User involvement in design and application of virtual reality gamification to facilitate the use of hearing aids

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Abstract— *The 3D Tune-In project aims to create an innovative toolkit based on 3D sound, visuals and gamification techniques to facilitate different target audiences in understanding and using the varied settings of their hearing aid to attain optimum performance in different social contexts. In the early stages of project development, hearing aid (HA) users participated in activities to identify user requirements regarding the difficulties and issues they face in everyday situations due to their hearing loss. The findings from questionnaire and interview studies and identification of current personas and scenarios of use indicate that the project can clearly and distinctly support the requirements of people with hearing loss as well as improve the general public's understanding of hearing loss. Five Future Scenarios of use have been derived to describe how the technologies and games to be developed by the 3D Tune-In project will address these requirements.*

Keywords—hearing aid users; gamification; scenarios of use

I. INTRODUCTION

Over 90 million people in Europe currently suffer from hearing loss, and, due to an ageing population, this number is likely to continue to increase [1]. Individuals may experience different types of hearing loss to different degrees of severity. A classification of hearing loss can be found at [2]. It is estimated that across the UK and Northern Europe, between 60 and 90% of people with hearing impairments could benefit from hearing aids (HAs), yet only 1 in 4 of these people actually own one [3]. While HA technologies have dramatically advanced in the last 25 years, user perception and use of these devices have changed very little. Modern HAs are now smaller and incorporate numerous functions beyond the simple amplification and equalization operations performed by the analogue devices [4]. The 3D Tune-In project will create an innovative toolkit and a series of Apps based on 3D sound, visuals and gamification techniques tailored to different target audiences (e.g. older users and children) intended to aid them in understanding and using the varied settings of their HA to attain optimum performance in different social contexts. The 3DTI Toolkit will comprise a 3D audio engine, allowing the spatialisation of sound sources for both headphones (binaural) and loudspeaker-based (ambisonic) systems. It will also include a general-purpose hearing aid simulation, which can be customised for specific hearing aid models, and a hearing loss simulator. This offers several functionalities which have not been implemented before in a similar tool, such as: Individualisation of the Head Related Transfer Function (HRTF), for a customised 3D sound rendering over headphones; Simulation of sound sources distance; 3D audio environmental acoustic simulation (reverberation). The 3DTI Toolkit will be integrated with other development tools (also for gaming) through a series of wrappers including; Unity, Pure Data, Max MSP and C++. The project consortium comprises technical experts in audiology, acoustics, gaming technologies and virtual reality as well as HA manufacture companies and hearing associations from across three European countries: UK, Italy and Spain [5].

We present the work led by the Human Factors Research Group at the University of Nottingham in the early stages of the project in which end-user representatives were involved in stakeholder activities to identify user needs and requirements that will be used as the basis for technical development of the 3D Tune-In Toolkit. The goal of the 3D Tune-In project is to help people with hearing difficulties to correctly use the available (yet often neglected) functionalities of their own HA in everyday situations to improve their hearing, and for people without hearing loss to understand the challenges faced by those with HA(s). The project fulfils this goal by enabling people with hearing difficulties to experience digital games which can be played in conjunction with either their own HAs or a virtual HA which can be calibrated to improve their hearing.

This paper describes the methods applied and outcomes of stakeholder studies to identify user requirements for the technologies and games to be developed by 3D Tune-In.

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II. Identification of User Requirements

The main goal of the requirements analysis task was to capture the experiences of people with hearing loss and their HA use. An understanding of the activities and challenges of this stakeholder groups can highlight gaps or needs which the 3D Tune-In technologies and applications can support. This section presents details on the participants, methods and results of the first study with children and adults with (and without) hearing loss.

A. Participants

Participants were recruited to take part in paired interviews to understand the challenges and problems people who are hard of hearing experience during their daily activities and in their communication with others. Each paired interview involved a person who wears a HA and one of their family members or friends with whom they communicate with regularly. The reasoning behind the paired interviews was that communication does not occur in isolation – we wanted to understand the challenges that both the hearing impaired and people who interact with them experience in different everyday situations.

