# Development and Feasibility of Using an Open-Source Portable Hearing Aid with EMA in the Real World

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## OBJECTIVE

- The purpose of this study was to investigate the feasibility of using a portable, open-source hearing aid paired with ecological momentary assessment and soundscape recording in the real world.
- Open-source hearing aids and ecological momentary assessment will enable the transparent and collaborative development and real-world testing of hearing aid processing algorithms.
- This study describes platform development, compliance, feasibility, participant experiences, and potential challenges and use cases.

## METHOD

Figure 1. Portable Hearing Aid Lab (PHL). Photo courtesy of BatAndCat Labs.

- This study was part of a larger study investigating acoustic features that contribute to complexity and speech perception in real-world environments. Participants (with and without hearing loss) were asked to collect data in 5–10 complex listening environments (environments with more than one sound) over a 7–10-day period.
- This study used the Portable Hearing Aid Lab (Fig.1 ), a BeagleBone computer with receiver-in-the-canal earpieces, running the Open Master Hearing Aid (openMHA) software [1].

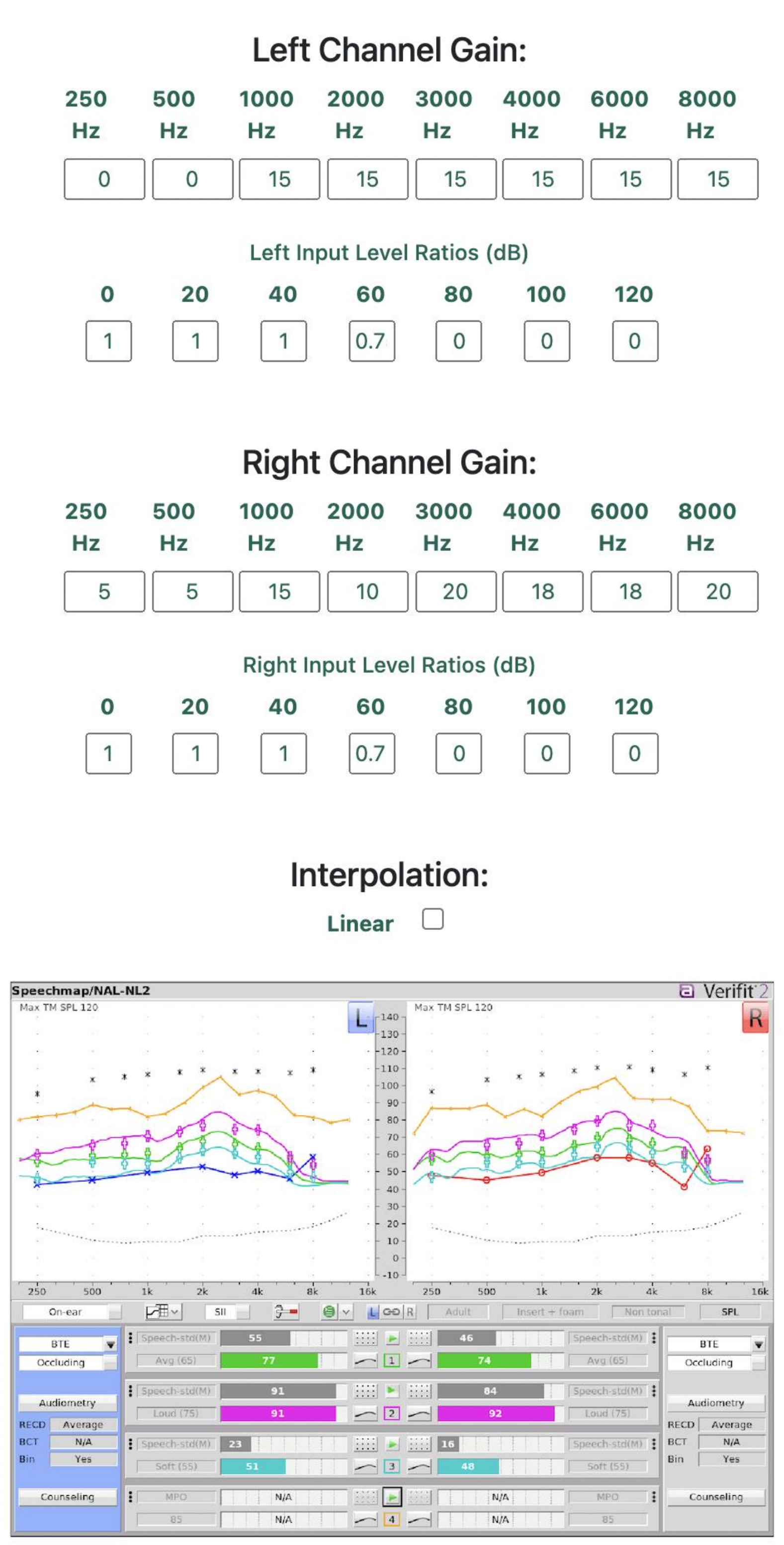


Figure 2. Programming interface to set gains for PHL (top) and example of real-ear aided responses relative to NAL-NL2 targets (bottom).

