Collaborative design of a gamified application for auditory-cognitive training.

Abstract

**Background:** Multiple gaming applications under the dementia umbrella for skills such as navigation exist, but there has yet to be an application designed specifically to investigate the role hearing loss may have in the process of cognitive decline. There is a demonstrable gap in utilising games to further the knowledge of the potential relationship between hearing loss and dementia. The aim of this study was to identify the needs, facilitators and barriers in designing a novel auditory-cognitive training gaming application.

**Methods:** A participatory design approach was used to engage key stakeholders across audiology and cognitive disorders specialisms. Two rounds, including paired semi-structured interviews and focus groups were completed and thematically analysed.

**Results:** 18 stakeholders participated in total and 6 themes were identified to inform the next stage of the application's development.

**Conclusions:** The findings can now be implemented into the development of the application. The application will be evaluated against outcome measures of speech listening in noise, cognitive and attentional tasks, quality of life and usability.

**Keywords:** auditory training; cognitive decline; gamification; participatory design; presbyacusis.

Introduction

**Background Research**

Globally approximately 50 million people live with a diagnosed dementia, with this figure expected to increase to 82 million people in the next 10 years [1]. There is currently no treatment available to either cure or prevent dementia, which has led the World Health Organisation (WHO) to classify dementia as a public health priority. The call to action is to reduce the risk of developing dementia through early diagnosis of cognitive decline, intervention and eventually prevention.

A commission by Livingston and colleagues [2] concluded that 35% of dementia diagnoses were potentially preventable, by identifying 9 modifiable risk factors with the capability to prevent dementia. Of those 9 risk factors, mid-life hearing loss was found to be the highest potentially modifiable factor at 9%. In comparison, other modifiable factors in later life included smoking (5%), depression (4%) and social isolation (2%). This evidence concurs with previous research suggesting that age-
related hearing loss (presbyacusis), increases the risk of developing dementia in later life by up to 5 times [3]. Despite these findings, the causality in this relationship is still unknown. As is whether any form of rehabilitation, either through hearing aids, auditory training, or assistive listening devices, could delay or prevent the onset of dementia symptoms [2].

The most robust methodology to further investigate this relationship would be an adequately powered, longitudinal, randomised controlled trial. A complex study such as this would need to ensure any treatments, such as hearing aids, were adhered to throughout the study. The adoption and use of hearing aids is known to be relatively low. In the age bracket of 55-74 year old’s, 80% of those people who require hearing aids do not own them [4]. This would be a key issue to address in the design of such a trial. Other methodologies should therefore be explored and, as hearing loss in mid-life could be a preventable factor, the focus, as outlined by the WHO, should be early detection and intervention. Cohort studies have suggested presbyacusis tends to precede dementia onset by 5-10 years [5]. Interestingly on average people tend to wait 10 years before they seek help for their hearing [6]. Diagnosing hearing loss is a simple, quick, diagnostic test and an easily measurable critical factor in potentially preventing cognitive impairment.

This work therefore highlights an under-researched group of people who may be in the early stages of presbyacusis and present with a mild to moderate hearing loss, do not seek treatment, but have an increased risk of developing dementia. There is potential to investigate these ‘pre-clinical symptoms’ of dementia in this group by targeting areas of the brain that contribute to auditory and cognitive function, with the possibility of delaying the onset of said symptoms. This area of research has the potential to impact upon one of the largest healthcare issues of the next century.

**Gamification in Dementia Research**

One potentially more achievable alternative to a formal randomised controlled trial is to engage people in preventing dementia symptoms through gamification. Gamification has been shown to be an effective research tool that can demonstrate and maintain health behaviour change [7]. The use of a gamified application would be highly accessible within the home environment and provide less of a barrier than seeking General Practitioner (GP) treatment for initial changes in cognition.

