individual experiences across a variety of listening environments. Lifestyle, personal preferences, needs, and individual limitations can all influence a user's perception of HA benefits. While

CONTACT Tahereh Afghah afghah@hz-ol.de Hörzentrum Oldenburg gGmbH and Cluster of Excellence Hearing4all, Oldenburg, Germany.

Supplemental data for this article can be accessed online at https://doi.org/10.1080/14992027.2025.2601653.

user satisfaction can be assessed through self-reported measures, HA effectiveness can, to some extent, be measured through listening experiments that examine aspects such as speech recognition, listening effort, and loudness perception. Furthermore, differences in the degree and type of hearing loss (HL) directly impact HA effectiveness. Furthermore, user satisfaction is also impacted by personality and lifestyle. An individual's HL is commonly determined through pure-tone audiometry, as a core measurement. However, the everyday hearing challenges individuals face involve multiple factors that are not captured by simple tone detection tasks in acoustically treated laboratories. Therefore, to better understand and minimise the gap between listener performance in controlled laboratory and in real-world conditions, assessment of speech recognition and listening effort should include conditions that reflect everyday listening scenarios. These include complex spatial configuration of the noise sources, the presence of reverberation, and different types of masking sounds.

The objective of this paper is to present a newly developed audiological dataset that characterises the performance of individuals with hearing impairment, both with and without using HA (in aided and unaided settings), as well as individuals with normal hearing. This unique and comprehensive database provides simulated real-life listening conditions through a combination of traditional and extended measures of hearing function. It includes 1. Standard clinical assessments for comparability with other commonly used measures, such as pure-tone audiometry; 2. Measures of listening effort and speech intelligibility obtained in acoustically complex environments with realistic background noise to simulate everyday listening situations, including multitalker scenarios; 3. Self-report measures collected through broad questionnaires to evaluate the daily functional consequences of hearing difficulties; 4. Loudness perception evaluations designed to capture realistic loudness experiences and variations in perceived sound intensity using a variety of everyday sounds.

The potential applications of the developed database are broad and span several aspects, including but not limited to: 1. Examining the consequences of HL on various auditory functions including speech intelligibility, listening effort, or loudness perception; 2. Enabling the creation of individual hearing profiles for participants that cover multiple aspects of their hearing status, 3. Assessing HA devices in listening conditions of varying acoustic complexity to address challenges in real-life communication; 4. Providing data from HA users that can be used in both aided and unaided conditions to evaluate models of auditory function. Ultimately, this dataset can help establish benchmarks for better understanding individuals' listening performance, perception, and HA benefits. This can be achieved through further development and evaluation of model-based audiology concepts that incorporate statistical, perceptual, or physiological models.

This database differs from previously published datasets, such as those provided in Jafri et al. 2025; Regev et al. 2025; Sanchez-Lopez et al. 2021; Vlaming et al. 2011, in several key aspects. It is open access and publicly available on Zenodo platform, includes both aided and unaided measurements for HA users, and involves a relatively large and diverse participant population. Furthermore, it was specifically designed to simulate complex daily-life listening situations to assess hearing performance and hearing-aid benefits under ecologically valid conditions.

Data accessibility

This database was generated within the Collaborative Research Centre SFB 1330 Hearing Acoustics project (HAPPAA 2018). The goal of this multidisciplinary project is to improve the assessment of communication abilities by gaining a deeper understanding of how humans perceive and process complex auditory scenes in everyday environments and to enhance the effectiveness of HA in such situations. The database content and outcomes are presented in four sources, and a link to each is provided in the References section.

1. Afghah et al. 2025a**, Database content:** The database is accessible on Zenodo platform. To maximise its usability for researchers and clinicians, the dataset is provided as Open access. The performed measurements generated results in formats tailored to each procedure; however, to enable public release, the data must be structured, meaningful, and compact. To achieve this, a robust dataset framework was developed to integrate the various file formats and data types, which were initially unstructured. The FAIR Guiding Principles (Findable, Accessible, Interoperable, and Reusable) (Wilkinson et al. 2016) were applied to ensure both machines and individuals can locate, access, and use data. These principles were followed to merge the results of different measurements to the extent feasible.

2. **The current paper:** Detailed technical descriptions of each measurement procedure and the overall data structure are included in this paper to guide researchers in effectively utilising the dataset.
3. Gerken et al. 2025a: The theoretical motivation and conceptual audiological justification for the inclusion of the measurements, as well as further details on a subset of measurement procedures and outcomes are available in this paper.
4. Afghah and Wagener 2025**:** The comprehensiveness of each measurement with regards to HL assessment requirements is analysed in this paper. Each measurement and its outcome is linked to the World Health Organization's International Classification of Functioning, Disability, and Health (ICF) coresets for hearing loss. This analysis determines the extent to which each measurement aligns with a patient-centred evaluation framework.

Materials and methods

Data were collected from May to December 2022 in multiple acoustically treated laboratories. Participants were recruited from the test-person database of Hörzentrum Oldenburg gGmbH which includes more than 2000 volunteering persons from the northwest region of Germany. The majority of volunteers are between 65 and 80 years old; both normal-hearing and hearing-impaired individuals (with and without own hearing devices) are included. General anamneses data, including pure-tone audiometry is available for all test persons. The study group was defined to represent both HA users and listeners without HA of comparable age. This ensures that the listeners reflect different hearing loss degrees that are not influenced by age differences among them. The degree of HL was determined by means of pure-tone average (PTA) based on the WHO HL classification (WHO, 1991), by averaging the air-conduction (AC) thresholds of the better ear at 500, 1000, 2000, and 4000 Hz.

Of the 79 recruited participants, 78 participated in the study, among which two did not complete all measurements. Consequently, the dataset includes measurement results from a total of 76 participants (35 female, 41 male), with an average age of 73.9 years (SD = 7.1, Range: 49–84), divided into the three age-matched groups:

1. "NH" group: 20 participants with normal hearing defined as better-ear PTA $<$ 25 dB HL. They ranged in PTA from 1.3 to 24.4 dB HL.
2. "HI-noHA" group: 25 participants with hearing impairment (HI) who do not use a HA in daily life, with PTA ranging from 26.9 to 53.8 dB HL.
3. "HI-HA" group: 31 HI participants who use HA in daily life, with PTA ranging from 33.8 to 76.3 dB HL. To refer to this group, two labels are used: "HI-HAu" is used when measurements were performed without their HA (unaided), while "HI-HAa" is used when measurements were conducted while wearing their own HA.

Measurements were performed over two appointments for NH and HI-noHA groups, and over three appointments for HA users.

First appointment

During this appointment, participants completed and signed consent forms. The type, brand, and duration of HA usage in months/years were recorded, if applicable, however, this information is not included in database.

Otoscopy

The structure of the outer and middle ear was examined by performing Otoscopy by an audiologist.

HEAR-COMMAND tool

The HEAR-COMMAND Tool (HCT[1]) is a questionnaire developed based on the World Health Organization's International Classification of Functioning Disability and Health (ICF) framework (WHO, 2001) to assess self-reported HL and individuals' daily functioning, with a focus on communication and conversation abilities. It is publicly accessible in multiple languages (Afghah et al. 2022, 2024, 2025b; Alfakir et al. 2025a, 2025b). In this study, the German version of the questionnaire was provided to participants to complete either during the first appointment or at home between the first and second appointments. About twenty minutes are required to complete the tool's 120 questions.

Pure-tone audiometry

Pure-tone Audiometry included measurements of AC, bone conduction (BC) thresholds, and uncomfortable loudness levels (UCL).