We interviewed up to 6 pairs of people from five different age groups from the UK, Spain and Italy in five age categories: 7-14 year olds (1 pair interviewed in the UK, 1 pair interviewed in Italy); 15-18 year olds (1 pair interviewed in Italy) ; 19-40 year olds (1 pair interviewed in the UK, 2 pairs interviewed in Spain, 1 pair interviewed in Italy); 41-60 year olds (4 pairs interviewed in the UK, 2 pairs interviewed in Spain); 61 year olds and over (3 pairs interviewed in the UK, 2 pairs interviewed in Spain)

In total, eighteen people with hearing difficulties took part in the study. The majority of participants (11 out of 18) had moderate hearing loss. There were many different causes of hearing loss, including perforated eardrums, severe ear infections, age-related, nerve damage and surgery. The mean number of years that participants (some exclusions owing to clarity of data) had been living with a hearing impairment was 17.5 years and the mean length of time that participants had been using HA(s) was 13 years. Most participants (15 out of 8) had used their current HA(s) for between 1 and 10 years. The most common type of HA used was BTE (14 out of 18), but some also used CIC (2 out of 18) and Retro RITE (1 out of 18).

B. Method

Questionnaires and interviews were used to collect data about the types of hearing difficulties people experience in their daily lives whilst wearing their HAs. Ethics approval for the study was granted by the Faculty of Engineering at The University of Nottingham and at The University of Malaga. Regarding the part of the study carried out in Italy, in line with usual practices, no formal process was required and ethics approval was gained internally through the 3D Tune-In Ethics Coordinator. The questionnaires and the interview protocol were originally developed in English and were translated into Spanish and Italian.

Participants with hearing impairments were asked to complete a questionnaire prior to attending the interview. The questionnaire was mainly custom-designed to address the research interests of the project, however a few questions were also used verbatim from the Characteristics of Amplification Tool (COAT) [6], although the scales were changed. A few questions were also adapted from the Satisfaction with Amplification in Daily Life (SADL) questionnaire [7]. The questionnaire took approximately 20-30 minutes to complete.

Full details of the study, participant information and questionnaire design can be found in the project deliverable report [8]. The findings from these methods are summarised below.

C. Questionnaires and paired interviews with people with hearing difficulties

Eighteen people with hearing difficulties took part in a study to elicit the difficulties and issues they face in everyday situations due to their hearing loss, and information about how well their HAs perform in these situations. The findings are described according to the main research themes of interest.

1) Frequency of hearing aid use and in which situations and why

Most of the participants use their HA(s) in quiet contexts such as their home in order to be able to hear quiet sounds and follow conversations, as well as in noisy contexts (such as cafes/ restaurants, busy roads and in the car) in order to be able to hear people speaking over varying levels of background noise.

2) Hearing and communication problems encountered in different social contexts when wearing hearing aids

The main problems faced by the HA users were background noise and a need to be able to see or be in close proximity to the person speaking to them. These problems were slightly alleviated by using their HAs however most were still unsatisfied with the quality and amplification of sound that they could achieve in these contexts. Further, listening to music was also difficult for some, resulting in a loss of enjoyment of music. For some, the HAs were the cause of this difficulty, for others the HAs alleviated difficulties somewhat.

3) Barriers to performing activities and socially engaging with others

HA users felt that the main barrier to their ability to participate in activities and social contexts was their reduced capacity to follow a conversation in the presence of background noise, resulting in either poor quality conversation with lots of repetition, or the HA user missing a lot of information. For the most part, HAs went some way to removing this barrier, but did not solve the problem completely. Others felt self-conscious about wearing a HA and chose to experience noisy contexts without them, which appeared to create some stress in already challenging situations.

4) How other people affect their experience of social situations – how they can improve/make things worse

Most of the HA users thought that their friends and family members did their best to speak clearly, loudly and position themselves face-to-face with them. However many reported

that they did not want to make a big deal out of their hearing loss so they did not encourage any major changes to other people's behaviour. Most people seemed to adapt to the hearing loss without realising that they were doing so.

5) Technological and non-technological strategies used to face challenges of social interaction and everyday tasks and situations

HA users reported a number of strategies that they use to facilitate their hearing: these strategies are predominantly non-technological owing to either the expense of technologies, the inconsistency of them (e.g. the loop), or their unfamiliarity with them. Many relied heavily on non-verbal communication cues such as body language and lip-reading.

6) Awareness and use of available hearing aid functionalities and barriers to using available functionalities

Although some were aware of, and frequently used, different HA functionalities, for the most part HA users were either unaware of, or unwilling to use the different functionalities of their HA. This seemed to be caused by a lack of knowledge and a lack of confidence in their ability to change settings without interfering with the audiologist's set up. Those who did know of, and use, the different settings reported that they made no difference to the sound quality they could achieve. Some HA users contradicted themselves when talking about how satisfied they were with their HAs – sometimes saying their hearing was very good with them and at other times saying that they were frustrated with their HA but did not appear to think that anything could be done to improve matters.