A literature review of games aiding early diagnosis of dementia and particularly Alzheimer’s Disease (AD) [8] concluded that games could be utilised to overcome important barriers in the AD diagnosis process. Delays in self-referral, physician factors, age and available services for assessing cognitive disorders were all identified as potential obstacles. A gaming application could be more motivational compared to a written memory assessment, maintaining a low cost/high reward if evidence demonstrated that the application could delay or prevent the onset of dementia symptoms.
Anguera et al. [9] tested the hypothesis that playing the 3D multi-tasking driving video game *NeuroRacer*, could improve cognition previously diminished through healthy aging. Older adults (n=46) demonstrated less multi-tasking costs when compared to controls over a 4-week playing period, with effects sustained at 6-month follow up. Of particular importance was the finding of a ‘Transfer of Benefit’. The authors claim that by playing the driving video game, participants demonstrated improvements in both working memory and sustained attention - two abilities that were not specifically targeted by the video game. This transfer of benefit outside of the on-task performance was a novel finding. The authors suggest possible reasoning for this being a) the use of a video game outside of a typical lab environment and b) the custom nature of the video game. As far as we are aware there has been no attempt to address hearing loss and impaired speech perception using such an approach.

Another example is *Kitchen and Cooking* [10]. Designed and evaluated as a game to assess the executive function of planning. Different cooking recipes could be played by participants with mild cognitive impairment (MCI) and AD. The MCI group (n=9) significantly improved over the 4-week period in Stroop Test performance, when compared to the AD group (n=12). It is unclear from the results if this improvement would be sustained over a longer period of time, as this pilot study collected data for only 4 weeks across a small sample. However, the results do lend support to the notion that interventions aimed at training cognitive abilities may be more effective for use in a pre-dementia stage [11].

It is unclear whether the MCI groups’ improvements compared to the AD group would have been any different to a healthy control group. There was a large variability in playing time within the small sample size. This not only emphasises the importance of designing a game that is capable to engage and maintain interest, but also to be able to measure engagement and evaluate how different levels of engagement impact on levels of effect. As suggested by Anguera et al. [9] the success of *NeuroRacer*, was attributed to the custom design of the game. Whereas *Kitchen and Cooking* was the premise for the design because food was rated as the most interesting area for older people in nursing homes. Thus, it would be prudent to employ a participatory design to involve key stakeholders in customising the design of future games and evaluate the results of said game with both validated quantitative measures and qualitative interviews.

One study that did utilise qualitative methodology investigated older adults’ perceptions of playing the Xbox Kinect game *Dr. Kawashima’s Brain Training*, as a way to maintain their cognition through intellectual exercise [12]. As previously suggested to ensure a game is successfully adopted by the intended user group, the design should be appropriate to engage said specific population to benefit. Talaei-Khoei & Daniel [12] attribute this to a ‘Perceived Transfer Effect.’

This occurs when adults who see a cognitive game as empowering, rather than supportive, so equates to a higher potential to yield long-term benefits. Rather it is
not only the content of the game, but how participants view said content in respect to their own selves. A key finding was that the mini-games in *Dr. Kawashima’s Brain Training* were perceived to be useful in maintaining cognition and transference to real-world daily tasks, such as reading. Participants (n=21) felt by sustaining function, through the mini-games, they would be able to live independently for longer providing long-term transfer of benefit.

Other key findings distinguish perceptions of supportive and empowering technologies. For instance, the use of hearing aids is categorised as supportive. Hearing instruments can only aid a person in a functional ability that has already begun to decline. This could lead hearing aids to be perceived as less useful, particularly in the long-term. Whereas, an empowering virtual game focusing on active auditory training could be perceived to have transferable long-term effects on cognitive ability. The authors also concluded that more qualitative research is required in the field, specifically on why end users would think a training game would be useful and adopted.

The literature shows that gamification can provide a platform to offer customised, home-based training for different areas of health behaviour change, including cognitive performance. Previous studies have demonstrated that certain games have the potential to transfer benefits of virtual play into self-confidence in maintaining cognitive effort for daily activities. More specifically, utilising training games that are deemed as useful and engaging to users in a pre-dementia stage may be more effective than after a dementia diagnosis. Given the findings from Livingston et al., [2] there is a demonstrable gap in utilising games to investigate age-related hearing loss and cognitive decline. There has yet to be an application that has been iteratively designed using qualitative input from key stakeholders to investigate the role of hearing loss and speech perception in cognitive impairment. The use of participatory design with a specific stakeholder engagement would have the ability to investigate this area further.