Binaural broadband loudness scaling and true loudness gain calculation

In order to restore a normal binaural broadband loudness perception, the trueLOUDNESS fitting method was used which considers both the audiogram and the binaural broadband loudness perception (Oetting et al. 2018). In the first step, narrowband loudness functions for six frequency bands (250, 500, 1000, 2000, 4000, and 6000 Hz) were derived from the audiogram to estimate narrowband loudness compensation (Suck et al. 2020). The narrowband loudness functions used are demonstrated in Zimmer et al. (2024). In the second step, binaural broadband loudness functions were measured using two types of stimuli: a unified excitation noise (UEN17, Zwicker 1961) and a female speech-shaped noise (IFnoise, Holube et al. 2010). These stimuli, amplified with individualised narrowband gain, were presented via Sennheiser HDA 200 headphones. Loudness perception was assessed through adaptive categorical loudness scaling (ACALOS; Brand and Hohmann 2002), where participants rated the perceived loudness on an 11-point scale ranging from "not heard" to "extremely loud". Loudness functions were fitted using the BTUX fitting method (Oetting, Brand, and Ewert 2014). The deviation of the measured broadband loudness function from a normal-hearing reference function represents the binaural broadband loudness summation (Oetting et al. 2016). This summation is then combined with the narrowband gain values to normalise binaural broadband loudness perception, and consequently gains for input levels of 50-, 65-, and 80-dB SPL were calculated. This gain calculation method is referred to as trueLOUDNESS.

Speech recognition of everyday sentences

Speech intelligibility was assessed using two methodologies, one of which involved the Göttingen Sentence Test (German: Göttinger Satztest, GÖSA; Kollmeier and Wesselkamp 1997) consisting of everyday sentences. In this measurement, free-field equalised Sennheiser HDA 200 headphones were used with the target speaker (GÖSA sentences) presented from 0° azimuthal angle and noise from 90° angle (S0N90). The stationary speech-shaped noise was constant at 65 dB SPL and the speech level was adjusted adaptively targeting 50% speech recognition (speech recognition threshold SRT) according to the A1 adaptive procedure in Brand and Kollmeier (2002). The SRT was measured in two conditions using headphones: (1) unaided, the signals were presented without gain adjustments (2) aided, with application of trueLOUDNESS gains described in 2.1.4. In both measurements, the noise was presented with pauses between the sentences.

Loudness validation method

The Loudness Validation Method (LVM)[2] is a measurement developed to assess the deviation of perceived loudness from NH individuals for HA users in a free-field setting (Exter et al. 2024; Jansen et al. 2020). The LVM was performed only in the HI-HAa group. To present a comprehensive selection of natural sounds, four frequency categories are considered: Low (200–920 Hz), Middle (920–2300 Hz), High (2300–6400 Hz), and Broadband (200 to 6400 Hz). The signals are further categorised into three presentation level categories: Soft, Medium, and Loud, corresponding to equivalent speech levels of 50-, 65-, and 80-dB SPL, respectively. Each of the resulting twelve presentation categories contains five different natural signals, resulting in a total of 60 signals, presented in a randomised order. Participants were assigned to rate the perceived loudness of each signal on an 11-point scale as used for categorical loudness scaling ranging from "not heard" to "extremely loud". The average response across the five samples in each presentation category is then compared to a reference range derived from a group of NH individuals involved in the development of the LVM procedure. The comparison results are classified using six labels to indicate deviations from normal loudness perception: much softer (dark blue), slightly softer (light blue), normal (green), slightly louder (yellow), much louder (light red), and extremely loud (dark red). The results in the twelve presentation categories are visualised on a loudness map, with each label represented by a specific colour.

Tone in noise detection

Tone in noise is a measure proposed to assess frequency-specific suprathreshold deficits (Schädler et al. 2020). Here, the tone in noise detection threshold was measured at 500 and 2000 Hz. The threshold was determined with an adaptive procedure of Kaernbach (1990) where the tone level was adapted using a single interval adjustment matrix targeting 75% correctly responded to trials. The broadband noise was fixed at the 30 dB spectral level, corresponding to the 69 dB broadband level. The thresholds in the dataset correspond to the absolute level of the tone at the threshold in dB SPL.

Coupler measurements

For the HI-HAa group, the sound pressure output of the participants' own HA was measured via Coupler measurements. For this purpose, an Aurical HIT test box equipped with Otosuite software (Natus Medical GmbH) and an ear simulator were used. For both HAs (Left and Right), insertion gains were measured for the International Speech Test Signal (ISTS) (Holube et al. 2010) at input levels of 50, 65, 80 dB SPL. In case of open fittings, vents were closed for measurements.

Second appointment

Free-field Setup: The second appointment was conducted in a free-field setup in a sound treated room with a size of 18 m^2 and a T60 reverberation time of 0.2 s. Participants were seated in the centre of a horizontal loudspeaker array with 24 Genelec 8030B loudspeakers, which were arranged equally spaced on a circle with a radius of 2 m at a height of 1.25 m (acoustic axis). In front of the participants, a touchscreen monitor was placed so that it did not block out the direct sound of the frontal loudspeakers. All measurements at second and third appointments were conducted in this setup, in some cases, using only a subset of loudspeakers as given in the respective procedure description.

Speech Recognition of unpredictable sentences

SRTs for different scenarios were measured using the Oldenburg Sentence Test (German: Oldenburger Satztest, OLSA; Wagener, Brand, and Kollmeier 1999 a,b,c I-III; Wagener and Brand 2005) with adaptive speech level (procedure A1 from Brand and Kollmeier 2002). During this appointment, the measurement for HA users was performed in unaided settings (without their HA) (HI-HAu). For corresponding aided conditions, see appointment three. Six acoustic conditions were included, two of which involved common spatial settings: 1) S0N0, where both target speech (OLSA sentences) and the corresponding stationary speech-shaped noise (OLnoise, Wagener, Brand, and Kollmeier 1999 a,b,c) were presented from 0° azimuthal angle. 2) S0N90, where the target speech remained at 0° while noise was presented at 90°.

Four additional conditions were implemented using three simulated auditory-virtual scenes designed for hearing research including a living room (Schütze et al. 2021), pub (Grimm et al. 2021), and underground (Hladek and Seeber 2022) scene, shown in Figure 1. The living-room test environment consisted of a 51 m^3 living room coupled to a 27 m^3 kitchen, connected by a door, with a combined reverberation time of $T_{30} = 0.56$ s. Two spatial sound-source configurations were evaluated: a symmetric (LR_sym) and an asymmetric (LR_asym) condition. In both cases, the listener was positioned on a sofa at location R1, and three kitchen maskers were present: a dishwasher noise (S6) and a two-female dialogue at positions S7 and S8 (Figure 1). In LR_sym, two additional maskers (S4 and S5) consisting of male-transformed ISTS noise were placed to the left and right of the listener, while the target source was located directly in front at S-TV. In LR_asym, the target was moved to S4, and a single additional male-transformed ISTS masker was placed at S-TV. The pub environment simulated a restaurant-like setting with multiple guest conversations, background music, and typical ambient sounds (beer pouring, clinking glasses, dishware handling). The room measured $15 \times 10 \times 2.95$ m (442 m^3) with a reverberation time of $T_{30} = 0.66$ s. The scene represented a group conversation at a table, with the listener positioned at R1 and the target talker located directly across at T2 (0.97 m distance). Three additional talkers at T1, T3, and T4 served as interferers (Figure 1). A realistic babble background was created by distributing numerous independent conversations throughout the room (positions S1–S8, N1–N3, P1–P8). The underground station environment (UG_station) simulated a subway platform with a total volume of 8555 m^3 and a reverberation time of T_{30}=1.68. The scene modelled a two-person conversation, with the listener positioned at R1 between the two tracks and the target talker placed 1.6 m directly ahead. Two additional maskers, also at 1.6 m distance and positioned at ±60°, presented temporally shifted male-transformed ISTS signals. A third masker, located 10.1 m from the listener, reproduced escalator noise. Real-world ambient station noise recordings were added to complete the acoustic background. The simulations and recordings of all acoustic scenes and room impulse responses are available on Zenodo platform (Gerken et al. 2025b) For the details regarding the realisation of these virtual scenes, refer to Gerken et al. (2025a).

Calibration of virtual scenes with reverberant target speech was performed as follows. To present target speech as part of the virtual scenes, it was convolved with the room impulse response (RIR) corresponding to the specific presentation position in the scene. This process added scene-dependent reverberation to the speech. On the one hand, reverberation affects the speech level in the virtual room, and, on the other hand, it deteriorates speech intelligibility depending on several parameters (Lavandier and Culling 2007).

