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Relationships between hearing loss and hearing aid usage in real world

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ABSTRACT

Many hearing aids are fitted with multiple programs that the user can choose between in different situations. In the H2020 EVOTION project hundreds of hearing aid users were fitted according to their audiogram with Oticon VAC rationale with four adaptive programs that differed in the noise management profile. The programs differed on how much the noise was attenuated and the threshold at which the device started to remove noise. The hearing aids also transmitted continuous data about the sound environment and the operation of the hearing aid to a dedicated app on a smartphone. The participants had a wide range of hearing losses and was recruited from amongst new and experienced hearing aid users in six different clinics in UK, Greece, and Denmark.

The data from the hearing aid users was collected for up to a year to investigate relationships between clinical factors and usage patterns. The data enables a detailed investigation of the complexity of sound environments throughout the day, relation between complexity as function of time to the clinical factors including and beyond the audiogram.

Keywords: Real world hearing aids usage, clinical data, hearing aid logging data

1. INTRODUCTION

This paper covers the early exploration and modeling of a joint analysis of continuous hearing aid data, fitting data, and clinical data for a subset of the participants of the EVOTION project. The EVOTION project had the objective to develop tools and demonstrations of big data supporting public hearing health policies. Among key questions for public hearing health policies is the ability to predict the effect of hearing health care with respect to both the standard intervention and variations of the standard intervention. In this paper daily use of the hearing aids acts as the proxy for quantifying the effect of the standard intervention, and it is analyzed as function of both contextual data characterizing every hearing day life of the participants and clinical data describing the participants.

2. PARTICIPANTS

The participants in came from hearing clinics in United Kingdom, Greece, and Denmark that all followed the same clinical protocol(1). However, this paper only deals with the data from the Danish participants. This imposes some limitations on the data analysis, as the number of participants is only 26 out of the 400, and moreover, the participants at the Danish site also have, narrower range of audiograms, more experience in using hearing aids, more experience from participating in hearing research. Thus, the present results must be interpreted with these limitations in mind.

Upon enrolling in the study participants in the project was 2 initial visits for collecting the clinical data, fitting the hearing aids, and instructing the participants in the use of the hearing aids and the

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companion mobile phone app. Participants was fitted according to their individual audiogram following Oticon's proprietary fitting rational with the Oticon EVOTION hearing aid prototype specially developed for the EVOTION project. Real ear measures were performed to verify the fit. All participants were fitted with 4 programs that provided increasing levels of help from the spatial noise reduction system in the devices. The default program was the default setting of the fitting software, and 2 programs provided more help than the default program, and fourth program provided less help than the default. Upon completing the two initial visits, the participants used the hearing aids and companion mobile app for 9-12 months in their daily lives.

3. Data

One type of data available for this analysis comes from clinical records describing the participants and their hearing. This includes age, audiogram, previous use of hearing aids, Glasgow Hearing Aid Benefits Profile (GHABP)(2), Montreal Cognitive Assessment (MoCA)(3), Hospital Anxiety and Depression (HADS)(4), etc. The other type of the data comes from continuous logging data collected from the participants' hearing aids during use. This data contains characteristics of the encountered sound environments, e.g. sound pressure level, noise floor, signal to noise ratio as estimated inside the hearing aid, the data also provides a four class classification of the sound environment and selected program. Sample hearing aid data is available for download (5) and described in the companion data report(6). When the participant had their hearing aids connected to their smartphone running the companion app the detailed HA logging data was collected once every minute from both hearing aids. All clinical and hearing aid logging data was associated with a randomized identifier such that clinical data and hearing logging data can be jointly analyzed.

The present data set which is a subset of the full data consists of data from 26 participants providing 6 MIO logging points from the hearing aids. The counting the unique combinations of participants and dates shows that more than 3000 unique user-days was logged.

4. PREPROCESSING

When combining the responses from several questionnaires across a number of participants along with other descriptors like age, correlation among the variables must be accounted for before the data can be analyzed with linear mixed model methods. With the limited number of participants in the sample, GHABP and MoCA, is represented by the aggregated total score, and HADS represented by one total score for the anxiety and one for depression. The second step in the preprocessing aims to account for correlation between Age, GHABP, MoCA, and HADS and reduce the dimensionality with Principal Components Analysis (named USER_DATA_PCA).

The data from the hearing aids is first aggregated to compute the daily duration of use for everyone for each day with sufficient data along with daily averages of the contextual parameters.

Correlation is also an issue with the aggregated logging data from the hearing aids where the correlation can originate from the design of the estimators and from the inherent correlations between the estimators caused by the sound environments, and thus in the modeling this space is reduced (named dailyuse_PCA).

4.1 USER DATA

Five parameters: Age, GHABP, MoCA, HADS (Anxiety), and HADS (Depression) was individually scaled to remove mean and normalize the variation. The 5 eigenvalues out of the PCA followed a linear trend ranging from 6.8 to 2.7 thus the dimensionality was not reduced however, the subsequent modeling can happen without correlation between the variables. The clinical records also store information about participants hearing status, in the modeling here, we include the presence of tinnitus, previous experience with hearing aids, and the audiogram summarized by the WHO classification(7).