**Aims and Objectives**

The overall aim was to therefore investigate whether an empowering gaming application could be designed to engage users in a mid-life population at risk of presbyacusis and mild or subjective cognitive impairment to improve speech perception and cognitive performance. This aim will be achieved with the following objectives:

- To adopt a participatory design approach with relevant stakeholders to produce an auditory-cognitive training application that has been iteratively designed.
- To understand facilitators and barriers to producing an auditory-cognitive training application.
- To identify the specific design requirements for an auditory-cognitive training application.
Methods

Participants
18 relevant stakeholders (service users, clinicians, researchers) were recruited across audiology and cognitive disorder clinics at Imperial College Healthcare; across research groups at Imperial College London and their corresponding research networks. Participants were chosen using an opportunity sampling method as it was a convenient way of accessing clinical, service user and researcher expertise. Participants were included in this study if they were considered to be a stakeholder and had capacity to provide informed written consent. Professionals were considered key stakeholders by the research team if they had experience with patients and families at risk of either presbyacusis and/or mild or subjective cognitive impairment. Service users were considered key stakeholders by the research team if they or family members reported mild hearing loss or mild or subjective cognitive impairment.

As the application will be designed for those who may report mild or subjective cognitive impairment, it would not have been appropriate to recruit service users with a moderate to severe cognitive impairment. Therefore, potential participants who already had a medical diagnosis of dementia were not considered. Decisions for stakeholder inclusion were taken by the research team to ensure the participants were representative of the desired end user of the final application. Table 1 describes the type of stakeholders recruited and when they participated in detail. This study was approved by the West Midlands – South Birmingham Research Ethics Committee. All interviews and focus groups were carried out at Imperial College Healthcare Trust, audio-recorded using a Zoom Q8 and transcribed verbatim.

Data Collection

Cycle 1: Identifying the current climate
The aim of the first cycle of data collection was to first gather knowledge about the potential facilitators and barriers in designing a novel auditory-cognitive training application. To maximise accessibility of the data, the first round of data collection consisted of two paired semi-structured interviews for service users and a focus group of 5 professional stakeholders, which were 45 minutes and 60 minutes respectively. This division of the stakeholder groups was beneficial for various reasons. The use of the focus group allowed discussion of professional opinion and fostered further collective thinking. Whereas interviewing service users in pairs allowed the interviewer to explore personal experiences and views in depth by comparing and contrasting. The topic guides used for both the interviews and focus groups are available in the supplementary files. The exploratory nature of cycle 1 allowed the data collected to be analysed and used in conjunction with the literature base to design the first version of the application. Further evaluation of this first version was then explored in cycle 2.
**Cycle 2: Exploring specific requirements and needs for collaborative design**

The purpose of including a second cycle was to demonstrate the initial version of the application and to stimulate participants into further thinking about the specific needs and requirements of the application. In order to achieve the objectives of cycle 2 and answer a more specific research question about the application design, an edited topic guide was used for both the professional and non-professional focus groups, which were approximately 60 minutes in duration. Topic guides can be found in the supplementary files.

2 service users, 1 spouse and 2 professional participants who wished to continue into cycle 2 participated alongside 9 new participants who did not have any prior involvement or knowledge of the application. A basic prototype of the application was demonstrated using an iPad with a coffee shop scenario, in which the player was asked to listen to an order placed in the coffee shop, choose the correct customer order that was heard, then choose the correct items from a list of 8 images/words to make up that specific order. The audio was originally played at a low Signal-to-Noise Ratio (SNR), which the player could improve by 2 dB at a time by replaying the order before moving on to choosing what had been heard from a 4-option list. Screenshots from the prototype demonstrated in cycle 2 can be seen in Figures 1-3. At time of writing, the application is still in development and is not freely available.