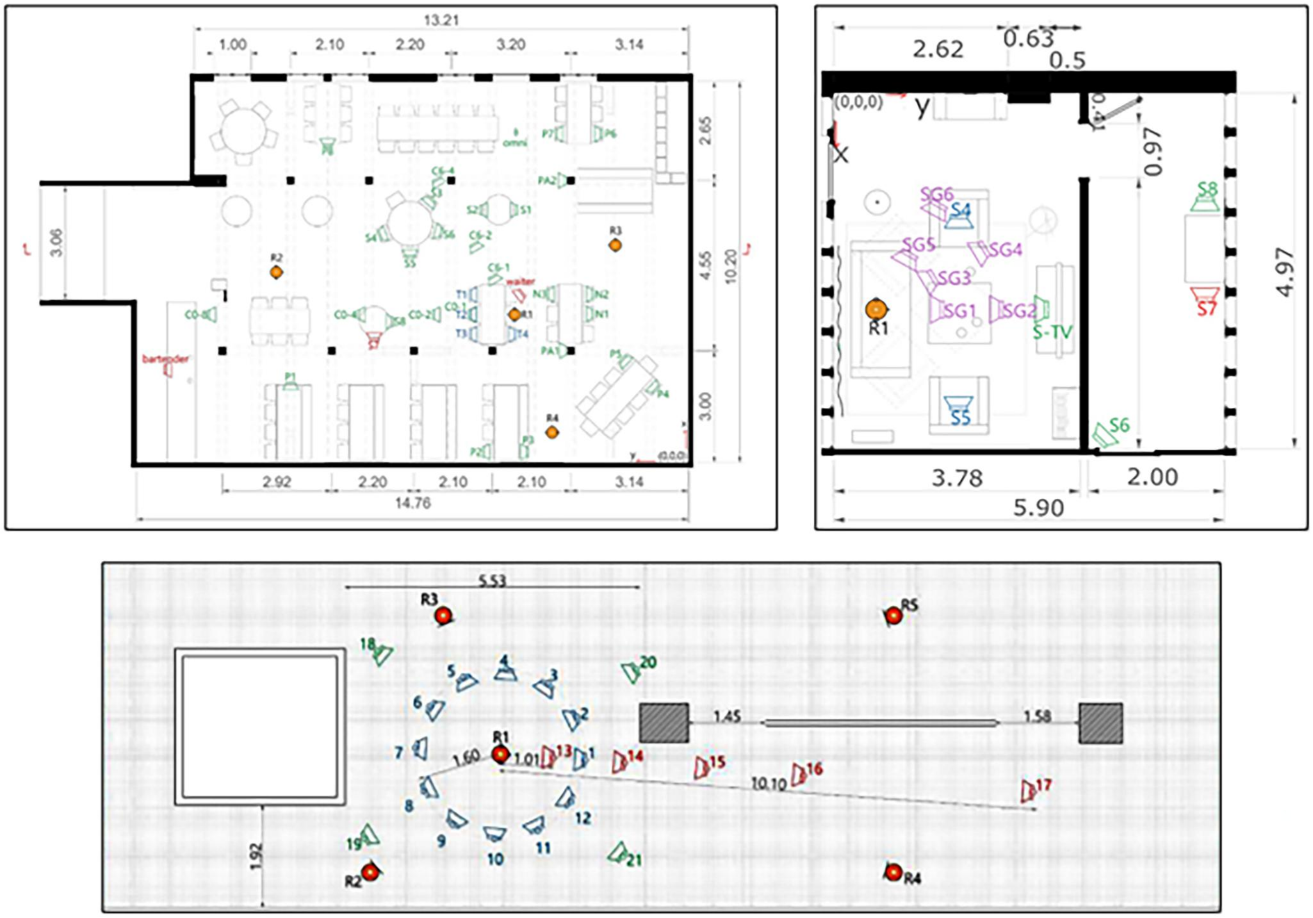

Figure 1. Drawings of the acoustic scenarios. Bottom: An underground station: Target speech: Loudspeaker #15, male ISTS maskers: Loudspeakers #3 and #11 and underground background noise, labelled as UG_station. Top right: Living room applied with listener at R1 position in two settings: Asymmetric layout, labelled as LR_asym: Target speech via loudspeaker S4 (−45°), Maskers: male ISTS via loudspeaker S-TV (0°), female dialogue, and dish washer noise from the other room. Symmetric layout, labelled as LR_sym: Target speech via loudspeaker S-TV (0°), Maskers: male ISTS maskers via loudspeakers S4 and S5 (±45°). Top left: Pub. Target speech via loudspeaker T2, maskers: conversations via loudspeakers marked with T and S and ambient pub noise including pop music [Image adapted from van de Par et al. (2022)].

To allow for a comparison of speech intelligibility across scenes and standard conditions, the target speech was calibrated using only the direct-sound part of the RIRs. Therefore, these direct-sound parts of the RIRs were identified visually and then framed using von-Hann windows. The windows were centred on the maxima of the direct sound and ended just before the first reflection.

Adaptive categorical listening effort scaling

Listening effort was evaluated using the Adaptive Categorical Listening Effort Scaling (ACALES) method (Krueger et al. 2017) under the same six spatial conditions applied in the OLSA measurement (S0N0, S0N90, pub, underground station, and living room with two layouts). The target speech included three consecutive OLSA sentences. Participants rated their listening effort on a 13-point categorical scale, which included seven labelled and six unlabelled categories, in the range of "no effort" to "extreme effort" corresponding to Effort Scaling Categorical Unit (ESCU) 1 to 13. An additional "only noise" category was provided, and participants were instructed to choose this option, if they perceived only noise without any speech.

Third appointment

In this appointment, OLSA, ACALES, and GÖSA measurements were repeated only for HA users while wearing their own HA (HI-HAa). For the OLSA and ACALES measurements, similar to the unaided evaluation, sounds were presented in a free-field setting using the same six simulated acoustic scenes. Probe tube recordings of all OLSA and ACALES measurements were performed. Additionally, real-ear measurements with standard signals (speech-shaped noise at 65 dB SPL, and ISTS at 50, 65, and 80 dB SPL) were performed using this probe tube setup. These recordings were not analysed but can be provided on request. In the GÖSA measurement, as opposed to the unaided measurement, where sounds were presented through headphones, they were presented in a free-field setting with the HA in place and continuous presentation of noise.

Results

Detailed outcomes of the OLSA, ACALES, HCT, TIN, PTA, and loudness scaling measurements are available in Gerken et al. 2025a. In this section, example outcomes for selected methodologies for two specific groups of participants are provided. (1) individuals with moderate HL ($40 < \text{PTA} \leq 60$ dB HL) who do not use a HA in daily life (HI-noHA), (2) individuals with moderate HL who use HA in both unaided (HI-HAu) and aided (HI-HAa) settings. Furthermore, details about the publicly available structured dataset, along with guidelines for its usage, are provided.

Measurements outcome

Pure-tone audiometry

Figure 2 (left panel) shows the distribution of the average AC thresholds over 500, 1000, 2000, and 4000 Hz for participants with moderate HL for both HI-noHA and HI-HAu groups.

Speech recognition of everyday sentences – GÖSA measurement

Figure 2 (right panel) shows the distribution of SRT values in multiple settings for the HI-noHA and HI-HAu groups with moderate HL, both with and without the application of trueLOUDNESS gains, and for the HI-HAa group in the free-field condition.

Loudness validation method

Figure 3 (left panel) shows the loudness map measured for a sample participant with moderate HL. Figure 3 (right panel) shows the bar chart of the total proportions of the six LVM loudness perception categories for the HI-HAa group with moderate HL.