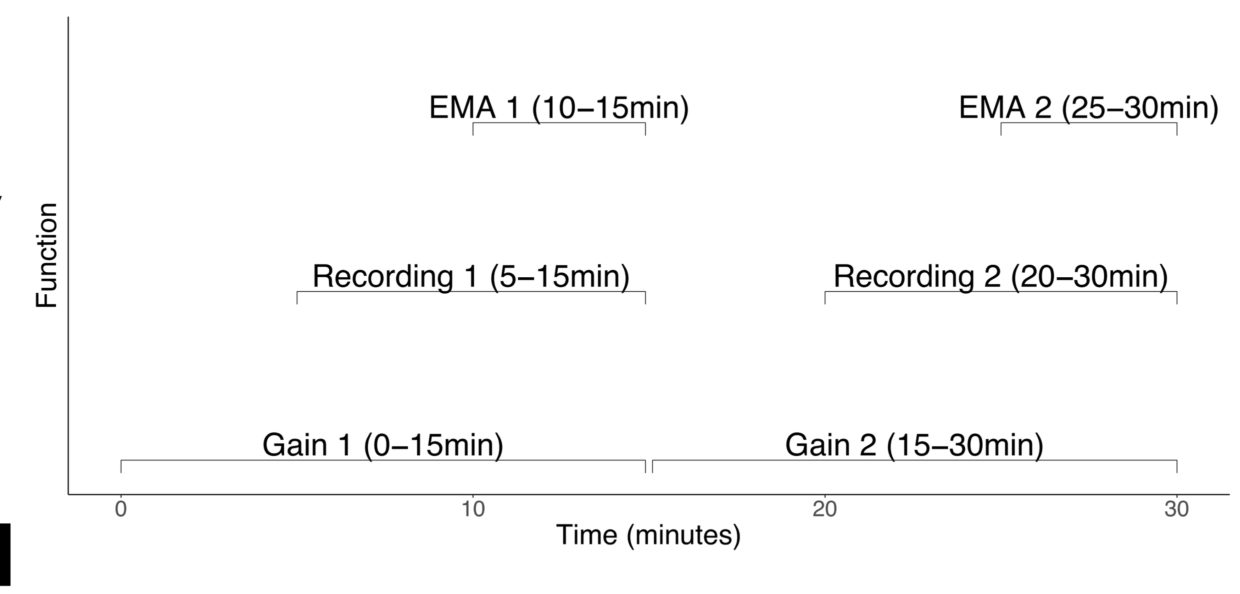


Figure 3. Sequences of data collection functions.

- Participants with hearing loss were fit to NAL-NL2 targets using a custom application to program gain and compression (Fig. 2). No other features were implemented. All participants with hearing loss used closed domes. Participants with normal hearing used open domes.
- For participants with hearing loss, the PHL was also programmed with an unaided gain program. This program had correction factors to make the hearing hearing aid acoustically transparent and simulate an unaided condition without removing the device. Participants with normal hearing only received 0 gain conditions.
- In each environment, participants wore the PHL and completed 2 ecological momentary assessments (EMA) on a smartphone (Samsung Galaxy 3) over the course of 30 minutes [2]. Between each EMA for participants with hearing loss, the smartphone triggered the PHL to switch gain settings from the aided to unaided condition, in random order. The PHL also recorded the environment from the ear-level mics (Fig. 3)
- The EMA was based on Weisser et al., 2019 [3]. Questions asked participants about the environment as well as their perception of the soundscape (Fig. 4).