| Table 1. Description of participating stakeholders across both cycles. |
|-----------------|--------------------|--------------------|--------------------|--------------------|----------------|
| **Type of Stakeholder** | **Cycle 1 (n=9)** | **Cycle 2 (n=14)** | **Total (n=23)** |
| **Interview (n=4)** | **Focus Group 1 (n=5)** | **Focus Group 1 (n=5)** | **Focus Group 2 (n=5)** | **Focus Group 3 (n=4)** | **Total (n=23)** |
| Service User | 3 | 5 | 3 | 11 |
| Audiology | 2 | 5 | 2 | 9 |
| Cognitive Disorder | 1b | 1b | 2 |
| Spouse | 1c | 1c | 2 |
| Volunteer | 1d | 1 | |
| Clinician | 4 | 3 | 7 |
| Audiologist | 3 | 3 | 6 |
| Older Adult Psychiatrist | 1 | 1 |
| Researcher | 1 | 1 | 2 |
| Dementia Research Nurse | 1 | 1 |
| PhD Researcher | 1 | 1 |

* A total of 23 participants took part across the two cycles. Five stakeholders participated in both cycles.

b This participant is primarily a service user of the cognitive disorders' clinic, but has also used audiology services.
This participant was recruited as a spouse of a service user, but has also used audiology services for themselves.

This participant is a volunteer in audiology, but also has a hearing loss.

A summary of the data collection, including start and stop dates, duration of each cycle and stakeholder participation can be found in Figure 4.

**Data Processing**

Audio recordings from the interviews and focus groups were transferred immediately to an encrypted PC and deleted from the audio recorder. The recordings were transcribed by the lead author in cycle 1 and by medical students, who had received prior training, in cycle 2. The transcriptions were subsequently coded by the lead author in cycle 1 and medical students in cycle 2 and stored in Microsoft Excel. To verify the integrity of the data, each cycle was secondary coded by either the lead author or medical students. All excerpts from the transcriptions were anonymized using the participant number that identified each participant only as either a service user or professional.

**Data Analysis**

A thematic analysis approach [13] was used to identify themes from the data related to the facilitators, barriers and needs of the stakeholders in developing a new auditory-training gaming application. This process involved the lead author and trained students identifying themes from the codes.

**Results**

Six themes were identified from the focus groups in relation to the needs, barriers and facilitators in developing an auditory-cognitive application that would be useful, fun and accessible. The themes are (1) Congruence with hobbies (2) Life gets in the way (3) Motivational challenge (4) Accessibility (5) Addictive competition (6) Realism.

1. **Congruence with hobbies**

Throughout the focus groups, service users commented particularly on what would continue to motivate them to play the game across an extended period of time, rather than a one-off use. At first it appeared to be different styles or themes of games that motivated them, such as word games or online chess. However further discussion by two service users who were not regularly playing mobile games led to the consensus that if the theme of the game was an extension of an enjoyable hobby then this would heavily facilitate not just initial interest, but extended and continued playing time.

‘I mean this game is educational but you want to make it fun as well, fun at the same time.’ [SU9]
‘For example, if you had one about art?’ [SU8]

‘Yes, I’d use it.’ [SU9]

‘You’d be at it all day!’ [SU8]

2. Life gets in the way
Whilst both service users and clinicians agreed that the premise of the application was a good idea, the issue of finding the time to use the application was raised as a potential barrier. In practical terms it was suggested that the user would need to be at home in a quiet space to be able to use headphones and concentrate. Others suggested that busy lives meant other responsibilities, such as taking care of grandchildren or house chores take priority over self-care. This feeling of being too busy to use the application draws parallel with reactive or passive healthcare, such as using hearing aids when a hearing loss has been diagnosed, as opposed to a preventative or active approach, whereby spending a small proportion of time each day may in fact benefit in the longer-term.

‘I find that I don’t pick up my iPad and read the paper anymore, I didn’t realise I didn’t do it. But then when I went to my iPad it had no battery and I didn’t care, so it was kind of like oh I’ve stopped reading the paper, but I didn’t really notice.’ [SU10]

‘I’m also quite involved in the church, and the grandchildren. So, I think when you are saying as to what might prevent you from doing these other pleasurable things, then it would be other equally pleasurable things that one has to do.’ [SU8]

Using notifications and reminders within the application was suggested to remind users that they were overdue a training session. Or to use commuting time on the underground or train as an opportunity to play. Interestingly in the professional group there was a misalignment in views regarding whether people in an older age group would engage with smartphones and headphones whilst travelling.

