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Technical Note

Performance of research hearing aids: technical evaluation of the portable hearing laboratory

Leistungsfähigkeit von Forschungshörgeräten: technische Evaluation des Portable Hearing Laboratory

Abstract

To accelerate hearing aid research, several mobile research platforms have recently been designed and some made publicly available. Here, we evaluate the electro-acoustic performance of the Portable Hearing Laboratory (PHL), a portable research hearing aid based on a miniature computer and wired Behind-The-Ear Receiver-In-Canal hearing aid headsets. To evaluate its performance capabilities, standard electro-acoustic performance metrics were determined according to IEC 60118-0:2015 and compared to those of current commercial hearing aids. In all performance metrics, the PHL is on a similar level as commercial devices of comparable style. The maximum output level in a 2 cm³ coupler is up to 115 dB SPL, and insertion gain values around 50 dB can be achieved across a broad frequency range. Also, the equivalent input noise and total harmonic distortion are in the same range as in commercial devices. More advanced features were purposely not evaluated here, since these are intended to be adjusted freely in the variable software environment. In conclusion, the PHL is a suitable platform for setting up field-usable experimental hearing aids for research purposes.

Keywords: coupler measurements, master hearing aid, open source

Zusammenfassung

Um die Forschung an Hörsystemen zu vereinfachen, wurden in den letzten Jahren verschiedene mobile Forschungsplattformen entwickelt und teilweise der Öffentlichkeit zugänglich gemacht. In diesem Beitrag zeigen wir beispielhaft eine Evaluation der elektroakustischen Leistungsmerkmale des Portable Hearing Lab (PHL), einem tragbaren Forschungshörgerät, das aus einem Miniaturcomputer und damit verkabelten Hinter-dem-Ohr-Headsets mit Exhörern besteht. Um die Leistungsfähigkeit zu beurteilen, wurden Standardmesswerte nach IEC 60118-0:2015 bestimmt und mit denen von aktuell erhältlichen kommerziellen Hörgeräten verglichen. In allen Messwerten erreicht das PHL ein vergleichbares Niveau wie kommerzielle Geräte gleicher Bauart. Der maximale Ausgangspegel in einem 2 cm³-Kuppler liegt bei bis zu 115 dB SPL, und Einsetzverstärkungen bis zu 50 dB können über einen breiten Frequenzbereich erreicht werden. Auch der Pegel des äquivalenten Eigenrauschens und der harmonischen Verzerrungsprodukte liegen im Bereich kommerzieller Geräte. Weiterführende Merkmale wurden hier bewusst nicht untersucht, da die Softwareumgebung des PHL dem Nutzer große Freiheiten für Anpassungen bietet, und diese daher sehr von der Einstellung und Anwendung abhängen. Insgesamt ist das PHL eine geeignete Plattform zum Aufbau experimenteller Hörgeräte, die sich sowohl für den Einsatz im als auch außerhalb des Labors eignen.

Schlüsselwörter: Kupplermessungen, Master Hörgerät, Open Source

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Introduction

Hearing aids have greatly evolved over the last decades, largely due to improvements in the area of digital signal processing. For commercial hearing aids, the principles and algorithms used in their features and how they interact are company secrets and therefore largely unknown to the users or independent researchers. While working with "black box" devices is no major issue for the users or dispensers of hearing aids, it is a significant problem for researchers who want to draw meaningful conclusions from studies using these devices. Further, laboratory experiments with oversimplified setups often do not reflect the real-life effect of hearing aids [1]. Hearing aid research therefore needs devices that are usable in the field, fully controllable by any researcher, and provide the full processing chain of modern, non-linear and adaptive hearing aids.

To pursue this need, since 2015 the National Institute on Deafness and Other Communication Disorders (USA) has posed two requests for funding to develop portable signal processing tools that provide substantial computing power for real-time processing of the perceived acoustic environment. In response to this call, several groups have been developing platforms for hearing aid research that allow for free user programming and mobile use in the field [2], [3], [4], [5]. One example for such research platforms is the Portable Hearing Lab (PHL) [3]. The PHL consists of an extended portable miniature computer with audio interface, tailored Behind-The-Ear with Receiver-In-Canal (BTE-RIC) or In-The-Ear (ITE) hearing aid headsets, and a real-time operating system that includes the open Master Hearing Aid (openMHA), an open-source software framework for hearing aid signal processing [6], [7]. The PHL thus offers a relatively simple possibility to set up a full hearing aid processing chain and run it in real time in portable hardware with an electro-acoustic front-end very comparable to commercial hearing aids.