7) Experiences with audiologists

Most HA users reported having had good experiences with their audiologist and seemed to trust their recommendations and settings unquestionably. In cases where experiences were not so good, participants were still very trusting and respecting of the audiologist's setting of their HA, but complained about other aspects of their care, for instance in troubleshooting problems.

8) Adequacy and usefulness of training

Most HA users received at least some training in using their HAs which was adequate for their day-to-day use, however there seems to be some tendency for audiologists to only tell clients about the settings that they think their clients will need.

D. Outcomes from the questionnaire study

The findings show that users wear their HAs in a variety of contexts including those with considerable background noise and quieter contexts. By far, background noise (i.e. understanding speech in noisy environments) is the biggest issue that HA users face, and they use many non-verbal strategies in order to overcome this issue. Family and friends (without hearing impairments) tend to adapt to the HA users' needs by using strategies such as positioning, raising their voice and mediating conversations. Overall, it seems that HAs go some way towards improving hearing, however users were not satisfied with their performance in all situations, either because the HAs were not powerful enough, or because they did not know enough about how to use the different features in order to optimise the performance of their HAs.

III. PERSONAS AND CURRENT 'AS IS' SCENARIOS

A set of six personas and eleven scenarios (two for each age group of HA users and one for the audiologist) were presented to describe the 'as is' or current experiences of the two stakeholder groups. The personas are descriptions of (fictional) typical users (adults and children of different ages with hearing difficulties as well as their communication partners who do not have hearing difficulties, and an audiologist) which are based on real stakeholder characteristics. The scenarios are descriptions of a typical user's typical daily activities and challenges in different environmental and social contexts, their HA use, and so on. The scenario representing an audiologist details typical activities (e.g. selection and adjustment of HAs) during appointments with clients. The common findings and themes from the interviews and the questionnaires are represented in these scenarios.

Full description of the personas and current scenarios can be found in the project deliverable report [7].

The findings from the questionnaire and interview studies and the current scenarios reveal that 3D Tune-In can clearly and distinctly support the requirements of people with hearing loss as well as improve the general public's understanding of hearing loss. 3D Tune-In can address motivational issues, lack of awareness and lack of self-confidence of people with hearing difficulties with regards to the full potential use of their HA's available functionalities in different acoustic environments.

IV. FUTURE SCENARIOS

From these activities, five future scenarios were generated which provide an initial description of how the 3D Tune-In applications/games could potentially help different stakeholders to fulfil their respective goals and needs, in terms of learning how, and when, to use different HA functionalities, or how digital games could be used to support HA calibration as part of, or following on from, sessions with an audiologist. It is envisaged that the games can be played with users' own HAs or with virtual HAs. As an illustration, Future Scenario 1 is presented in detail here.

Future Scenario 1: 'Calibration/assessment for children' describes a main game with a series of mini-games which aim to teach children with hearing loss how to calibrate their HA in specific contexts. This game could be played at home, with or without the guidance of an audiologist. If played as part of a scheduled training programme, a child's progress through the different levels of the game and their changing audio profile over time can be relayed to the audiologist.

A. Example persona and scenario of use

Aaron is 10 years old and likes playing computer games, especially adventure games, strategy and puzzle games. Aaron is not sure if he is aware of all of his HA settings, he only knows of and uses two settings: volume and mute. During a recent visit to his audiologist, he was introduced to a game called "Dartanan". He was told a series of mini-games would show him ways in which his HA could help him in different

situations. The audiologist gave Aaron a flyer about the 3D Tune-In project which included details of a weblink to access the game. The audiologist informed Aaron's mum that with her permission he would be able to track Aaron's progress through the different mini-games and can create a training schedule for him when he comes back for his next appointment. The audiologist told Aaron's mum that he may need her help to set up the game initially.

Dartanan uses a simple gamification technique: unlock a new mini-game after progressing through each level. The main game has three levels and is fun, fast and colourful and is used to engage the players. There is the potential for an infinite number of mini-games that train players on how to calibrate the different settings of their HA and use this learning to progress through the different levels.

This division is designed to develop a leisure game that also contains serious games: children can play the main game with their friends and parents; and the mini-games can be adapted to different target devices for training and learning purposes.