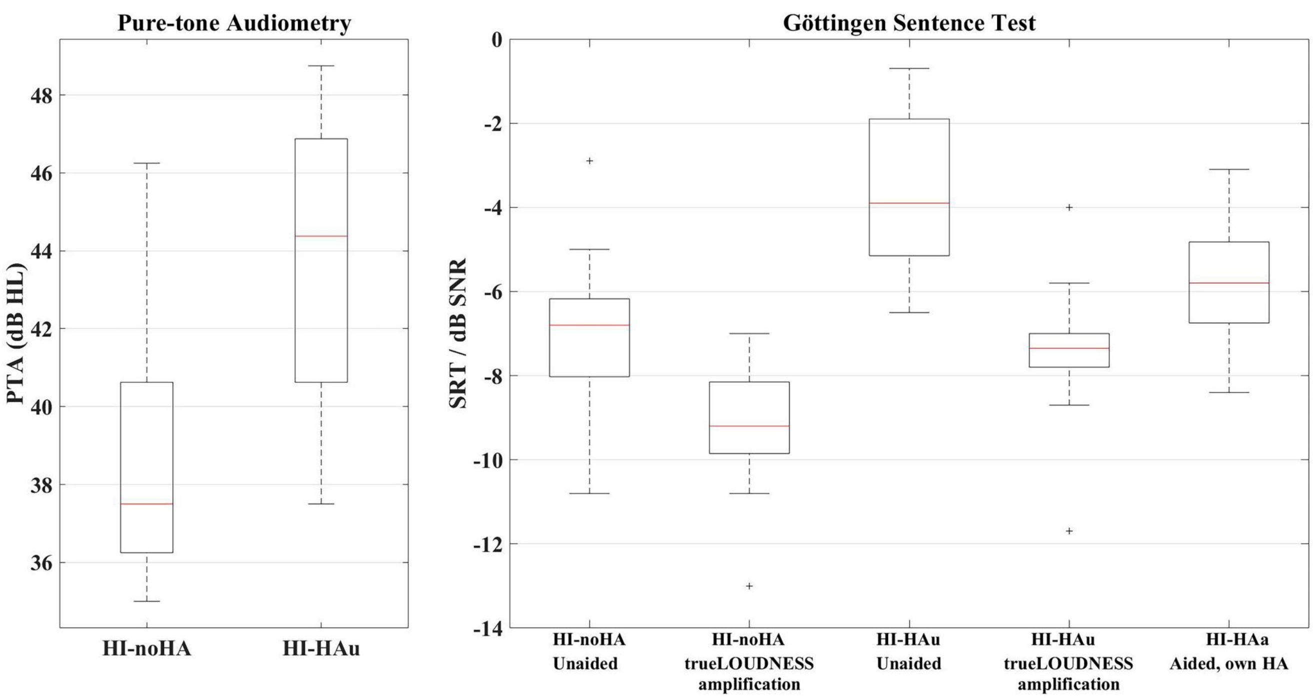

Figure 2. Left: Pure-tone audiometry results for participants with moderate hearing loss, AC thresholds averaged over 500, 1000, 2000, and 4000 Hz for better ear. Right: Göttingen Sentence Test results, Speech Reception Threshold (SRT) in aided (with own hearing aid in free field) and unaided settings (no gain adjustment and with applied measure trueLOUDNESS gains). HI-noHA: Participants who do not use hearing aids. HI-HAu: Hearing aid users, measured in an unaided setting (without a hearing aid). HI-HAa: Hearing aid users, measured in an aided setting (with own hearing aid).

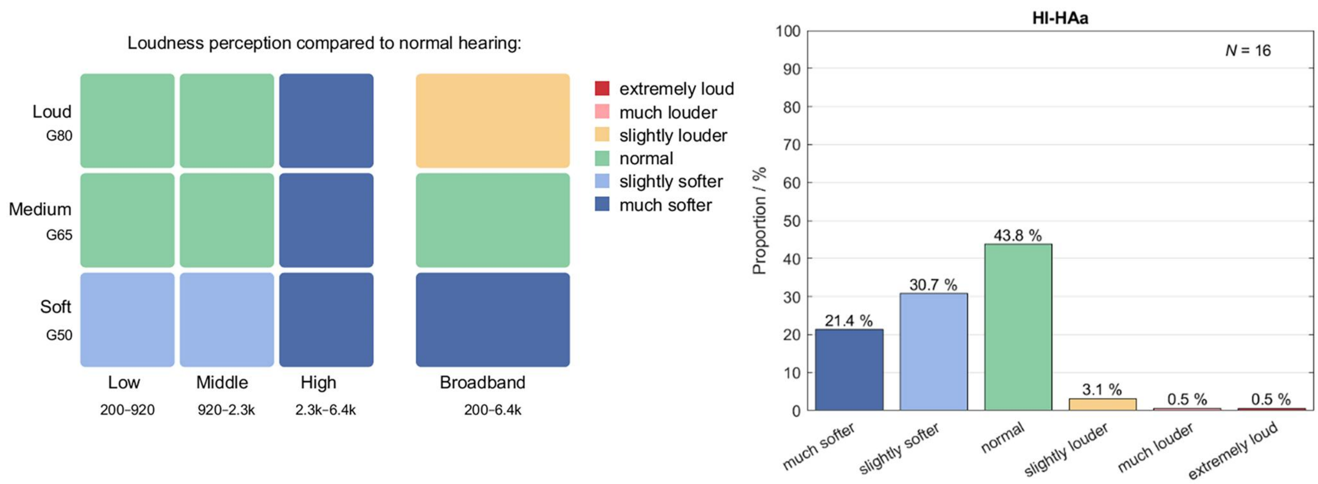

Figure 3. Loudness Validation Method (LVM) outcome: Left, example loudness map: outcome demonstration for a hearing aid user with moderate hearing loss. The x-axis represents LVM frequency categories and the y-axis represents LVM level categories. Right, bar chart of the total proportions of the six LVM loudness perception categories for the HI-HAa group with moderate HL.