In this work, we assess standard technical performance metrics of the PHL with its BTE headset according to IEC 60118-0:2015 (largely equivalent to ANSI S3.22:2014 [8]), and compare it to current state-of-the-art hearing aids. With these tests we evaluate whether the basic electro-acoustic performance of the PHL is on a comparable level as that of commercial hearing aids. We purposely refrain from obtaining performance metrics that depend more severely on the signal processing chain, since with the PHL it is intended that the user can configure it very freely to their needs.

Methods

Three samples of the PHL were examined (first version, from Beta phase 2020/2021), each comprising one processor, a wired binaural BTE-RIC hearing aid headset, and a set of exchangeable M (medium power output, type Sonion RIC-E50D) and S (small power output, type Sonion RIC-4400) receivers. Measurements were only conducted for the right side of each unit. The latest firmware as of August 2021 (Mahalia 4.16-R2) that included a generic hearing aid configuration of the openMHA was used without modifications. All its algorithms were deactivated except for a five-band dynamic range compressor, into which an equal linear gain was programmed in each channel. Other than for commercial hearing aids, the Full-On-Gain (FOG) setting, i.e., the maximum gain allowed by the fitting software, is not specified for the PHL, but required for measurements according to standards. We defined the FOG by taking the nominal peak output values (included for calibration purposes) and subtracting 65 dB, with the intention that the device would be able to reproduce a speech-like input signal with a crest factor of 15 dB at 50 dB SPL without triggering peak limiting. This resulted in broadband gains of 51 dB with the M receiver, and 45 dB with the S receiver.

For reference, the typical (10% to 90% interquantile) range of measured values of commercial BTE-RIC hearing aids that have undergone type approval in our lab during the year 2020 are given. This includes most BTE-RIC hearing aids that entered the German hearing aid market in 2020 (125 with S receiver, and 130 with M receiver), making up a large coverage of the world market.

Standard electroacoustic performance metrics according to IEC 60118-0:2015 [9] were measured using our test stand in an anechoic chamber. The test stand comprised a 2 cm^3 coupler (Brüel & Kjær 4969, with 4192 microphone and 2669 preamplifier) to which the receiver unit of the PHL earpiece was coupled using airtight seal, and a pressure microphone (Brüel & Kjær 4192 with 2669 preamplifier) mounted 12±2 mm above the center point between the hearing aid microphones. Frequency-dependent measurements of the levels in free field and in the coupler with different settings of the PHL were performed using sine tones with variable frequency between 100 and 10,000 Hz. Sound was presented from a loudspeaker positioned in 1 m distance from the device under test, all controlled by a Rohde & Schwarz UPV Audio Analyzer. These responses were captured with the devices under test in FOG setting at 50 dB SPL input (FOG response curve) and 90 dB SPL input (OSPL90). From these measurements, a device-specific Reference Test Gain (RTG) was derived according to IEC 60118-0:2015 and programmed into the devices for measurement of the Equivalent Input Noise (EIN) and Total Harmonic Distortion (THD).

Results

The top panel of Figure 1 shows the OSPL90 for each unit of the PHL, as well as the range of appropriate commercial devices. With the M receiver, the PHL reaches an OSPL90 of up to 115 dB SPL peak, and high-frequency average (HFA, across 1,000, 1,600 and 2,500 Hz) of 111.5 dB SPL on average across devices. With the S receiver, these values are lower, with a peak of up to 112 dB SPL and an HFA value of 106.3 dB SPL.

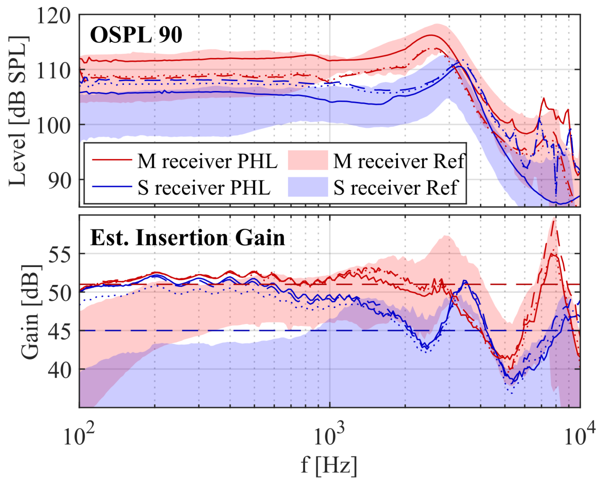

Figure 1: OSPL90 (top panel) and estimated insertion gain (bottom panel) for PHL (individual lines) and commercial reference devices (shaded areas denoting range between 10% and 90% percentile; each line style denotes one PHL unit, red lines indicate results with the M receiver, blue lines those with the S receiver. Horizontal dashed lines in the bottom panel denote the programmed gain values.