‘I don’t think I’ve seen anyone like in their sixties even [using a smartphone?].’ [P1]
‘I have.’ [P2]

‘Have you been on the tube?! I think they do!’ [P3]

‘I could probably play it on the bus or something you know, when you are travelling, something to just fill time.’ [SU7]

‘Yes, on the tube.’ [SU10]

3. Motivational challenge
Despite the issue of needing to set aside time to play each day, a main facilitator identified from both the service user and clinician groups was that the application must provide the correct amount of motivation and element of challenge to ensure it was fun, useful and enticed the user back to play. The motivation did not necessarily need to come from improving one’s own prowess. The idea of altruism being a motivator was discussed. It was suggested that if a person was aware that playing the application would be contributing to the research knowledge on dementia, they would be much more likely to play it as it may not necessarily gratify them personally in the short-term. The professional group suggested that using multiple scenarios would increase the relevance to challenges faced by hearing impaired people and therefore increase the motivation to improve in all situations.

‘For me I would be more encouraged if I knew it was paying back into research. If I knew that somebody thought it was good for me too. If I was playing it just for the sake of playing it then I would be playing it for nothing. But if I’m playing it and I’m contributing then I can pretend I’m contributing even if I’m just playing for myself.’ [SU10]

‘It would be good if they can select what do you want to train. I had the problem the other day speaking with my friend at the cafe...Maybe I’ll give it a go, yes today I’ll play the cafe.’ [P19]

‘It’s motivation as well, because if you do terribly at the one in the cafe but you’re doing fantastic at all the others. I am going to the do that cafe one again, I am going to smash the cafe one today.’ [P1]
4. Accessibility
One clear need highlighted from both cycles was that the application needed to be accessible for all ages, catering for those with visual or audio impairments and available to play on appropriate platforms. Using appropriate screen resolutions, font sizes, images and colours were all design parameters that were identified as important.

‘I have been testing patients as well, elderly patients for my study and I use an app on the iPad as well as computer tasks and they tolerate it very well. They never complain when I say let’s switch it to the iPad, actually they like the one on the iPad more.’ [P19]

‘I think most people are going to play for that age on a phone or an iPad. I think it would need to go across both platforms because what is it 25% Apple, 75% Android?’ [SU3]

‘If I could do it via the computer... simply I'm used to using the computer.’ [SU8]

‘I think the size is relevant actually, that tiny screen it [of a smartphone] it's not quite the same as if you were looking on the screen.’ [SU9]

5. Addictive competition
Comparing the premise of this application to other successful games that the participants played resulted in agreement as to why people went back to playing certain games repeatedly, and over a long period of time. The applications or games that were the most successful were addictive to play. Not only in terms of the aim of the games themselves, but also the competitive nature of moving through levels to beat a family member, partner or friend. Having a shared platform to engage in healthy competition was seen as a driver for playing an application. Using scores, rewards and trophies were all seen as additional extras that would provide extra facilitation in prolonged and repetitive play.

‘Maybe I could compare this with my husband or my friends and then I would know they were able to do it like three tones before me, so maybe I am actually a bit worse.’ [P19]
‘Another way that I’ve mentioned might be to pair up with a relative or have some kind of competitive nature you know in the household.’ [P5]

‘My mother-in-law could see my scores if that was of interest to her.’ [SU10]

‘Gives you more motivation I think, if you’re in a competitive nature.’ [SU13]

6. Realism
The application in cycle 2 was demonstrated using a coffee shop scenario, which received positive feedback from all participants as it involved a real-world environment, where it was likely that a person may have difficulty hearing speech. All participants agreed that it would be most appropriate to use ‘real-life’ scenarios in the game, instead of complete gamification. It was suggested that using realistic scenarios would make the application more useful and the skills built in the game more transferable. It was suggested that using realistic tasks would also make the game more appealing to an older person, as it made it feel less like a game. The clinician group felt that using these scenarios would also make it easier for them to recommend the game and also to use the game to obtain feedback about specific situations that the person was having particular difficulties with. By being realistic the game would also tie in with the theme of using hobbies as scenarios.