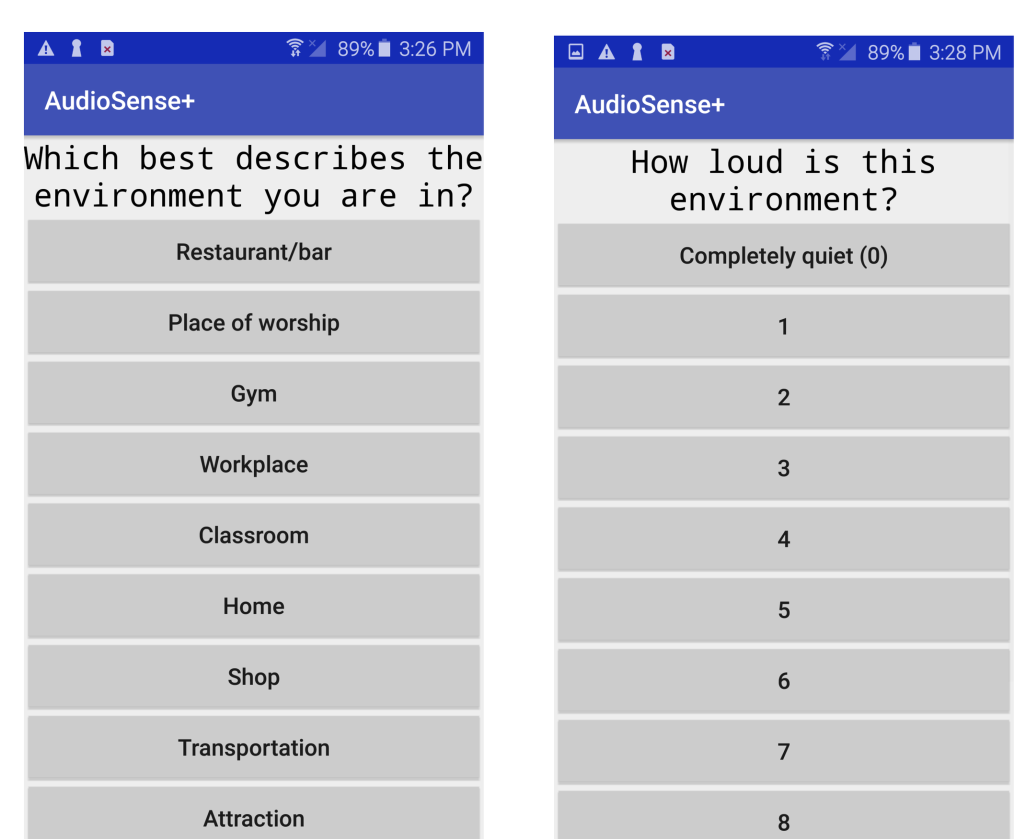


Figure 4. Example of the AudioSense+ EMA. Questions were either categorical (left) or Likert scale (left).

- Once participants were in the complex listening environment, the sequence of events was automated. Participants were required to turn on the phone and the PHL, put the PHL on, and press "Start" on the EMA app. This began the 30-minute data collection period. Gain switching, survey delivery, and recording happened automatically.
- When the participant had completed the 2nd EMA, the data collection period was over and they could take off the PHL, turn off the devices, and charge them.

## RESULTS

### COMPLIANCE

- 12 participants with hearing loss (mean age=57.5 years; range=18--75 years; sd=23.3 years) and 10 with normal hearing mean age=30.7 years; range=20--54 years; sd=11.5 years) completed the study.
- Data were collected from December 2021-April 2022.
- 266 EMA surveys were completed, but only 127 had associated recordings (48%).
- Only 1 participant (hearing loss group) declined to complete the study because the devices were too complicated.
- Participants with normal hearing completed EMAs in, on average, 7 complex listening environments and participants with hearing loss completed EMAs in, on average, 5 environments. Compliance did not differ significantly between groups.
- Compliance tended to improve over the course of the study as training was adapted (see discussion).

### ENVIRONMENTS

- Because participants were explicitly asked to collect data in complex listening environments, this may affect how well participants were able to operate the devices. Data were collected at home (46%), in restaurants and bars (14%), transportation (10%), shops (8%), work (6%), and other environments, suggesting participants could use the device successfully in different places (Fig. 5).

