Data-driven hearing care with time-stamped data-logging

NIELS HENRIK PONTOPPIDAN[1,*], XI LI[1], LARS BRAMSLØW[1], BENJAMIN JOHANSEN[1,2], CLAUS NIELSEN[1], ATEFEH HAFEZ[1], AND MICHAEL KAI PETERSEN[1, 2]

[1] *Eriksholm Research Centre, Oticon A/S, Snekkersten, Denmark*

[2] *Department of Applied Mathematics and Computer Science, Technical University of Denmark, Kgs. Lyngby, Denmark*

Modern hearing aids holds significant personalization potentials while the processes associated with the administration do not fully accommodate the dialogue for finding the optimized and personalized settings. The hearing aids presented here use a connected smartphone to log a snapshot of 21 sound environment parameters every minute, e.g., sound pressure level in low, mid, and high frequencies and broadband, the estimate of the signal-to-noise ratio in the same 4 bands, the sound environment detector, etc. This data stream shows the sound environments that the user of the hearing aids experiences. The continuous stream of sound environment data is supplemented by the user's operation of the hearing aid, e.g., which program is chosen when, and how is the volume control adjusted as well. Whenever the user changes program or volume, the change is logged with the time stamp. Together, the continuous and event based data logging reveals in which situations the user prefers a given program and on the bigger time-scale, which program that should be the default program. The close integration of the hearing aid, the mobile phone, and cloud services turning the hearing aid into an Internet of Things device not only enable the learning and adaptation but also supplementing the dialogue between user and audiologist with objective data about the actual use of the hearing aids.

INTRODUCTION

How can a hearing-aid user describe what they did not hear? How can a hearing aid user describe situations where hearing is difficult to the extent where the audiologist becomes sufficiently certain about the validity of the description? This dialogue based trial and error procedure can be rather time consuming, and may prevent the fitting process from exploring sufficient number of alternatives, and thus may prevent the fitting of the hearing aids from reaching the degree of personalization which modern hearing aids support.

We present a prototype hearing aid that can provide information about sound environments and use. With this hearing aid, we ask, can data logging enhance the hearing aid fitting? Moreover, if so, how can analysis of logged data enhance hearing

*Corresponding author: npon@eriksholm.com

Proceedings of the International Symposium on Auditory and Audiological Research (Proc. ISAAR), Vol. 6: Adaptive Processes in Hearing, August 2017, Nyborg, Denmark. Edited by S. Santurette, T. Dau, J. C.-Dalsgaard, L. Tranebjærg, T. Andersen, and T. Poulsen. The Danavox Jubilee Foundation, 2017.
 ISBN: 978-87-990013-6-1.

aid fitting? The prototype hearing aid is developed for the H2020 project EVOTION (http://h2020evotion.eu) and transmits program changes, volume adjustments, and continuous sound environment data to a connected smartphone for buffering, local storage, and upload to cloud services utilizing the Internet of Things services of Oticon Opn (Oticon, 2016), the hearing aid which EVOTION hearing aid is based on.

The perspectives for use of such hearing aids in future hearing-care are very diverse; ranging from empowering the hearing-aid user, empowering the dialogue between hearing-aid user and audiologist, learning based adaptation of selected hearing-aid features, providing developers feedback on use of prospective hearing-aid features to clinical trials with new hearing-aid features. Additionally, the scenarios are not limited to hearing-aid features, but can also evaluate if auditory training increases the ability to hear in difficult situations or to cope with increasingly difficult situations. In fact, in the H2020 project EVOTION the hearing aids will contribute to research on public health policy modelling (Prasinos *et al.*, 2017).

METHOD

Internet services

Hearing aids connect to internet and internet services through an accompanying service installed on a smartphone and connected to the hearing aid using Bluetooth Low Energy (Oticon, 2016). This enables interaction with internet enables services, such as If This Then That (IFTTT, http://www.ifttt.com). Through IFTTT the individual user can define so-called recipes, where defined actions on the hearing aid can trigger another service and vice versa. Such recipe could connect the low-battery alert on the hearing aid to a text-messaging service, alerting a parent that the child's hearing aid is running low on battery. Another recipe connects an IFTTT enabled doorbell to the hearing aid, and alerts the wearer when someone presses the doorbell. The EVOTION hearing aids use the same communication methods between hearing aid and mobile as the IFTTT service.

The present data logging system use the NRF Connect app available on Google Play and App Store to intercept the data transmitted from the hearing aid to the smartphone. It also requires that the hearing aid user remembers to save the data stored in the NRF Connect app every night to a file. In this study with only a few hearing-aid users, the hearing-aid users must remember to save and upload the logging data every night. However, this is only true for the hearing-aid users taking place in this pilot study, the hearing-aid users in EVOTION will have a special app that acts as a remote control for the EVOTION hearing aids (like the Oticon On app does for Oticon Opn).