The OSPL90 for the PHL lies well within the range or at the top end of appropriate commercial devices with either receiver. Differences between devices reach up to 3 dB and most probably originate from the receivers, which we tested by further measurements where the drivers were exchanged between PHL devices. It can also be seen in Figure 2 that the differences between units are not consistent between receiver types.

Figure 2: PHL including the processor box and wired BTE-RIC headsets; a neckband is attached to the top of the processor box.

The bottom panel of Figure 1 shows the estimated insertion gain values for frontal incidence, which were computed by subtracting the appropriate CORFIG values [10] as given by Bentler & Pavlovic [11] from the coupler gains (level in coupler re. free field) with FOG setting. The Coupler Response for Flat Insertion Gain (CORFIG) includes corrections for difference in response in the 2 cm^3 coupler versus the real ear, as well as effects of microphone location present in the real ear but not the test setup. The PHL with the M receiver achieves insertion gain values around 50 dB, except for a 10 dB dip in the frequency range between 3 and 7 kHz. These values and frequency dependencies are similar to those of commercial devices. The PHL with the S receiver reaches insertion gain values up to 50 dB at frequencies below 1 kHz, and frequency-dependent values between 37 and 50 dB at higher frequencies. Depending on the frequency, these gains are at the upper end or, especially for frequencies lower than 1 kHz, higher than seen in commercial devices. The target maximum gain settings defined in the present study (shown as dashed lines in the lower panel of Figure 1) were largely met by the PHL within ±3 dB up to 3 kHz in case of the M receiver, but show consistent deviations of up to 5 dB with the S receiver. The estimated insertion gain values with the PHL do not differ more than 1 dB between devices up to 1 kHz, and 4 dB up to 8 kHz, which are smaller variations than for the OSPL90.

Table 1 shows a summary of performance values, namely the HFA of the OSPL90 and the coupler gain in FOG setting. Please note that the FOG coupler gains differ from the estimated insertion gain values, and are provided here for reference purposes. Furthermore, the EIN with the M receiver is close to the average of commercial reference devices, while with the S receiver, it is approx. 3 dB above the average but still within one standard deviation of commercial reference devices. It should be noted here that level expansion at low input levels was disabled in the PHL, but may have been active in the commercial devices. The THD is not routinely assessed with type approval of hearing aids in Germany and thus not available for the reference devices. However, the THD values of the PHL are well within the range acceptable for the appropriate receiver types and in the typical to low range of hearing aid datasheet values.

Table 1: Standard performance metrics with the PHL and reference devices, average and standard deviations given for the 3 PHL units or all commercial reference devices.

Quantity	PHL-M	Ref. M	PHL-S	Ref. S
OSPL90-HFA [dB SPL]	111.5±1.7	112.3±1.6	106.3±1.2	104.1±2.9
FOG-HFA [dB]	50.8±0.3	48.8±3.3	45.9±0.4	38.4±6.5
EIN [dB SPL]	17.6±0.2	17.0±2.7	19.8±0.3	16.9±3.0
THD@500 Hz [%]	0.6±0.2	n.a.	1.8±0.7	n.a.
THD@800 Hz [%]	0.8±0.3	n.a.	1.7±0.6	n.a.
THD@1600 Hz [%]	0.2±0.0	n.a.	0.9±0.2	n.a.
THD@3200 Hz [%]	0.1±0.0	n.a.	0.3±0.0	n.a.

Discussion and Conclusion

The insertion gain values provided by the PHL were similar to those of commercial devices and correspond well to the programmed gain values with the M receiver, whereas some deviations to the programmed gains were observed with the S receivers. Although the insertion gain values estimated here are only a coarse estimation for an average ear [10], [12], our results demonstrate that as in regular hearing aid fitting, the programmed gain values of the PHL are not necessarily equal to the actual gains achieved in the real ear. Both systematic as well as random deviations from the programmed gain values are to be expected in real ears. The results seen here are well in line with previous measurements on one PHL unit in our lab using a test box setup as well as in KEMAR, where similar or larger deviations to programmed gains were noted in one commercial reference device [13]. The PHL showed higher gains and output level, lower EIN, lower THDs and better match to programmed gain with the M receiver as compared to the S receiver. The differences in output performance between S and M receivers observed in the present study is consistent with the difference in sensitivity provided by the manufacturer. Therefore, if space in the ear canal allows, for most applications the PHL will probably reach better performance when the M receiver is used.

Finally, we conclude that the PHL provides a suitable basis for setting up a full research hearing aid whose basic electro-acoustic performance is equivalent to commercial devices.

Notes

Competing interests

The authors declare that they have no competing interests.

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