Obtaining Data on Hearing Experience Through Self-tracking

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Abstract
This position paper argues that self-tracking data can enrich a pre-fitting process of hearing aids. It is argued that hearing loss consist of three parts. Tonal sensitivity, signal to-noise-sensitivity, and cognitive capabilities which can be assessed by using smartphones. Combining this with contextual data and subjective data (perceived fatigue for example), could generated a hearing profile for the end user. This could be used for continuous fitting based on user feedback of the hearing instruments at a later point in time.

We suggest, that pre-fitting and a continuous process could create a paradigm shift empowering and transforming the user into an essential part of the solution, through increased awareness and inclusion. The end result could be a potentially better fitting, and a better hearing experience for the individual.

Author Keywords
Hearing Aids; Cognition; Working Memory Capacity; quantified self, non-clinical setup; Personal Informatics; wearables; smartphone

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous.

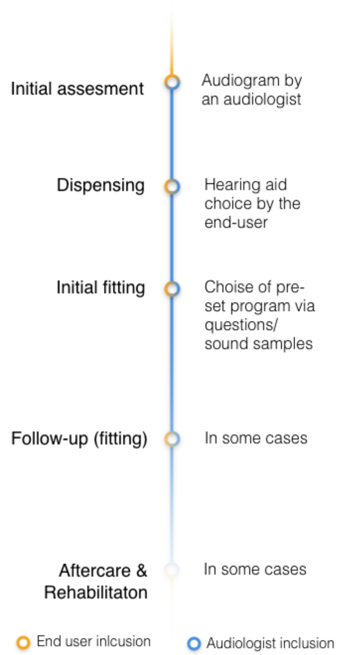

Figure 1: Fitting today is a linear process relying heavily on audiologists. The *blue* lines indicates that the audiologist are the primary decision maker in the current process, where the end user have little to say.

Introduction

Hearing impairment affects a growing part of society. Lack of speech intelligibility is a severe problem, decreasing the life quality for individuals. Negative effects associated with this are; withdrawal from social life, cognitive decline [9] and increased risk of dementia and dementia related diseases [6].

Hearing impairment also negatively impact society. Costs associated with hearing impairment include, but are not limited to, social care, health care, societal burdens and loss of income. In the UK alone it is estimated that hearing loss carries a price tag of £30 billion per annum [1].

It is predicted that an increasing size of the population will suffer from hearing loss. Both in the growing population of 70 year or older, as well as in the middle aged and younger segments of the population. Today it is already documented that both adolescents [11] and people in their 40's [3] are struggling with speech intelligibility in environments with noise.

The hearing care industry have created leaps of innovation since the introduction of the digital hearing aid in the mid 90'ies. The research and development have focused on hardware optimization and advanced algorithm design for hearing instruments, with less attention to the overall user experience.

This have resulted in neglect of the fitting process of these instruments. Fitting today still relies on audiograms and pure tone audiometry (PTA) tests invented in the first half of the 20th century. These assessments can only describe a part of the hearing loss. The fine tuning of the hearing instruments progresses over months. The process of dispensing and fitting a hearing instrument is illustrated in Figure 1. Time and resource constrains limits the full potential of personalizing hearing instruments, leaving the end user with a suboptimal fitting. Today it is estimated that the assessment, dispensing and fitting is done within 15 minutes. The consequence is that a portion of the devices end in drawers and is rarely used, if at all. A possible explanation could be that the devices are simply not sufficiently fitted to the needs of the users.

The main position presented in this paper is: How can quantified self data, obtained prior to dispensing hearing instruments, be used for a better hearing experience?

Data Collection to Assess Hearing Loss

Hearing loss is a complex problem consisting of at least 3 parts. These are: 1) Lower frequency sensitivity & hearing threshold, 2) Signal-to-Noise sensitivity and 3) cognitive capabilities. Each is described in the following paragraph.

Lower frequency sensitivity & hearing threshold
The PTA describes the hearing loss (in decibel) that occurs in various frequency bands. This is usually tested by playing a pure tone within the interval of 250 Hz up to 8000 Hz, for each ear, and mapping hearing sensitivity on both ears.

Signal-to-Noise sensitivity
The second factor to describe hearing loss is assessing the signal-to-noise ration (SNR) capabilities. This is a non-trivial task, describing how much noise the brain can process without loosing speech intelligibility [5]. The ability to filter out noise, or getting help with filtration, increases the speech intelligibility [8]. We all have individual thresholds for the SNR, and this determines how well we cope in challenging sound environments. An example of testing SNR is to overlay a single speech audio stream with a noise stream, such as white noise or

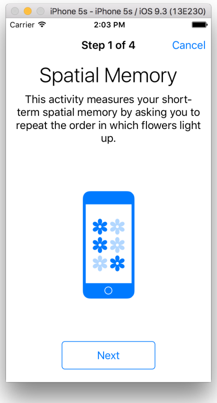

Figure 2: Continuous self-administered cognitive assessment would profile a persons cognitive capacity.