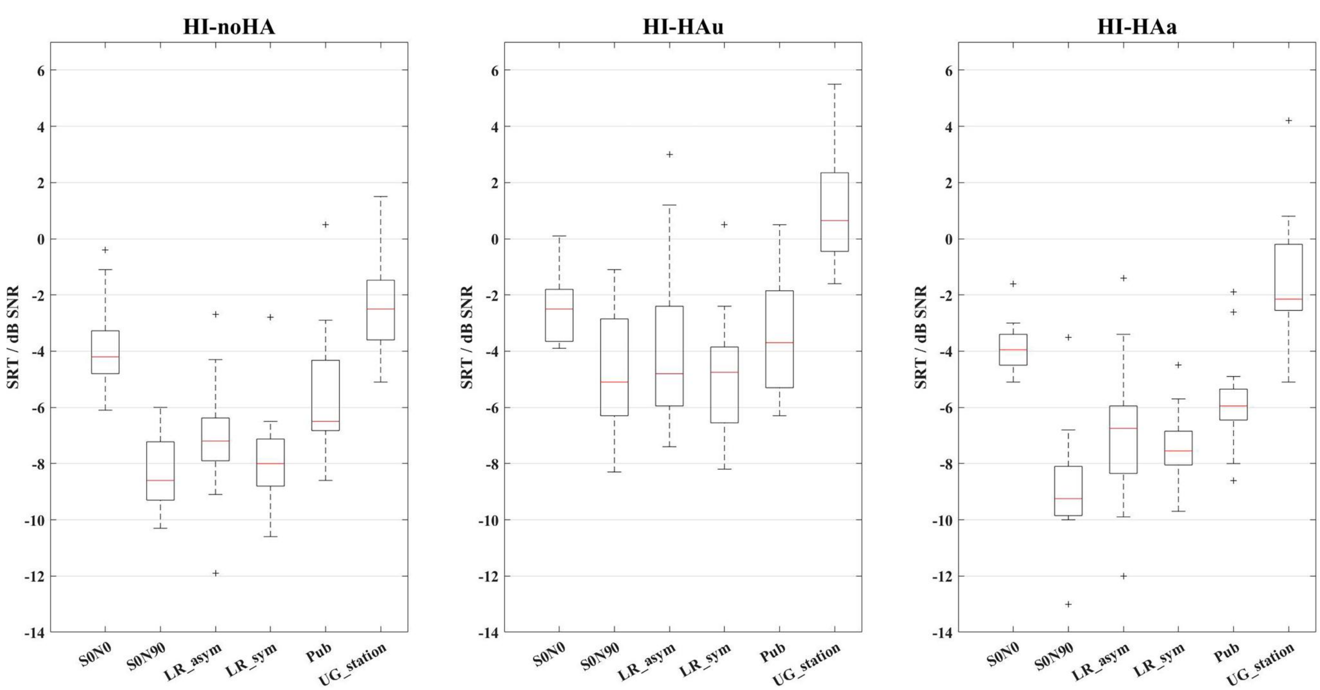

Figure 4. OLSA Speech Reception Threshold (SRT) values for participants with moderate hearing loss. Left, HI-noHA: Participants who do not use hearing aids. Middle, HI-HAu: Hearing aid users, measured in an unaided setting (without a hearing aid). Right, HI-HAa: Hearing aid users, measured in an aided setting (with their own hearing aids). LR_sym: Living room with symmetric layout. LR_asym: Living room with asymmetric layout, UG_station: Underground station.

Speech recognition of unpredictable sentences, OLSA measurement

The SRT values over the six conditions were collected. As examples, Figure 4 shows the distribution of measured SRT value for participants with moderate HL.

Adaptive categorical listening effort scaling

The distribution of the measured SNR values for participants with moderate HL, selected at ESCU 1, 7, and 13 as examples, is provided in Figure 5.

Dataset structure

All measurement data and metadata were transferred into an SQL dataset. To enhance comprehensibility and allow a broad use of data, a data description as pdf file is available. The *.sql files to generate a SQL dataset as well as the data description are publicly accessible on zenodo.org platform (Findability, Accessibility). To describe the tables and their columns of the SQL dataset, unique and descriptive names were chosen from the specialised terminology of hearing research. In some cases, abbreviations have

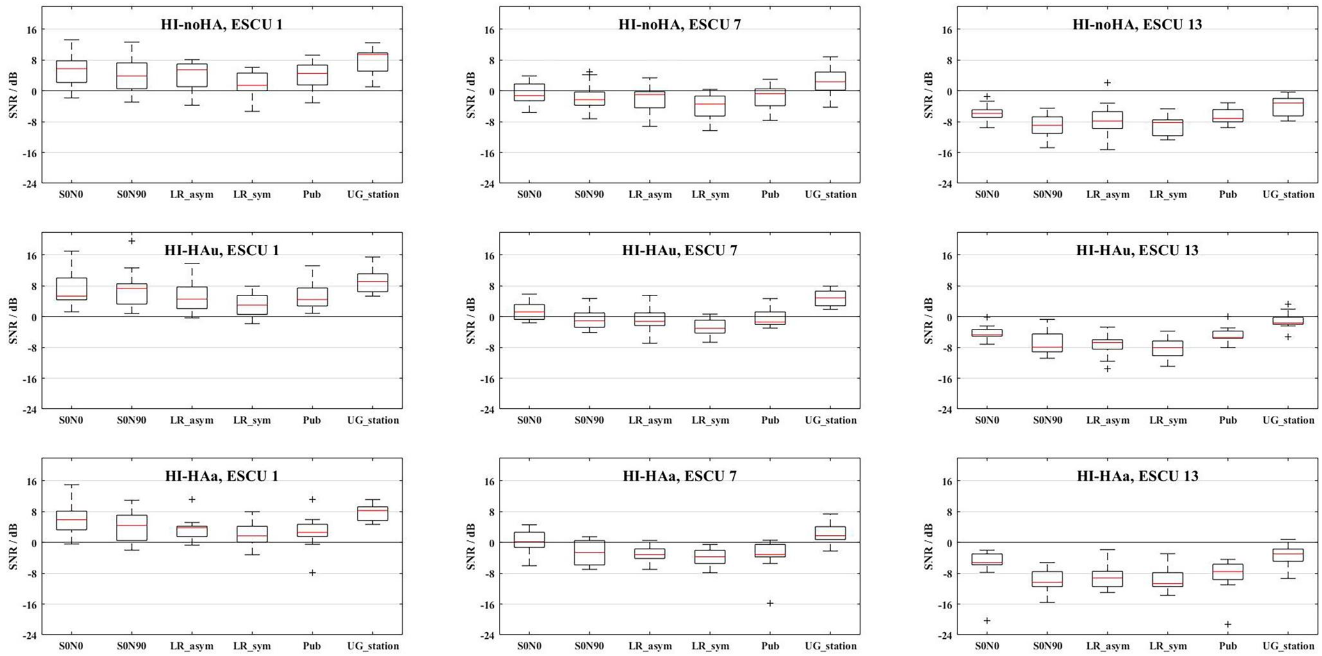

Figure 5. SNR values distribution at three Effort Scaling Categorical Unit (ESCU) levels (1, 7, and 13) for participants with moderate hearing loss. Top row, HI-noHA: Participants who do not use hearing aids. Middle row, HI-HAu: Hearing aid users, measured in an unaided setting (without a hearing aid). Bottom row, HI-HAa: Hearing aid users, measured in an aided setting (with their own hearing aids). LR_sym: Living room with symmetric layout. LR_asym: Living room with asymmetric layout, UG_station: Underground station.

been used, but by using the data description these are clearly understandable. To link these data to the participants of the study, a unique identifier for the participants, *VP_ID,* is in place. Additionally, this identifier can be used to join data from multiple tables together.

The data description offers a concise overview of the existing tables and their contents, along with a reference to the comprehensive description of the measurements performed to ensure that data can be reused as easily as possible. To enrich the dataset, reference values documented within the data description are also available as entries in the dataset itself, if applicable (Reusable). The basic structure of the dataset (Figure 6) comprises a central participant table that contains basic identifiers and information about which measurements each participant completed. This central table is connected to measurement tables, each representing the results of the above-described measurements. A detailed Entity-Relationship-Diagram can be found in the Appendix. The hear_command_tool_subject_responses table is another central table. It stores the values of the HEAR-COMMAND Tool. It is possible to map all questions and answers of the questionnaire by utilising this table and their connected tables.

Discussion

An audiological perception dataset has been developed that includes a variety of hearing loss evaluation measurements aimed at advancing HA modelling. This broad dataset supports a holistic assessment of hearing impairment, with the potential to enhance the effectiveness of HA algorithms and overall user satisfaction. By evaluating speech intelligibility and listening effort in real-life simulated virtual scenes, the dataset offers an ecologically valid approach that better reflects the hearing challenges individuals face in their daily lives.

This dataset provides a unique resource for comparing the outcomes of diverse measurements conducted on the same participants. Hearing difficulties can occur in various ways, and a multi-modal analysis allows for a more comprehensive assessment. Furthermore, such cross-methodological analysis facilitates identifying correlations between a participant's performance across different measurements, each addressing a different aspect of HL. For example, self-reported data collected via the HEAR-COMMAND tool, particularly speech perception scores, can be compared with speech intelligibility evaluation in laboratory settings via OLSA measurements as demonstrated in Gerken et al. (2025a). Furthermore, the