‘It has to cover areas that a person like myself would find it very difficult to hear, like for instance I said the gym, but also airports they can be a nightmare as well, you know I still have to travel even if I’m deaf.’ [SU13]

‘Particularly if they are already isolated and they’re already staying at home and they’re sort of scared of going outside, it’s a nice way to bring outside in, so they can build up their experience in other situations without actually having to get there.’ [P3]

‘And it’s an element of control that they’re taking over their situation and so that it’ll give me some confidence you know I’m doing something about it. Makes you feel good.’ [P1]
### Summary of Results

| Theme                          | Facilitators                                                                 | Barriers                                                                 | Needs                                                                 |
|-------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------------------|
| 1. Congruence with hobbies    | Initiate and maintain interest over time to allow repeated play. Concentrate on being educational and enjoyable | Limitation of number of pre-programmed scenarios to cater for all hobbies. | Relate to common enjoyable hobbies for the intended user groups.       |
| 2. Life gets in the way       | Promote using the app during unavoidable daily tasks e.g. commuting.         | Incorporating the app into busy daily lives. Reliance on passive healthcare models. | App to send notifications and reminders when the user is overdue a training session. Allow offline play e.g. when commuting. |
| 3. Motivational challenge     | Promoting altruism to contribute to research.                               | App not offering the right level of, or type of challenge leading to a lack of repeated play/training. | Level of difficulty to be challenging enough to entice repeated play. Multiple scenarios relevant to difficult hearing situations. |
| 4. Accessibility              | Design considerations e.g., use of colours, font sizes and images.          | Smaller screens on smartphones. Inappropriate screen resolution for each device. | Accessible to all ages. Available on multiple platforms and devices including PC. |
| 5. Addictive competition      | Option to share progress with family and friends to encourage competition.  | Not a driver to play for people who are not of a competitive nature.    | Include daily high scores that are comparable to friends or self across time. |
| 6. Realism                    | Skills honed in the app would be more transferable. More likely to recommend to friends. | May prefer more realistic graphics rather than taking a gamified approach. | Relatable to true to life environments where hearing is difficult.       |

*Table 2. Summary of findings in relation to the research question*
Discussion
This study aimed to engage relevant stakeholders from the worlds of audiology and cognitive disorders to collaborate in the design and development of an auditory-cognitive training game application. Stakeholders were recruited and engaged in two cycles of semi-structured paired interviews and focus groups to understand the facilitators and barriers in producing such an application and to elicit specific design requirements for the application in addition to the current literature.

Facilitators
A popular choice for facilitating a new gaming application was for it to provide a high level of addictive competition for the user. The results demonstrate that this can be achieved through a number of ways including rewards, achievements and competitive play with family and friends. This draws parallel with the findings from Talaei-Khoei & Daniel [12], who found that their participants were motivated to improve their memory age as it provided them with a sense of achievement and reward. This study also found that participants wanted an extra level of socialisation within the application through a virtual competition with friends to share scores and achievements.

This sharing of information was also addressed in ensuring the application was motivationally challenging enough to encourage them back to play. A particularly interesting finding was that the motivation to play the application was not necessarily to improve one’s own skills, or for personal gain, but to provide data altruistically to a research database on a topic such as dementia. This draws parallel with the popularity of Sea Hero Quest developed by Deutsche Telekom, which has been downloaded by over 4.3 million players [14]. Sea Hero Quest is an application developed to collect large data sets on how navigational cognition changes over the human life span. Collecting data through gameplay has provided data that would have taken 176 centuries to obtain through standard dementia research practices.

Barriers
One of the themes that was perceived as a barrier to producing a successful application for high adoption was that other life activities would get in the way of using the application on a regular basis, as it would require a quiet space to concentrate. Participants gave examples of other activities that required their attention and efforts that were placed above auditory-cognitive training, such as household chores. The low level of importance placed on maintaining cognitive reserve in light of other daily activities by participants is in contrast to the theory of Weinstein [15], who suggests the building of cognitive resilience is of utmost importance in the window of opportunity that is mid-life. It is critical to engage the cognitive reserve in mid-life to allow the brain to cope better with damage in later life.
The findings from this study demonstrate that even with this knowledge, changing health behaviours is a challenge and often unsuccessful [16]. It is therefore critical to follow the proposals from Talaei-Khoei & Daniel [12] and employ qualitative methods, as in this present study, to focus specifically on why end users would find a training game to be useful and adopt it.