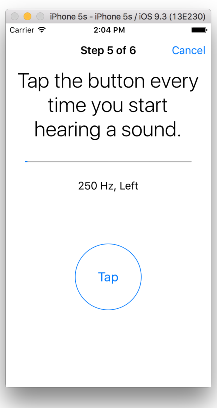

Figure 3: PTA performed on a smartphone could give users direct feedback on tone and amplitude loss.

competing speakers. This assesses the amount of noise reduction needed, to comprehend the single speech stream.

Cognitive Capabilities
The third factor for assessing speech intelligibility is cognitive capability. The working memory capacity is individually different, and describes the available resources for cognitive processing. Working memory capacity consist of a processing component and a storage component [7]. As an example, in quite surroundings, retrieving cues from speech requires less processing, leading to more resources for storage and retrieval. Where as in noise, more processing is required, leading to a reduction in storage capacity. The working memory capacity is correlating positively with age, and is positively correlating with hearing impairment [2]. The processing component is related to spatial speech intelligibility, e.g. separating sound sources spatially, and focusing on the information stream, affects the working memory [2]. This could be assessed by distorting a signal or changing the signal-to-noise ratio. A tool such a spatial memory test, where the objective is to remember a sequence of visual stimuli see Figure 2, can asses the storage component. The ability to store and retrieve information, affects the working memory [10].

Based on the hypothesis of hearing loss, we propose a smartphone solution. We propose a solution consisting of both a PTA, combined with a cognitive assessment. A PTA can be administered from a smartphone by the end user. A demo is currently in development using Apple's ResearhKit framework. The demo can be seen on Figure 3. The cognitive assessment would assess the working memory capacity, processing capacity and storage capacity.

An app would have a low barrier of entry, allowing more individuals to actively assess the degree and type of hearing loss. Several studies have shown that smartphones (both Android and iOS) are capable of conducting reliable hearing assessment of pure tones [4, 12].

Continuous Pre-Fitting and Self-Tracking

Assessing hearing loss is the first step in the proposed solution. In order for this solution to be effective, we propose continuous pre-fitting and self-tracking. A factor for success is active engagement and self-tracking from the user. The solution could empower the patient through more insights of the pre-fitting process, and through interaction with elements of hearing loss. This can give the end user more insights about their condition, encouraging active participation during the fitting process. The outcome would be a set of hearing profiles, based on the individuals personal preferences and capabilities.

Allowing the end user to administer self-assessment changes the fitting process, which allows the end user to actively participate, before entering an audiology clinic. The new process of fitting and dispensing can be seen on Figure 4.

Data collected over an extended period of time could give a more detailed image of the individuals state. A greater frequency of samples, for example, doing assessment 3-7 times, should be encouraged. It will make it easier to identify false-positives in the data sets. Positive side effects of active engagement through self tracking, could be more awareness of the hearing issues. Larger samples of repeated trials will provide an assessment that will be good enough to optimise the hearing instruments.

The self-assessment conducted before meeting an audiologist would consist of 3 layers of data. The layers

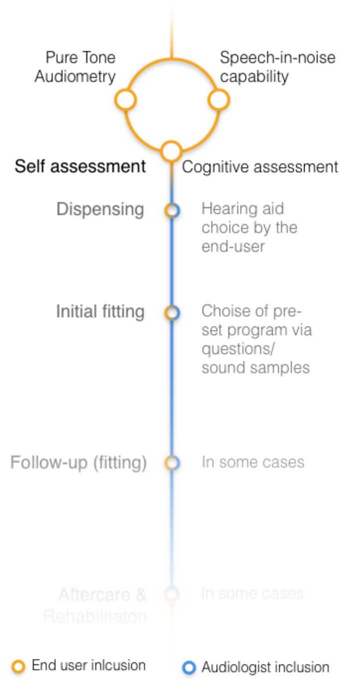

Figure 4: A Continuous pre-fitting would front-load the fitting process of hearing instruments, this first step is called "self-assessment". This would enable user generated data and an optimised fitting loop This is indicated by the larger *orange* circle. This indicate more inclusion of the end user.

are divided in pervasiveness/autonomy. The first layer would consist of various assessments and would be the layer the end user interacts most with. The second layer would be user feedback to various sound environments. This could also be combined with subjective feedback, such as perceived fatigue or mood. The 3rd layer is based on pervasive input such as localization and calendar entries from the user. Such information could enrich the data, with the typical whereabouts and environment of the end user. Inferred context could be a calendar entry like "Lunch with John, 13:00 at Cafe Belle". This could give insights into; a) the environment - cafes are usually noisy, and b) how many people are present. Such information could give an audiologist better insight into which sound environments a person is moving in, assisting in a personalized fitting profile of the hearing instruments. This in combination with the second layer would enrich the contextual data collected, creating a more detailed description of the users life. This model is visualized in Figure 5.