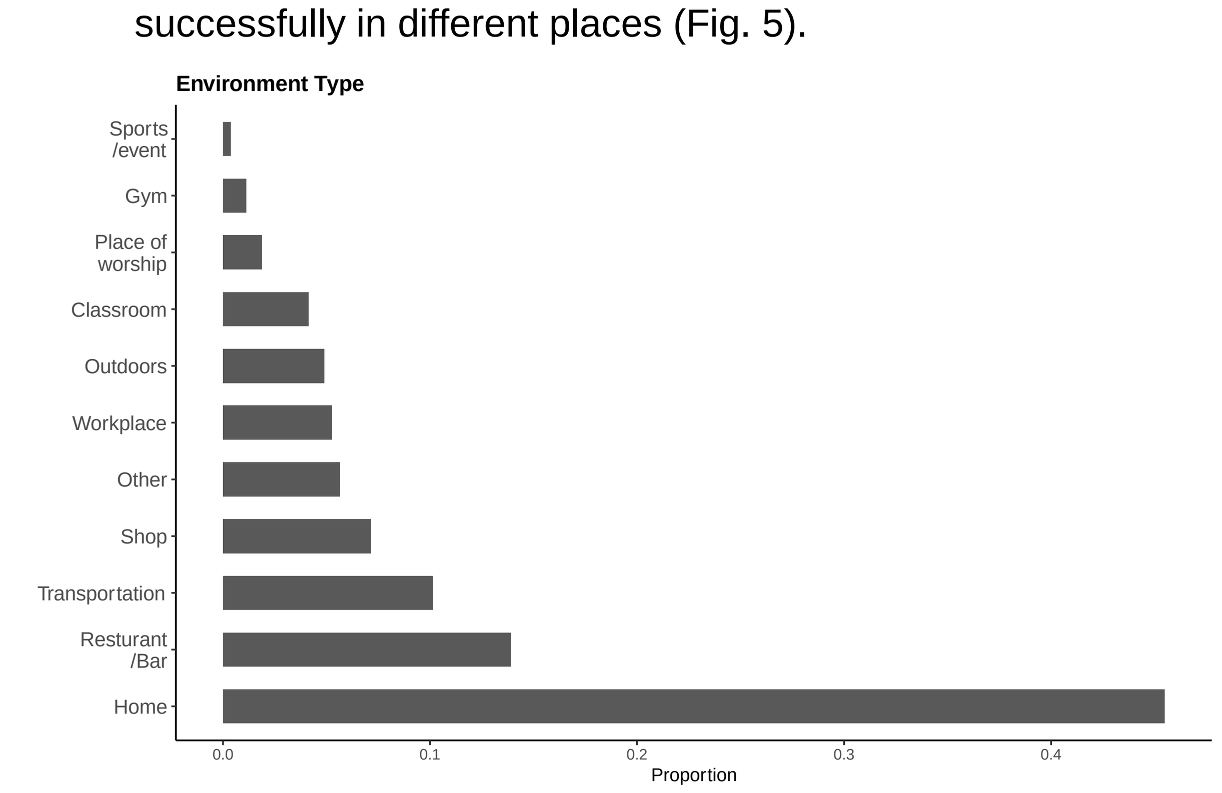


Figure 5. Environments where participants completed data collection.

### LISTENING ACTIVITIES

- Participants also wore the PHL for a variety of listening activities, including passive speech listening (26%), one-on-one conversation (22%), music listening (17%), and group conversation (9%). Results also indicate participants often had multiple listening activities at once.