Sound environment data

Every minute an interrupt triggers the EVOTION hearing aid to transmit the current value of 21 sound environment parameters. The first 20 parameters are Sound Pressure Level, Noise Floor Level, Modulation Index, Modulation Envelope, and Signal to Noise Ratio measured in dB in four frequency ranges: 0-1.3 kHz, 1.3-4.1 kHz, 4.1-10 kHz, and 0-10 kHz. The last parameter is Sound Environment, which can take four values Quiet, Speech, Speech-in-Noise, and Noise. The 21 parameters are merely a small subset of the estimators running continuously in the hearing aid to characterize the sound environment and adapt the automatic systems to the current sound environment. When the connected mobile phone receives the message with the 21 sound environment parameters the values are stored and time-stamped.

Personalization

The personalization explored with the EVOTION hearing aids are the settings of OpenSound Navigator™ (Le Goff *et al.*, 2016). As shown in Fig. 1, the settings of OpenSound Navigator have different thresholds where OpenSound Navigator increases the amount of processing. The labels: High, Medium, and Low refer to how much help, e.g., how often the hearing aid attenuates a sound labelled as noise. In the Low setting, the signal to noise ratio required to trigger a certain amount of attenuation is higher than for the High setting.

The usual fitting practice is to assign each hearing-aid user to one of the settings: High, Medium, and Low, based on their preferences assessed in a questionnaire. The fitting of the EVOTION hearing aid gives the user access to four OpenSound Navigator settings as four programs. Allowing the hearing-aid user to shift between the four programs, provides the hearing-aid user access to a meta-parameter (Schum and Beck, 2006), which was previously only available to the audiologist.

As the hearing-aid user explores the different programs in different sound environments, the data logging will show which program the hearing aid user prefers, measured as the program used the most in such situation. Obviously, this requires the hearing-aid user to try out the different programs in different sound environments. When instructed to do so, hearing-aid users do vary the used programs (Johansen *et al.*, 2017), however, in that study the hearing aids did not transmit the sound environment data as is the case with the EVOTION hearing aids.

The personalization takes place the moment that the analysis of the logged data enables the selection of a single profile as the preferred profile. Either as an overall preference or as the preferred profile in a given situation characterized by the 21 sound environment parameters. The overall preference can be obtained by modifying the default program of the hearing aid, while the situation based preference require the mobile phone to use the remote control interface to select the preferred program.

With the EVOTION hearing-aids we collect preferences in a different way than the popular ecological momentary assessment (EMA) method (Wu *et al.*, 2015; Kissner *et al.*, 2015). The data-logging supports EMA and the two methods can be used in parallel, such that an EMA event is logged on the phone similar to the program shifts and volume adjustments. It is evident that some kind of hearing-aid user input must be logged, but whether asking the hearing-aid user to rate settings at certain intervals or if usage patterns are sufficient remains to be investigated.

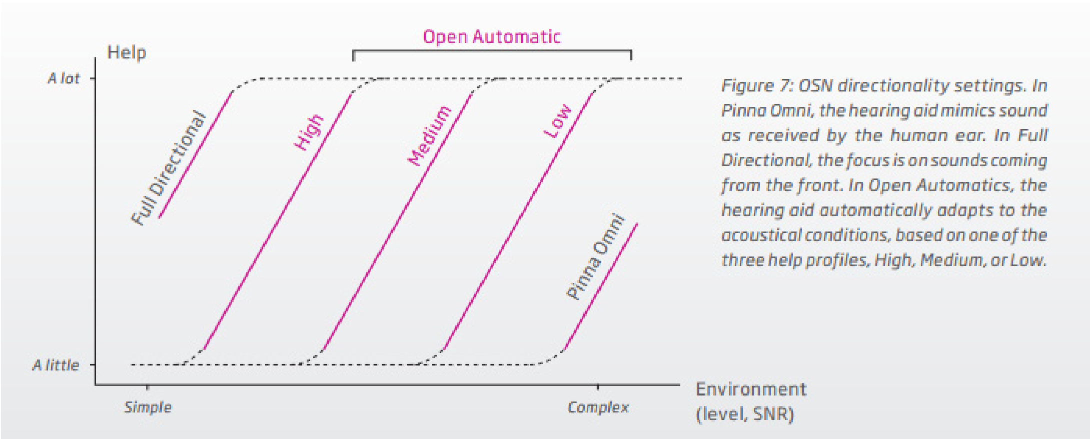

Fig. 1: OpenSound Navigator settings as function of environment.