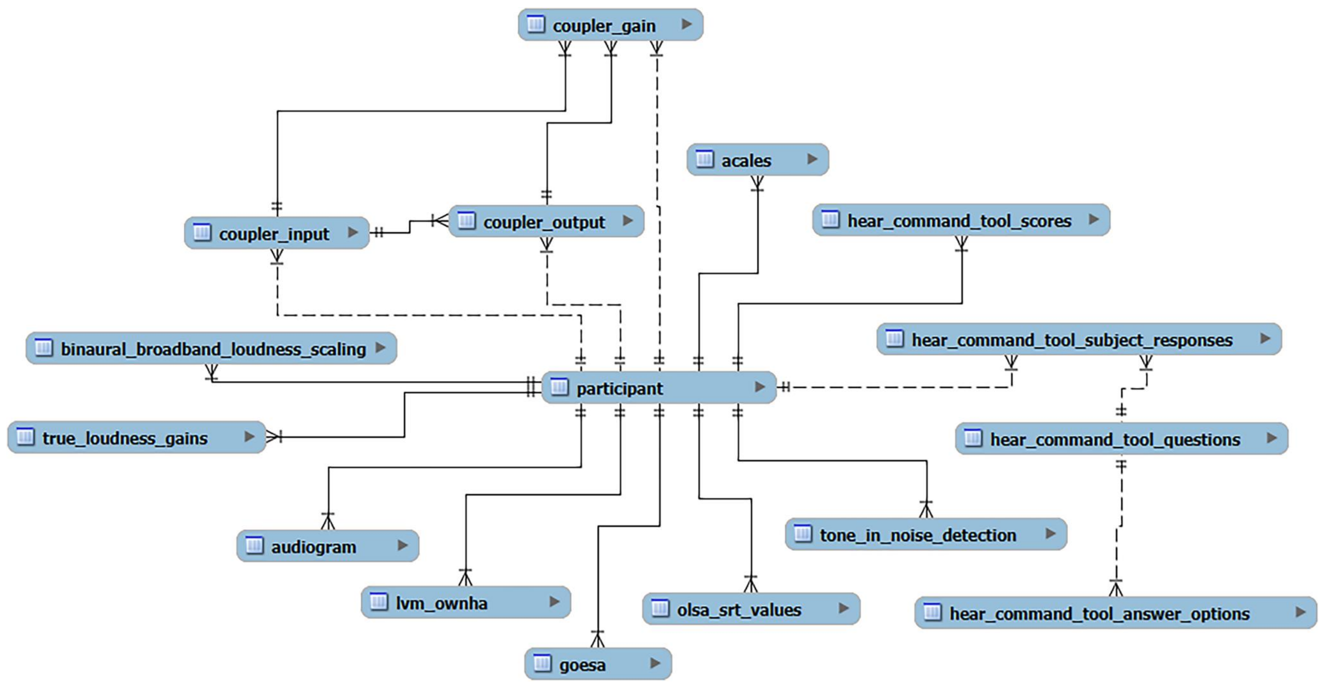

Figure 6. The basic structure of the dataset, represented as an Entity-Relationship-Diagram. A detailed ER diagram can be found in the appendix.

relationship between pure-tone audiometry, a traditionally fundamental HL evaluation method, and hearing difficulties revealed through more complex methods, such as ACALES and OLSA measurements, can be analysed. As a result, this analysis determines the extent to which a single value (i.e., the average AC thresholds of the better ear) accurately reflects hearing difficulties and the actual degree of HL (Gerken et al. 2025a).

Conducting measurements for HA users (in this case OLSA, GÖSA, and ACALES) both with and without a HA allows researchers to compare an individual's performance in aided and unaided settings that provides a clear evaluation of HA effectiveness in terms of speech intelligibility, listening effort, and other relevant concepts. Factors such as the HA brand and model, built-in features, duration of usage, and settings adjusted based on personal preference highly impact the participant's performance. Therefore, since participants used their own HA with their typical settings, rather than identical HA with similar usage features, general conclusions based on the measurements' outcomes should be avoided.

Although there is currently no plan to expand this dataset by adding other measurements or increasing the sample size, the structured model based on FAIR principle and public accessibility of the data facilitate the expansion. For example, as the acoustic scenes are publicly available (Gerken et al. 2025b), by following the provided documentation, researchers can replicate the included measurements and add other relevant measurements specific to a certain HI population, such as Cochlear Implant users. Additionally, real-life measurements can be included, conducted in locations where participants spend most of their time, such as their homes or workplaces, to identify the practical effectiveness of HA in daily functioning.

As the OLSA and ACALES measurements in virtual acoustic scenes require 24 loudspeakers to conduct, reproducing these measurements demands complex and costly recording settings. It is safe to assume that for most audiology clinics, implementing such a setting is challenging and impractical. However, further analysis of the collected data is needed to determine the extent to which these measurements provide unique information on listening effort and speech intelligibility that cannot be captured with typical simpler setups, such as S0N0 and S0N90, which require a maximum of two loudspeakers.

A variety of measurements were included in the database, and when combined, they have the potential to yield a detailed patient-centred profile of hearing function. To define the extent to which factors relevant to HL were represented, it is essential to evaluate the database against a globally accepted standard (Afghah et al. 2023). The World Health Organization's International Classification of Functioning Disability and Health (ICF) framework (WHO 2001, World Health Organization 2013) can serve as a reference to adapt the database to a comprehensive list of factors related to the HL, its causes and consequences. In another study, database inclusiveness was highlighted, and missing concepts from this analysis were revealed (Afghah and Wagener 2025), by following the ICF linking guidelines (Cieza et al. 2002, 2005).

Notes

1. https://www.hz-ol.de/en/open-tools-for-science/hear-command-tool/.
2. The Loudness Validation Method is offered as a commercial product by Hörzentrum Oldenburg gGmbH under the name "revoloud".

Acknowledgments

The authors would like to express their sincere gratitude to the project assistants Anja Schröck and Fabian Eberling for their collaboration in data collection.

Ethics statement

The studies involving humans were approved by the "Research Ethics Committee of the Carl von Ossietzky University of Oldenburg", in German: "Kommission für Forschungsfolgenabschätzung und Ethik der Carl von Ossietzky Universität" (Drs.EK/2021/031, Drs.EK/2021/031-02, Drs.EK/2021/031-03, Drs.EK/2021/031-04).

Author contributions

CRediT: **Tahereh Afghah**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Jan Heeren**: Conceptualization, Data curation, Methodology, Project administration, Resources, Software, Validation, Writing – original draft, Writing – review & editing; **Laura Hartog**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Pascal Biermann**: Conceptualization, Data curation, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing; **Antje Wulff**: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; **Anna Warzybok**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing; **Kirsten C. Wagener**: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing.

Disclosure statement

No potential conflict of interest was reported by the authors. The Loudness Validation Method described in this article is offered as a commercial product by Hörzentrum Oldenburg gGmbH under the name "revoloud".

Funding

This study was funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – Project ID: 352015383 – SFB 1330, A5/C4/C5.

ORCID

Tahereh Afghah http://orcid.org/0009-0005-5343-0818
Jan Heeren http://orcid.org/0000-0002-8489-8705
Laura Hartog http://orcid.org/0009-0004-0866-4212
Pascal Biermann http://orcid.org/0009-0001-8434-5393
Antje Wulff http://orcid.org/0000-0002-2550-2627
Anna Warzybok http://orcid.org/0000-0002-4298-4605
Kirsten C. Wagener http://orcid.org/0000-0003-2858-2789

Data availability statement

The dataset content is publicly accessible on Zenodo platform under "SFB 1330 Hearing Acoustics" community. https://doi.org/10.5281/zenodo.14864856.

References

Afghah, T., R. Alfakir, M. Meis, L. van Leeuwen, S. E. Kramer, M. Hammady, M. Youssif, and K. C. Wagener. 2022. "The Development of a Self-Rated ICF-based Questionnaire (HEAR-COMMAND Tool) to Evaluate Hearing, Communication, and Conversation Disability: Multinational Experts' and Patients' Perspectives." *Frontiers in Rehabilitation Sciences* 3:1005525. https://doi.org/10.3389/fresc.2022.1005525.

Afghah, T., R. Alfakir, M. Meis, M. Hammady, M. Youssif, M. Abd Al-Ghaffar, S. E. Kramer, and K. C. Wagener. 2024. "ICF-Based Hearing and Functioning Assessment: Validation and Research Outcomes of Utilizing the HEAR-COMMAND Tool for Patients with Mild to Moderately Severe Hearing Loss and Individuals with Normal Hearing." *Frontiers in Rehabilitation Sciences* 5: 1389653. https://doi.org/10.3389/fresc.2024.1389653.