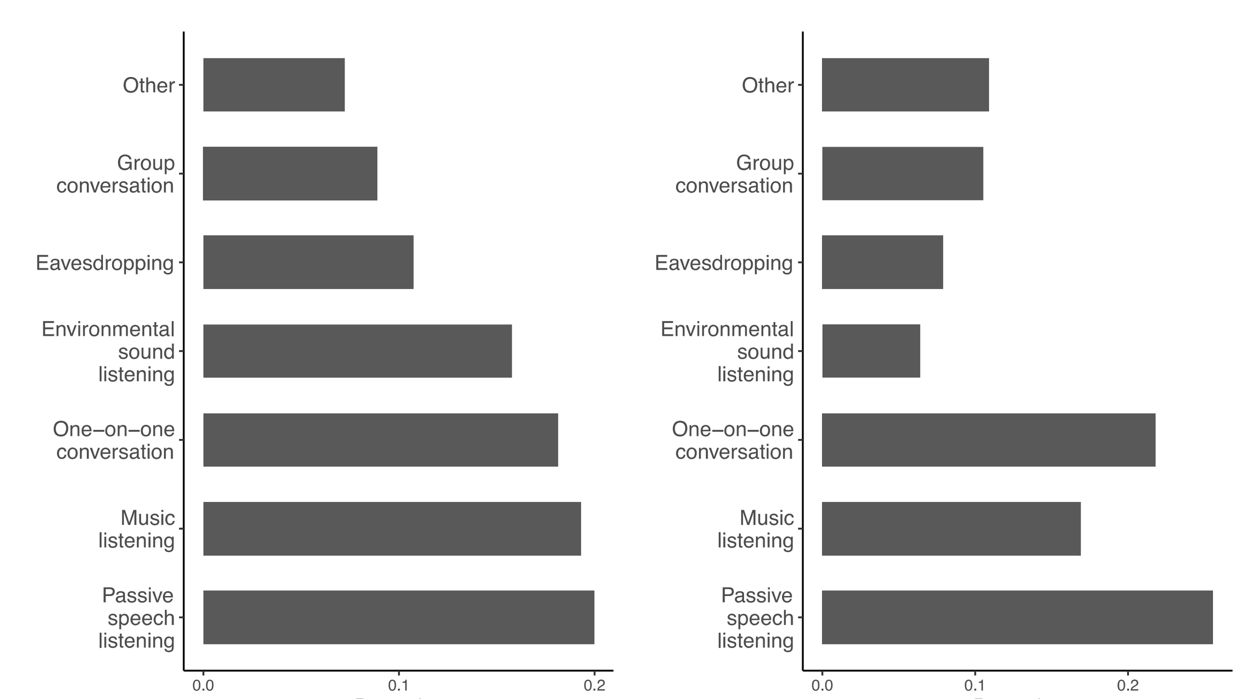


Figure 6. Proportions of all (left) and primary (right) listening activities of participants in each complex environment.

## DISCUSSION

- Using an open-source hearing aid platform paired with EMA and sound recording in the real world is feasible. Participants were able to use the device and collect EMA and sound recordings in a variety of real-world contexts.
- This method can be used to assess the benefit from different hearing aid processing algorithms in-situ with high context resolution. Accompanying ear-level sound recordings enable further contextualization of hearing aid benefit within specific soundscapes.

### MISSED RECORDINGS

- Only half of the EMAs had associated recordings. Interviews with participants indicated this was likely due to user error. Common problems users had:

1. Failure to fully turn on PHL. The PHL requires users to hold a button down for several seconds. As most hearing aids are not like this, it was confusing for some participants.
2. The PHL has 2 large large buttons, one of which is the power button. Some participants got the buttons confused.
3. Failure to charge PHL. Some participants reported difficulty remembering to charge both devices each night.
4. Failure to establish WiFi connection between PHL and smartphone before pressing Start. The WiFi connection between the 2 devices takes approximately 30 seconds to become established. Attempting to start the data collection before this can result in failure of recording and gain changing. A second version of the EMA app in this study sent a push notification if the participant opened the EMA app before the connection was established.

### OTHER PITFALLS

- The original version of the PHL used in this study had a battery life of approximately 4 hours. An updated version provides over 6 hours, making longer use feasible.
- Many participants reported difficulty with using 2 new devices (smartphone and PHL). Although every attempt was made to make the technology as automated and easy to use as possible, operating both devices was cumbersome for some participants.
- The PHL can produce significant heat. When worn around the neck, this was uncomfortable for many participants.
- This study did not implement any features, particularly feedback management. Thus, all participants used occluding domes. For participants used to open fits, this was a common complaint.
- Although most participants reported satisfaction with the sound quality of the PHL, the differences in the sound and form factor between the PHL and participants' hearing aids was a challenge for some participants. This might be improved by having participants wear the devices more frequently or for longer time periods to acclimatize.
- In general, as issues arose and were addressed in the training protocol for using the devices, compliance and satisfaction improved, indicating the need for adequate training and user guides for studies using these technologies.

### CONCLUSIONS

- Using the PHL in the real-world with EMA and sound recording is a potentially powerful tool for researchers to better understand factors that affect hearing aid outcomes in the real world and improve programming strategies, potentially through A/B comparisons within-environments.
- Adequate training and expectation management are essential. Future applications may consider building instructions into the EMA app for powering on the PHL, ensuring a secure connection, and other reminders on use of the device.

**References:** [1] Carl von Ossietzky University Oldenburg & HorTech gGmbH Oldenburg. Open community platform for hearing aid research, 2021. [2] Hasan et al., 2013. Audiosense: Enabling real-time evaluation of hearing aid technology in-situ. *Proceedings. IEEE International Symposium on Computer-Based Medical Systems*, *2013*, 167–172. [3] Weisser et al., 2019. Complex Acoustic Environments: Review, Framework, and Subjective Model. *Trends in Hearing*. 2331216519881346. **Funding:** The project was supported by grants from the National Institute on Disability, Independent Living, and Rehabilitation Research (NIDILRR 90REGE0013), the National Science Foundation (SCH 1838830) and the NIH/NIDCD (F32DC018980). **Contact:** Erik Jorgensen, University of Wisconsin-Madison, erik.jorgensen@wisc.edu. **Acknowledgements.** Many thanks to Chas Pavlovic, Hendrick Kayser, and everyone at BatAndCat Sound Labs and the University of Oldenburg. Their extraordinary help ranged from software design issues to even designing (at no cost) a special PHL edition for us with a substantially larger battery life. Thanks also to Justin Jensen for this help early on with the project. Thank you to all the participants for your efforts.