RESULTS

Figures 2 and 3 show the first data logged by a hearing-aid user with the EVOTION hearing aids and acts to demonstrate the that hearing aids can log continuous sound environment data and event based program changes.

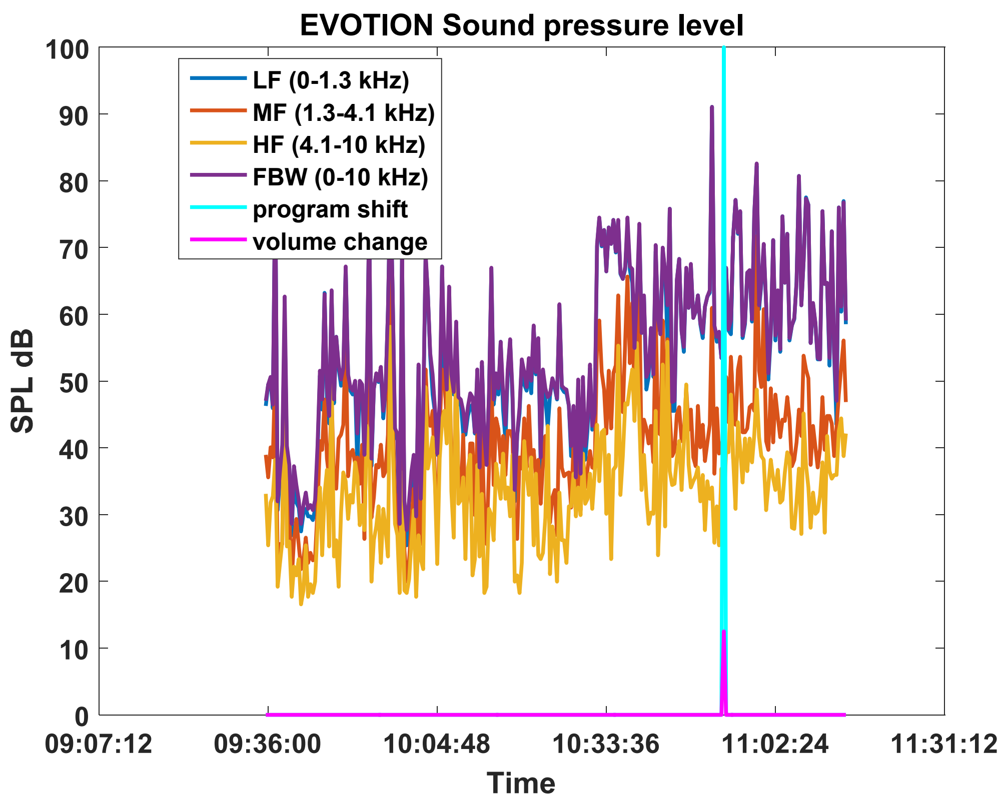

Fig. 2: Logged Sound Pressure Level data and program shift.