Afghah, T., J. Schütze, M. Meis, B. Kollmeier, and K. C. Wagener. 2023. "Conformities and Gaps of Clinical Audiological Data with the International Classification of Functioning Disability and Health Core Sets for Hearing Loss." *International Journal of Audiology* 62 (6):552–561. https://doi.org/10.1080/14992027.2022.2078433.

Afghah, T., P. Biermann, A. Warzybok, J. Heeren, A. Wulff, M. Gerken, J. Schütze, C. Kirsch, B. Seeber, S. D. Ewert, et al. 2025a. "A FAIR and Open-Access Database of Audiological Perceptual Measures." [Data set]*Zenodo* https://doi.org/10.5281/zenodo.14864856.

Afghah, T., and K. C. Wagener. 2025. "A Comparative Analysis of a Perceptual Hearing Loss Assessment Dataset and the International Classification of Functioning, Disability, and Health Core Sets for Hearing Loss." *Zenodo* [Preprint] https://doi.org/10.5281/zenodo.17085375.

Afghah, T., R. Alfakir, M. Meis, L. van Leeuwen, S. E. Kramer, M. Hammady, M. Youssif, M. Abd Al-Ghaffar, J. Hyun, H. Sagong, et al. 2025b. "HEAR-COMMAND TOOL Source files (in English/German/Arabic/Korean)." *Zenodo* https://doi.org/10.5281/zenodo.7586178.

Alfakir, R., M. Hammady, T. Afghah, M. Abd Al-Ghaffar, and M. Youssif. 2025a. "Translation, Cultural Adaptation, and Validation of the Arabic Version of the HEAR-COMMAND Tool: A Self-Rated ICF-Based Questionnaire for Assessing Hearing, Communication, and Conversation Disability in Arabic-Speaking Populations." *The Egyptian Journal of Otolaryngology* 41 (1). https://doi.org/10.1186/s43163-025-00832-4.

Alfakir, R., L. Dunaway, J. Hyun, H. Sagong, T. Afghah, and S. Kang. 2025b. *Translation, Cultural Adaptation, and Field Testing of the Korean Version of the HEAR-COMMAND Tool: A Self-Rated ICF-Based Questionnaire for Assessing Hearing, Communication, and Conversation Disability in Korean-Speaking Populations*. The Korean Audiological Society. https://doi.org/10.7874/jao.2025.00136.

Andersen, A. H., S. Santurette, M. S. Pedersen, E. Alickovic, L. Fiedler, J. Jensen, and T. Behrens. 2021. "Creating Clarity in Noisy Environments by Using Deep Learning in Hearing Aids." *Seminars in Hearing*. 42(3): 260–281. Thieme Medical PublishersInc https://doi.org/10.1055/s-0041-1735134.

Brand, T., and B. Kollmeier. 2002. "Efficient Adaptive Procedures for Threshold and Concurrent Slope Estimates for Psychophysics and Speech Intelligibility Tests." *The Journal of the Acoustical Society of America* 111 (6):2801–2810. PMID: 12083215. https://doi.org/10.1121/1.1479152.

Brand, T., and V. Hohmann. 2002. "An Adaptive Procedure for Categorical Loudness 7ucaling." *The Journal of the Acoustical Society of America* 112 (4): 1597–1604. https://doi.org/10.1121/1.1502902.

Cieza, A., T. Brockow, T. Ewert, E. Amman, B. Kollerits, S. Chatterji, T. B. Ustün, and G. Stucki. 2002. "Linking Health-Status Measurements to the International Classification of Functioning, Disability and Health." *Journal of Rehabilitation Medicine* 34 (5):205–210. https://doi.org/10.1080/165019702760279189.

Cieza, A., S. Geyh, S. Chatterji, N. Kostanjsek, B. Ustün, and G. Stucki. 2005. "ICF Linking Rules: An Update Based on Lessons Learned." *Journal of Rehabilitation Medicine* 37 (4):212–218. https://doi.org/10.1080/16501970510040263.

Danermark, B., A. Cieza, J.-P. Gangé, F. Gimigliano, S. Granberg, L. Hickson, S. E. Kramer, B. McPherson, C. Möller, I. Russo, et al. 2010. "International Classification of Functioning, Disability, and Health Core Sets for Hearing Loss: A Discussion Paper and Invitation." *International Journal of Audiology* 49 (4):256–262. https://doi.org/10.3109/14992020903410110.

Danermark, B., S. Granberg, S. E. Kramer, M. Selb, and C. Möller. 2013. "The Creation of A Comprehensive and A Brief Core Set for Hearing Loss Using the International Classification of Functioning, Disability and Health." *American Journal of Audiology* 22 (2):323–328. https://doi.org/10.1044/1059-0889(2013/12-0052).

Diehl, P. U., Y. Singer, H. Zilly, U. Schönfeld, P. Meyer-Rachner, M. Berry, H. Sprekeler, E. Sprengel, A. Pudszuhn, and V. M. Hofmann. 2023. "Restoring Speech Intelligibility for Hearing Aid Users with Deep Learning." *Scientific Reports* 13 (1):2719. https://doi.org/10.1038/s41598-023-29871-8.

Diehl, P. U., H. Zilly, F. Sattler, Y. Singer, K. Kepp, M. Berry, H. Hasemann, M. Zippel, M. Kaya, and P. Meyer-Rachner. 2023. "Deep Learning-based Denoising Streamed from Mobile Phones Improves Speech-in-Noise Understanding for Hearing Aid Users." *Frontiers in Medical Engineering* 1:1281904. https://doi.org/10.3389/fmede.2023.1281904.

Exter, M., T. Jansen, L. Hartog, and D. Oetting. 2024. "Development and Evaluation of a Loudness Validation Method With Natural Signals for Hearing Aid Fitting." *Trends in Hearing* 28:23312165241299778. https://doi.org/10.1177/233121652412997.

Fiedler, L., T. S. Ala, C. Graversen, E. Alickovic, T. Lunner, and D. Wendt. 2021. "Hearing Aid Noise Reduction Lowers the Sustained Listening Effort during Continuous Speech in Noise—A Combined Pupillometry and EEG Study." *Ear and Hearing* 42 (6):1590–1601. https://doi.org/10.1097/AUD.0000000000001050.

Gannot, S., E. Vincent, S. Markovich-Golan, and A. Ozerov. 2017. "A Consolidated Perspective on Multimicrophone Speech Enhancement and Source Separation." *IEEE/ACM Transactions on Audio, Speech, and Language Processing* 25 (4):692–730. https://doi.org/10.1109/TASLP.2016.2647702.

Gerken, M., J. Schütze, C. Kirsch, B. U. Seeber, S. D. Ewert, J. Heeren, T. Afghah, K. C. Wagener, B. Kollmeier, and A. Warzybok. 2025a. "Perceptual Measures of Normal and Hearing-impaired Listeners Across Defined Virtual Acoustic Scenes." *Zenodo* [Preprint] https://doi.org/10.5281/zenodo.17086129.

Gerken, M., J. Schütze, C. Kirsch, B. U. Seeber, S. D. Ewert, J. Heeren, K. C. Wagener, and A. Warzybok. 2025b. "Simulations and Recordings of Scenes used in "Perceptual Measures of Normal-hearing and Hearing-impaired Listeners across Defined Virtual Acoustic Scenes." [Dataset]*Zenodo* https://doi.org/10.5281/zenodo.16895975.

Grimm, G., M. Hendrikse, and V. Hohmann. 2021. Pub environment [Dataset]. Zenodo. https://zenodo.org/records/5886987

HAPPAA 2018. Collaborative Research Centre SFB 1330 Hearing Acoustics, University of Oldenburg. https://uol.de/en/sfb-1330-hearing-acoustics.

Hladek, L., and B. U. Seeber. 2022. Underground station environment [Dataset]. Zenodo. https://zenodo.org/records/6025631

Holube, I., S. Fredelake, M. Vlaming, and B. Kollmeier. 2010. "Development and Analysis of An International Speech test Signal (ISTS)." *International Journal of*

Audiology 49 (12):891–903. https://doi.org/10.3109/14992027.2010.506889.