4.2 DAILY USE DATA

The hearing aids store 20 contextual parameters on the smartphone every minute. For estimating the duration of daily use, we assume that each datapoint accounts for one minute of usage whilst also accounting for overlaps between data from left and right hearing aids. Thus, the estimate of the daily usage is almost a count of datapoints stored for everyone each day. The contextual parameters are: Sound Pressure Level, Signal-to-noise ratio, Noise floor, Modulation envelope (supplement to Sound

Pressure Level), and Modulation Index (supplement to Signal-to-noise ratio) in the full frequency range 0-10 kHz, and three frequency ranges from 0-1.4 kHz, 1.4-4.1 kHz, and 4.1-10 kHz. Since this is just a preliminary analysis the number of components is fixed to 5 for the subsequent modeling, and inspection of the eigenvalues shows that this accounts for 97% of the variability in the input space

5. LINEAR MIXED MODELS

The linear mixed model analysis is performed with R in Rstudio using the LME4 package.

Model: scale(dailyuse) ~ factor(TINNITUS_BOTH) + factor(PREVIOUS_AID) + USER_DATA_PCA1 + USER_DATA_PCA2 + USER_DATA_PCA3 + USER_DATA_PCA4 + USER_DATA_PCA5 + dailyuse_PCA1 + dailyuse_PCA2 + dailyuse_PCA3 + dailyuse_PCA4 + dailyuse_PCA5 + (1 | pta4_who)

The results of the mixed linear modeling is summarized in Table 1 and Table 2 that indicate that previous experience with hearing aids, 3 out of 5 USER_DATA principal components, 2 of 5 dailyuse principal components, and the degree of hearing loss a have a significant impact on the daily use with significance lower than 0.01. The model also outputs the intercepts for the categories of the hearing loss according to WHO(7), estimated as 0.11 for Normal, -0.19 for Slight, 0.03 for Mild, and 0.04 for Moderate.

Table 1 - Fixed effects

	Estimate	Std. Error	df	t value	Pr(>|t|)
(Intercept)	-7.518e-01	1.424e-01	3.742e+01	-5.279	5.77e-06 ***
TINNITUS BOTH Ears (Yes)	-1.980e-02	5.468e-02	1.082e+03	-0.362	0.717376
PREVIOUS AID EITHER (Yes)	8.375e-01	1.258e-01	3.513e+03	6.657	3.22e-11 ***
USER_DATA_PCA1	-5.591e-02	8.732e-02	3.310e+03	-0.640	0.521994
USER_DATA_PCA2	-3.192e-01	1.057e-01	6.502e+02	-3.020	0.002627 **
USER_DATA_PCA3	1.956e-03	9.019e-02	3.527e+03	0.022	0.982701
USER_DATA_PCA4	-5.896e-01	9.860e-02	1.812e+03	-5.980	2.68e-09 ***
USER_DATA_PCA5	8.751e-01	1.019e-01	1.054e+03	8.590	< 2e-16 ***
dailyuse_PCA1	-1.634e+01	1.430e+00	3.488e+03	11.427	< 2e-16 ***
dailyuse_PCA2	1.269e+00	1.397e+00	3.522e+03	0.908	0.364063
dailyuse_PCA3	-1.466e+00	1.444e+00	3.529e+03	-1.015	0.310073
dailyuse_PCA4	-4.510e+00	1.903e+00	3.520e+03	-2.369	0.017873 *
dailyuse_PCA5	5.029e+00	1.411e+00	3.465e+03	3.564	0.000371 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Table 2 - Random effects

	Npar	logLik	AIC	LRT	Df	Pr(>Chisq)
<none>	15	-4883.4	9796.8			
(1 | pta4_who)	14	-4900.4	9828.8	33.97	1	5.598e-09 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Since the analysis is not done on the full data set, and since there might be some biases related to the participants in the current sample further interpretation of the data is not performed. However, the preliminary analysis suggests that the daily use is a function of the contextual parameters logged from the hearing aids, data from hearing aid fitting process (the WHO hearing loss type), previous experience with hearing aids, and age, and finally clinical data which describes the individual according to GHABP, MoCA, and HADS questionnaires.

6. FINAL REMARKS

As this analysis only covers a subset of our joint data and with the assumption that it is not covering the full data set, we have not drawn firm conclusions from the analysis. Instead, this paper serves as a tangible example of joint analysis of continuous hearing aid logging data and clinical data

The preliminary analysis indicates that the daily use of hearing aids can be predicted based on clinical user characteristics measured with standard questionnaires like GHABP, MoCA, and HADS combined with continuous contextual data logged from hearing aids, and fitting data. Further work will combine the data from more clinical sites to provide a full demonstration of the opportunities arising from combing continuous, fitting, and clinical data.

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