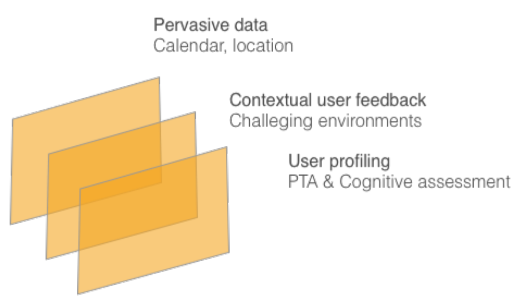

Figure 5: A more detailed model of data, consisting of 3 layers. The layers indicate the degree of pervasiveness and user interaction. Process such as self-assessments requires more user interaction, than pervasive calendar and location tracking.

Based on the data collected, the smartphone app generates a hearing profile for the individual. This profile would be similar to what exist on the market today, though not always used due to time and resource constrains in the clinics.

The proposed profile would contain information about cognitive capability. This could be an indicator of when the hearing instrument should help with; decreasing background noise, volume gain to speakers, sound focus of the hearing aid (narrow or wide). Combining this with the PTA, would give an indication of volume gain over frequencies. Enriching this with feedback from the user, and information related to context, would create a profile reflecting real use cases.

In the clinical setting, the pre-fitting would not just be a fitting tool optimizing hardware. It would be a communication tool, from where the audiologist and the end user could start dialogues. The audiologist would get an indication of the severity of the hearing loss. On top of this, contextualisation would provide an additional layer of depth. This layer could be the base for specified sound sample testing at the audiologist, which are relevant for the end user.

From Pre-Fitting to Trends

The process of pre-fitting, providing continuous stream of data, feedback and contextualization, could make the way for new insights and trends.

Including a large group of participants may show trends of hearing loss, not currently documented. Combining large data collection, data analysis, trends and insights, enables large scale studies. Studies that are comparable with clinical studies, which might provide insights not seen before [13].

Insights in the end-users current and present state, can be a supportive tool in continuous rehabilitation, which plays an essential role in hearing care. Rehabilitation is a process where the user trains to recognise cues in audio streams. For example, high frequency tone loss results in difficulties recognizing *f*, *s* and *th* in speech. A pre-fitting app could indicate this loss. Over time, it could assess whether the hearing instruments are supporting the rehabilitation process.

Correlations between pure tone loss, speech in noise recognition, cognitive capacity combined with demographics, location and other contextualised information, may provide not only new insights to hearing impairment but also transform hearing aids into augmented auditory Internet of things (IoT) interfaces. This information could be the basis of improving advanced hearing instruments, and hearing care in the future. These insights may also be able to indicate whether the user are in need of hearing aids or not, or if it is related to something else. It may even contribute to early dementia diagnostics and cognitive decline. Both symptoms that can be halted by timely training.

Discussion

We suggest that encouraging end users to actively assess their hearing loss brings benefits for them, and for the audiologist fitting the hearing instrument. Parameters such as cognitive assessment leads to the next generation of self-tracking, which may combine physical factors, psychological factors and context data - a combination of quantitative and qualitative data. The data generated from these assessments need careful implementation, as they have to move beyond numbers. The domain is shifting towards making sense of the brain, and to actively use this self-awareness in cognitive assessments. This also enables a personal hearing experience based on individual preferences and other factors such as fatigue. Furthermore several layers of data pervasiveness can enrich the assessment with correlating factors not previously investigated.

The prototype needs to be deployed to further investigate the impact of quantified self in hearing loss. Certain questions remains unanswered and needs to be verified. Questions related to the correlation of physical factors and cognitive factors have been indicated in related literature [2, 10]. However, this has only been tested in clinical setups, with patients already using hearing aids. A comparison study would also assess how well a non-clinical setup works, and if they can be supplemented with self-assessments.

Using quantified self as a framework can make hearing loss assessment more widely available than it is today. It can be an enabler in developing countries, and for a younger demographic population, already accustomed with smartphones.

Learning from this study could also give insights into how off the shelf products, and smartphones, can be utilised for cognitive assessment and capabilities. Key actors such as audiologist should be considered in the deployment of the prototype.

Conclusion

We have presented how we plan to proceed with using self-assessment and contextualization to enrich the fitting process of hearing aids. A proof of concept, currently in development, have been discussed.

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