Jafri, S., D. Berg, M. Buhl, M. Vormann, S. Saak, K. C. Wagener, C. M. Thiel, A. Hildebrandt, and B. Kollmeier. 2025. The Oldenburg Hearing Health Record (OHHR) (p. 2025.03.30.25324761). medRxiv. https://doi.org/10.1101/2025.03.30.25324761.

Jansen, T., L. Hartog, M. Hansen, and D. Oetting. 2020. "Entwicklung und evaluation eines Verfahrens zur Bestimmung der Lautheitswahrnehmung von Hörgeräteträgern für natürliche Signale." In *23. Jahrestagung der Deutschen Gesellschaft für Audiologie* (1–4). German Medical Science GMS Publishing House. https://doi.org/10.3205/20dga183.

Kaernbach, C. 1990. "A Single-interval Adjustment-Matrix (SIAM) Procedure for Unbiased Adaptive Testing." *The Journal of the Acoustical Society of America* 88 (6):2645–2655. https://doi.org/10.1121/1.399985.

Kollmeier, B., and M. Wesselkamp. 1997. "Development and Evaluation of a German Sentence Test for Objective and Subjective Speech Intelligibility Assessment." *The Journal of the Acoustical Society of America* 102 (4):2412–2421. https://doi.org/10.1121/1.419624.

Krueger, M., M. Schulte, T. Brand, and I. Holube. 2017. "Development of An Adaptive Scaling Method for Subjective Listening Effort." *The Journal of the Acoustical Society of America* 141 (6):4680–4693. https://doi.org/10.1121/1.4986938.

Lavandier, M., and J. F. Culling. 2007. "Speech Segregation in Rooms: Effects of Reverberation on both Target and Interferer." *The Journal of the Acoustical Society of America* 122 (3):1713–1723. https://doi.org/10.1121/1.2764469.

Nossier, S. A., M. R. M. Rizk, N. D. Moussa, and S. el Shehaby. 2019. "Enhanced Smart Hearing Aid using Deep Neural Networks." *Alexandria Engineering Journal* 58(2):539–550. https://doi.org/10.1016/j.aej.2019.05.006.

Oetting, D., T. Brand, and S. D. Ewert. 2014. "Optimized Loudness-function Estimation for Categorical Loudness Scaling Data." *Hearing Research* 316:16–27. https://doi.org/10.1016/j.heares.2014.07.003.

Oetting, D., V. Hohmann, J.-E. Appell, B. Kollmeier, and S. D. Ewert. 2016. "Spectral and Binaural Loudness Summation for Hearing-impaired Listeners." *Hearing Research* 335:179–192. https://doi.org/10.1016/j.heares.2016.03.010.

Oetting, D., V. Hohmann, J.-E. Appell, B. Kollmeier, and S. D. Ewert. 2018. "Restoring Perceived Loudness for Listeners with Hearing Loss." *Ear and Hearing* 39 (4):664–678. https://doi.org/10.1097/AUD.0000000000000521.

Olusanya, B. O., A. C. Davis, and H. J. Hoffman. 2019. "Hearing Loss Grades and the International Classification of Functioning, Disability and Health." *Bulletin of the World Health Organization* 97 (10):725–728. https://doi.org/10.2471/BLT.19.230367.

Regev, J., J. Zaar, H. Relaño-Iborra, and T. Dau. 2025. "Dataset for: "Investigating the Effects of Age and Hearing Loss on Speech Intelligibility and Amplitude Modulation Frequency Selectivity" [Dataset]." *Technical University of Denmark* https://doi.org/10.11583/DTU.25771884.v1.

Sanchez-Lopez, R., S. G. Nielsen, M. El-Haj-Ali, F. Bianchi, M. Fereczkowski, O. M. Cañete, M. Wu, T. Neher, T. Dau, and S. Santurette. 2021. "Auditory Tests for Characterizing Hearing Deficits in Listeners With Various Hearing Abilities: The BEAR Test Battery." *Frontiers in Neuroscience* 15:724007. https://doi.org/10.3389/fnins.2021.724007.

Schädler, M. R., D. Hülsmeier, A. Warzybok, and B. Kollmeier. 2020. "Individual Aided Speech-recognition Performance and Predictions of Benefit for Listeners with Impaired Hearing Employing FADE." *Trends in Hearing* 24:2331216520938929. https://doi.org/10.1177/2331216520938929.

Schütze, J., C. Kirsch, K. C. Wagener, B. Kollmeier, and S. D. Ewert. 2021. "Living Room Environment." *Zenodo* [Dataset] https://doi.org/10.5281/ZENODO.5747753.

Suck, L.-C., L. Hartog, S. Ewert, V. Hohmann, and D. Oetting. 2020. *Verkürzung der trueLOUDNESS-Anpassmethode zur binauralen breitbandigen Lautheitsnormalisierung in Hörgeräten*. German Medical Science GMS Publishing House. Germany. https://doi.org/10.3205/20dga040.

van de Par, S., S. D. Ewert, L. Hladek, C. Kirsch, J. Schütze, J. Llorca-Bofí, G. Grimm, M. M. E. Hendrikse, B. Kollmeier, and B. U. Seeber. 2022. "Auditory-Visual Scenes for Hearing Research." *Acta Acustica* 6:55. https://doi.org/10.1051/aacus/2022032.

Vlaming, M. S. M. G., B. Kollmeier, W. A. Dreschler, R. Martin, J. Wouters, B. Grover, Y. Mohammadh, and T. Houtgast. 2011. "HearCom: Hearing in the Communication Society." *Acta Acustica United with Acustica* 97 (2):175–192. https://doi.org/10.3813/AAA.918397.

Wagener, K., V. Kühnel, and B. Kollmeier. 1999a. "Development and Evaluation of a German Sentence Test I: Design of the Oldenburg Sentence Test." *Zeitschrift Fur Audiologie* 38:4–15.

Wagener, K., T. Brand, and B. Kollmeier. 1999b. "Development and Evaluation of a German Sentence Test Part II: Optimization of the Oldenburg Sentence Test." *Zeitschrift Fur Audiologie* 38:44–56.

Wagener, K., T. Brand, and B. Kollmeier. 1999c. "Development and Evaluation of a German Sentence Test Part III: Evaluation of the Oldenburg Sentence Test." *Zeitschrift Fur Audiologie* 38:86–95.

Wagener, K. C., and T. Brand. 2005. "Sentence Intelligibility in Noise for Listeners with Normal Hearing and Hearing Impairment: Influence of Measurement Procedure and Masking Parameters." *International Journal of Audiology* 44 (3):144–156. https://doi.org/10.1080/14992020500057517.

Wilkinson, M. D., M. Dumontier, I. J. J. Aalbersberg, G. Appleton, M. Axton, A. Baak, N. Blomberg, J.-W. Boiten, L. B. da Silva Santos, and P. E. Bourne. 2016. "The FAIR Guiding Principles for Scientific Data Management and Stewardship." *Scientific Data* 3 (1):160018. https://doi.org/10.1038/sdata.2016.18.

World Health Organization (WHO). 2001. International Classification of Functioning, Disability, and Health. Available from: https://www.who.int/classifications/international-classification-of-functioning-disability-and-health (Accessed Oct 07, 2024).

World Health Organization 2013. *How to use the ICF: A practical manual for using the International Classification of Functioning, Disability and Health (ICF). Exposure draft for comment*. Geneva: WHO, 13.

Zimmer, J., L. Hartog, D. Oetting, H. Pöntynen, and M. Dietz. 2024. “Loudness and Lateralization of Binaural Broadband Noise for Subjects with Asymmetric Hearing Loss.” *GMS Z Audiol (Audiol Acoust)* 6 Doc10https://doi.org/10.3205/zaud000045.

Zwicker, E. 1961. “Subdivision of the Audible Frequency Range into Critical Bands (Frequenzgruppen).” *The Journal of the Acoustical Society of America* 33 (2):248–248. https://doi.org/10.1121/1.1908630.