Aaron accesses the weblink to the game Dartanan from the 3D Tune-In website by using his Safari web browser on his iPad. The first screen informs Aaron that he can use either a desktop computer (PC Windows or MacOsX) or a mobile device (iOS or Android) to interact with the game. He's happy about this as it means he can play the game even when he's not at home. If he uses his Mac, he can use a keyboard and/or joypad and/or mouse to be able to move, jump and run in the main game. The mini-games can also be played through the use of a keyboard, joypad, and/or mouse combined with head tracking and some haptic devices (like NOD ring).

When playing on a mobile device, Aaron can use his touchscreen to move, jump and run in the main game. In the mini-games, he can play using sensor input (accelerometer) by moving the mobile device, and use his iPad's camera for head tracking as well as some haptic devices.

People who do not have hearing problems can play the game using headphones to hear the 3D sounds/music and find the right path to get to the next level. Aaron has two options as he has hearing difficulties. First, he can either use his own HAs as headphones via a Bluetooth connection to his iPad or he can choose to use a virtual HA. If he chooses to use his own HA, only the hearing loss compensation features of the HA (stage 1 processing) will remain functional; thus the HA will compensate for how much less a person hears for each frequency band by using an equalization filter and where required, a dynamic range compression/expansion. The HA is able to do this after a specific hearing loss curve is inputted into the device. Any additional functions of Aaron's HA (stage 2 processing) will be disabled – these may include algorithms for noise reduction, directional, speech enhancements etc., as these functions will be rendered directly inside the video game via a generalised virtual hearing simulator. Aaron's second option is that he can remove his HAs and use headphones instead, and the virtual HA in the game will perform both stage 1 and stage 2 processing. In order to do this Aaron or his mum could input his hearing loss curve directly into the game or Aaron could download another app which will allow him to perform a quick hearing self-assessment. The virtual HA will then be automatically calibrated accordingly. Both of these options allow the virtual HA to correctly perform the stage 1 processing to suit each player's hearing profile/abilities.

The opening page of the game told Aaron that Dartanan is based on three worlds with different goals, environments and enemies. Aaron would be the character Dartanan and he would have to defeat his enemies.

It would require a different strategy to defeat each enemy boss and complete the world. Dartanan will be able to collect different objects to transform him and give him special abilities. There will also be a process of collecting coins to be able to advance through the game and give him extra lives.

A number of mini-games will be based around this main game. The mini-games are used for the calibration of the virtual HAs. Aaron can select whether or not he wants to move into this mode at the beginning of the game. Aaron decides to remove his own HAs and use the virtual HAs. He clicks on the appropriate option and uses the Wizard to perform a hearing assessment and calibrate the virtual HA.

Every level of the game exploits the potential of the virtual HA and requires Aaron to select the correct setting/calibration to find the right way through the labyrinth. Aaron is a child and gets bored very quickly and therefore the virtual HA calibration performed during the game makes it a more pleasant and interactive experience rather than having long adjustment sessions with an audiologist.

In some areas of the game Aaron will have to 'fight in the dark', hitting enemies only with the sounds generated from the enemies themselves. The different sound frequencies, different volumes and so on used in the game will generate an audio profile for Aaron (indicating what Aaron is capable of hearing with or without calibrating the HA). The game is designed to be fast and intuitive. It may be possible that sometimes Aaron may hit an enemy by sheer luck or miss hitting an enemy due to being distracted. Repeating the mini-games a few times can help to generate a more accurate audio profile.

As Aaron progresses through the game, he unlocks the different mini-games. Each of the games then becomes re-playable. Aaron reads through the game tutorial for each mini-game which explains the game's goal and how to play it. An example of one of the mini-games is "Escape from a 3D labyrinth". The object of the game is to escape the labyrinth whilst not being able to see the path. Dartanan will be offered incorrect paths and tiles that are traps. As a result, there is the possibility that Dartanan may fall and die. To find the right path, Dartanan must follow the sounds and/or music in the environment. In order to do well in the game, Aaron must learn to change his HA settings in order to hear and respond to the sounds in the environment.

In addition to background noise, there will be enemies that will emit noise to distract Dartanan. This simulates noisy contexts such as restaurants, parks, schools, underground stations, bus and tram, etc. Some enemies such as the bad ghost will try to push Dartanan. These enemies generate a fast-moving sound similar to a car. In this situation, Dartanan recognises the sounds of enemies to avoid and must continue to follow the right sound (this is important to learn about multi- or

mono- directionality HA settings). Aaron learns to listen and learns when and how to use noise reduction, volume, mono/multi directionality, improve the sound of speech and other HA settings.