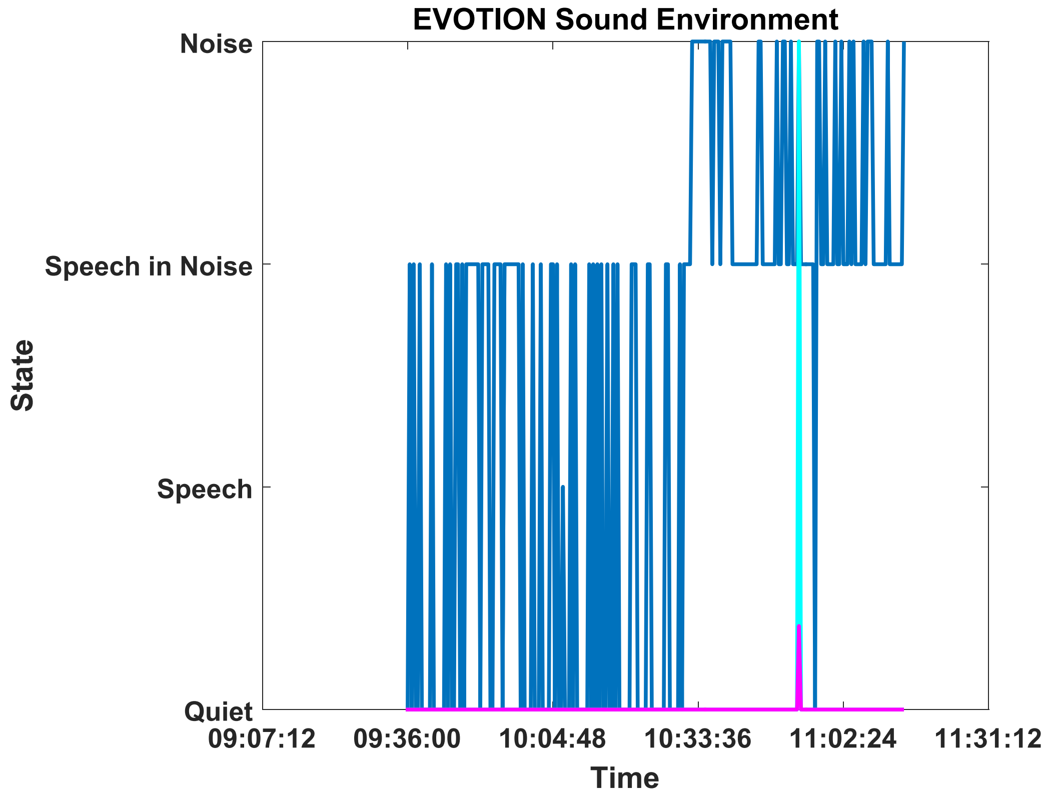

Fig. 3: Logged Sound Environment data.

Figure 2 shows a hearing-aid user who spends most of the morning in a relatively quiet environment, and Figure 3 shows that even if the levels are not loud, the sound environment shifts between quiet, and speech in noise. However, at 10:30 something seems to happen, as the sound levels go up, and also the sound environment detector suddenly shifts between speech in noise and noise.

The EVOTION hearing aids may also provide valuable data even if the user is not using all of the four programs. The logging of an event indicates that the hearing aid is in use, and thus an app or a cloud based data analysis tool can tell hearing-aid users for how long they use their hearing aid, if they are adhering to the agreed usage target, as well as providing a much more detailed overview of when the hearing aids were in use. In previous studies using objective measure of hearing aid use (Laplante-Lévesque *et al.*, 2014) was based on aggregated tables of hearing aid use, and did not give access to as detailed information about usage patterns as the current study allows.

CONCLUSIONS

We have presented the EVOTION hearing aid and showed the first sound environment data, logged by a hearing-aid user.

ACKNOWLEDGEMENTS

This work was partly funded by European Union's Horizon 2020 Research and Innovation Program under grant agreement 727521 EVOTION (h2020evotion.eu). Benjamin Johansen's PhD project is funded by Oticon Foundation and Copenhagen Centre for Health Technology (www.cachet.dk). The authors are grateful to the hearing-aid users using the EVOTION hearing aids even if the functionality of the NRF connect app far from matches the performance and stability of the mobile application developed for Oticon Opn.

REFERENCES

Johansen, B., Flet-Berliac, Y.P.R., Korzepa, M.J., Sandholm, P., Pontoppidan, N.H., Petersen, M.K., and Larsen, J.E. (**2017**). "Hearables in hearing care: Discovering usage patterns through IoT devices," in *International Conference on Universal Access in Human-Computer Interaction*, Springer, pp. 39-49.

Kissner, S., Holube, I., and Bitzer, J. (**2015**). "A smartphone-based, privacy-aware recording system for the assessment of everyday listening situations," Proc. ISAAR, **5**, 445-452.

Laplante-Lévesque, A., Nielsen, C., Jensen, L.D., and Naylor, G. (**2014**). "Patterns of hearing aid usage predict hearing aid use amount (data logged and self-reported) and overreport," J. Am. Acad. Audiol., **25**, 187-198.

Le Goff, N., Jensen, J., Pedersen, M.S., and Callaway, S.L. (**2016**). "An Introduction to OpenSound Navigator," retrieved from https://www.oticon.com/~/media/Oticon US/main/Download Center/White Papers/15555-9950 - OpnSound Navigator.pdf

Oticon (**2016**). "Opn hearing aid offers 'open sound' experience," The Hearing Journal, **69**, 44. doi: 10.1097/01.HJ.0000489201.24832.e3

Prasinos, M., Spanoudakis, G., and Koutsouris, D. (**2017**). "Towards a model-driven platform for evidence based public health policy making," 29th International Conference on Software Engineering and Knowledge Engineering, Pittsburgh, USA. doi: 10.18293/SEKE2017-035

Schum, D., and Beck, D. (**2006**). "Meta controls and advanced technology amplification," AudiologyOnline, March 27, retrieved from http://www.audiologyonline.com/articles/meta-controls-and-advanced-technology-989.

Wu, Y.-H., Stangl, E., Zhang, X., and Bentler, R.A. (**2015**). "Construct validity of the ecological momentary assessment in audiology research," J. Am. Acad. Audiol., **26**, 872-884.