One potential barrier to using hobbies as a motivator is the effect of apathy on motivation. Apathy is a major neuropsychiatric symptom in dementia, and is sometimes observed in MCI patients [17]. Individuals with clinical apathy would be less likely to be motivated by the type of training described. However, it should be noted that the intended user group is specifically focused on individuals with subjective cognitive impairment and MCI, who have a much lower incidence of apathy than those with more severe cognitive impairment [18].

Needs
One of the specific requirements that was elicited from the discussion was to ensure that the application was accessible for older adults, who may be unfamiliar with using tablets or smartphones to access applications. This is also a potential barrier raised in the general gaming literature; however, in Vallejo et al. [11] there were no usability problems reported for participants without previous computer experience when using a joystick or touchscreen.

Interestingly participants felt that making the scenarios more realistic to daily living would be more useful, transferable and more appealing to older adults by making it less gamified. Results showed that if the scenarios were congruent with or an extension of an enjoyable hobby for the end user, this would increase the level of interest, fun and ultimately adoption. This finding could provide reasoning for why lab-style auditory training programs, such as those evaluated by Ferguson & Henshaw [19] have failed to extrapolate on-task learning to off-task daily activities. As suggested by Anguera et al. [9], their training game was successful due to being delivered outside of the laboratory environment and its custom design. Similarly, the reason Manera et al. [10] found large variations in playing time in their application based around cooking may be due to the design lacking engagement and interest for their particular end user group. Therefore, the use of multiple common scenarios based around daily activities and a custom scenario based on a hobby may in fact increase adoption and success rate outside of the application.

Limitations
The use of a small sample size is more common in participatory design, as it is about the rich quality of the data rather than the quantity. Demographically, the age range and use of hearing aids was skewed from the desired end user group. However, it allowed exploration of using this type of application as a supplement to hearing aid provision in more severe hearing losses in the future. As this application is in its infancy and has yet to be evaluated to see its effectiveness – there is potential to use
the application in other, more hearing-impaired populations. However, for the scope of this project, involving those with varying hearing loss severities would introduce a confounding variable when assessing if using the application does indeed improve un-aided speech listening in noise.

Lessons Learned

Stakeholder Recruitment
The inclusion of non-clinical stakeholders that already have existing relationships can enhance data collection. In both cycles the stakeholders included spouses and friends. This extended the depth of data collection around more sensitive questions, such as thoughts and feelings about developing cognitive impairment and current cognitive performance. Stakeholders were more comfortable discussing these issues with someone they already knew, as opposed to the interviewer. This was observed in a design workshop with aphasia patients [20]. The author concluded that using a relative is essential in fostering a ‘communication culture’, which gives the stakeholder with the condition confidence to express and verbalise their thoughts and feelings.

It was also useful in stimulating further discussion as the stakeholders had more background information about each other in comparison with the interviewer. Stakeholders were able to ask further appropriate probing questions when discussing content. This was evident when discussing possible scenarios for the gaming levels, as one stakeholder was able to talk more to their spouse about their enjoyment of art galleries and bring this idea to the discussion.

When holding clinical stakeholder focus groups, a multi-disciplinary discussion should be used to uncover shared thinking that provides not only useful data for answering the research question, but also to take further into wider clinical practice outside of the application design. In this instance mixing clinicians from audiology, psychiatry and cognitive disorders research brought together specialists that do not usually meet, but share common patient groups and challenges. This allowed clinicians time away from their individual departments to discuss ways in which they could support each other to improve the care of patients that may unknowingly access each other’s services. For instance, implementing the use of a hearing screening pathway for patients referred for cognitive assessment to trigger a referral for audiology assessment and facilitate communication in cognitive assessments. Where possible, clinical stakeholders should include those with a range of experience from newly qualified to consultant level, to tap into both new learning and wealth of experience. Consideration should also be taken to include geographical variance to allow for deviances in service delivery away from national guidelines. Woods et al. [21] used co-design to develop a mobile health application in the area of cardiac health, also concluded that using participatory design within a healthcare delivery setting with multiple clinicians improves patient-centered care. Using participatory design with multi-disciplinary stakeholders can facilitate a wider and unforeseen positive impact across service delivery both locally and nationally.
When focusing on designing an application to be used in a pre-clinical symptomatic population it is prudent to recruit from multiple sources outside of the standard clinical settings, such as hospitals and GP clinics. Groups in the community such as clubs, neighbourhood associations and religious groups should be targeted as potential sources of recruitment as they are likely to include stakeholders that may have symptoms that are not severe enough to seek clinical intervention and are therefore not frequenting clinical settings such as audiology or cognitive disorder clinics.