To increase the complexity, there are visible and invisible objects in the game. These produce occlusion of the sound that is produced. These simulate real-life obstacles such as windows, fences, walls, partitions, etc.

B. *Sound / Music Position*

Aaron moves in the space accordingly. Music and sounds indicate the right direction but the distance between the sounds and Aaron changes. This forces him to change some HA settings in order to follow the music/sounds (for example, a distant sound may be covered by background noise, and music can be occluded by an object).

Aaron has enjoyed playing the mini-games every day for the last two weeks. Aaron has learned about the capabilities of his HAs and how to use them in different real-life situations; as a result his hearing is much better when there is background noise.

C. *Technical details*

This game will be developed with the Unity3D engine in classic 2D style. To interact with the binaural sound, mini-games will be developed in a 3D environment. To create longevity for the game play, further mini-games can be developed using an "owner script" from templates within the game structure.

V. Other Future Scenarios

Four other scenarios are summarized here and described in detail in the project deliverable report [7].

Future Scenario 2: 'Listening to music' describes a game designed to be used at home, providing an exploratory landscape using binaural sounds to represent a multi-venue music festival. The aim of the game is to teach players that correctly using the different modes of their HA could improve their hearing in everyday life.

Future Scenario 3: 'Calibration for the elderly - Hearing Aid Tuner' describes a game which can be played at home, aiming to enable people with hearing loss to understand the basic parameters that influence the quality of sound in different contextual situations (e.g. a restaurant with lots of people talking, or a noisy street). In addition, the game can be used under the guidance of an audiologist in order to support discussions with clients and help to facilitate sessions on adjusting HAs.

Future Scenario 4 'Hearing loss education – Fallen Angel' aims to educate people without hearing impairments about hearing loss, raising awareness and empathy for people who do experience difficulties. The game simulates hearing loss and requires players to complete tasks based on their ability to hear sounds and instructions in different acoustic environments.

Future Scenario 5 'Calibration/demonstration of hearing devices using smart phones' describes an application that is specifically designed to link with HAs developed by GN-Resound. The application will allow GN-Resound to demonstrate, through a series of video games, specific functionalities of their HAs, and to support end-users in understanding the impact of these functionalities in their everyday life. It will also allow the end-user to help the audiologist to optimise the calibration of certain functions of the HA using a gaming approach.

VI. Conclusion

It is important to note that these future scenarios are primarily examples of what could be developed in each of the applications and that these will evolve during the specification and development work of the 3D Tune-In toolkit and applications. In particular, further thought is required with regards to both the mechanism by which a user's HA will be connected to a game and how the game is subsequently adapted according to his/her hearing curve, as well as the process by which a virtual HA will be calibrated.

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References

[1] T.N. Roth, D. Hanebuth, R. Probst, Prevalence of age-related hearing loss in Europe: a review. European Archives of Oto-Rhino-Laryngology. 2011 Aug 1;268(8):1101-7.

[2] ASHA (American-Speech-Language-Hearing-Association). Type, Degree, and Configuration of Hearing Loss, 2015, Audology Information Series, 10802. http://www.asha.org/uploadedFiles/AIS-Hearing-Loss-Types-Degree-Configuration.pdf (accessed 27th July 2016)

[3] B. Shield, Evaluation of the social and economic costs of hearing impairment, 2006, Report for Hear-it AISBL http://www.hear-it.org/Hearing-loss-in-Europe (accessed 27th June 2016)

[4] J. Kerckhoff, J. Listenberger, M. Valente, Advances in hearing aid technology. Contemporary Issues in Communication Science and Disorders. 2008;35.

[5] http://www.3d-tune-in.eu/ (accessed 27th June 2016)

[6] R.M. Cox and G.C. Alexander, Measuring satisfaction with amplification in daily life: The SADL scale. Ear Hear, 1999, 20(4), 306-320.

[7] S.A. Sandridge and C.W. Newman, Improving the efficiency and accountability of the hearing aid selection process: use of the COAT. Audiology Online, March 6th 2006. Available at http://www.audiologyonline.com/articles/improving-efficiency-and-accountability-hearing-995

[8] H. Patel, M. Hallewell, M. D'Cruz, M. Zaninoni, S. Tamascelli, Y. Levtov, L. Simeone, T.M. Linares, B. Vallina, J. Shell and L. Picinali. 3D Tune-In deliverable report D1.1 'Requirements analysis and current and future scenarios of digital games for hearing aids' 30/11/2015. Available from http://www.3d-tune-in.eu/Deliverables (accessed 27th June 2016)