It can also be useful to include stakeholders from a wider pool that, although may be less relevant to the prospective end users, can offer ideas for future implementation of the application. Using stakeholders that have already experienced a condition can provide data on past experiences. These stakeholders are also useful in patient and public involvement activities before data collection begins to advise on research question development, advertising materials and focus group questionnaire design.

**Developing Content and Gameplay**

When asking stakeholders to contribute in designing content for a new game or task that requires an element of training or behaviour change, it is important to begin the discussion by asking the stakeholders about hobbies or activities that they already enjoy participating in. Particular focus should be given to why they enjoy them and what stimulates them to regularly participate in that particular activity. For example, in cycle 2 the playing of online chess and online crosswords were introduced as an enjoyable platform for distraction, competition and accessibility at all times of the day.

The reasons behind successful adoption and enjoyment of other applications should be understood and consequently integrated into tasks for the new game in conjunction with recommendations from the literature specifying special attention to customisation and individualisation. This was evident when discussing design for different scenarios. Stakeholders foresaw that they were more likely to regularly use the application if the scenario was individualised to an environment that they associated with enjoyment or relaxation, such as an exercise class or an art gallery. Additionally, they were also likely to use it if it was customised to a situation that they found difficult to communicate in reality and would want extra practice virtually. Examples of these included a café, airport and train station. Similarly, Jessen, Mirkovic & Ruland [22] used this approach whilst researching participatory design frameworks for a self-management application in a chronic disease population. They used common enjoyable games such as Super Mario, Crosswords and Monopoly as a vehicle to elicit further thoughts for discussion on the concept of creating their design.

**Further development of the application**

To overcome the barriers and incorporate the design needs from the findings, within the scope of the project, the application will additionally include:
• The option to deliver daily notifications to remind the user to take some time to play the application.
• Inclusion of scores and comparisons to daily or weekly high scores.
• A re-design of the visual representation to use only images as opposed to a mixture of words and images.
• Coloured boxes (green=correct; red=incorrect) that will appear around the images when selected them to notify the user of correct and incorrect selections during repeated attempts.
• A range of six realistic scenarios that are reported by people with a hearing impairment as challenging.
• Include a customised scenario for participants evaluating the application that they consider relevant to them.
• Allow offline play so that users will be able to play the application during other daily activities e.g. commuting.

Conclusions
Utilising a participatory approach in conjunction with the literature base when designing a novel application ensures that the final product is useful, fun and accessible to the intended user group. Both cycles of this project have demonstrated that an application that could provide training for both auditory and cognitive performance in a way that would motivate users to regularly play it, would be welcomed as an alternative to hearing aids, a fun activity and used if it could keep the brain active and healthy. The idea of completing an active, preventative task does still not carry enough weight to drive people to use it and so would require other competitive and reward elements to overcome the barrier of having enough time to use it. The results of this study will now be used to finalise the application design and complete a randomised controlled study to evaluate the effectiveness of using the application on speech-in-noise, cognitive ability and quality of life, in addition to a usability evaluation.

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Author’s Contributions
EF and LP were involved in conceptualizing the study with input from TP on the methodology and data curation. EF was responsible for the investigation, conducting the interviews, analyzing the data and writing of the original draft. All authors were involved in writing, reviewing and editing the final manuscript.

Conflicts of Interest
None declared.
Abbreviations
AD: Alzheimer's disease
MCI: Mild cognitive impairment
GP: General Practitioner
SNR: Signal-to-Noise Ratio
WHO: World Health Organisation

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