University of Southampton
Electronics and Computer Science

A Group Design Project report submitted for the award of MEng Computer Science

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Mobile Intervention Authoring

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Abstract

One in a thousand babies are born deaf and many more become deaf as they age. However, cochlear implants, which are electrodes inserted into the inner ear, allow patients to hear again. These are tested annually, but this requires patients to visit Cochlear Implant Centres, which can prove both costly and inconvenient given the distances involved. To make lives easier, UBhave framework, which allows researchers to create dBCIs (Digital Behavioural Change Interventions) that run on a smartphone, may be used to create a bespoke intervention for these users.

An intervention was created with the UBhave framework to allow cochlear implant patients to monitor hearing loss on their smartphone using a speech in noise test, order spare parts and complete a diagnostic survey. The intervention is designed to mimic check-up appointments with cochlear patients which the team observed. Using the pervasive logging capabilities of UBhave, patient data from the intervention can be sent to audiologists to build a telemedicine solution. To create the intervention the UBhave framework was extended to support media files on the intervention editor and the android client. The intervention passed extensive technical testing, a user acceptance test and an experts review and was extremely well-received by the client.

Contents

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We would like to thank both Helen and the ISVR Centre for setting up observation sessions with cochlear implant patients, and the patients in allowing us to view them, as this made an invaluable contribution to the end result.

We would also like to acknowledge the great contribution of our fellow student Chris Baines who carried out the initial development of the dynamic app editor, provided us with indispensable support in setting up our development environments, and assisted us whenever and wherever he could.

Finally, we would like to thank everyone who completed our User Assessment Test for donating their valuable time.

Statement of Originality

The ideas behind this project were originally conceived by Mark Weal, Charlie Hargood and Helen Cullington. The authors of this report confirm that it is all their own work and that any references, quotations or existing work have been correctly acknowledged.

There is copyright on the waveform files used for the triple digit test implemented. The copyright is owned jointly by the University of Southampton and Hörtech in Oldenburg.

1 Introduction

1.1 Project Motivation

The motivation behind the overall project stems from the marriage of two mutually complementary objectives, namely extending the UBhave Framework and automating cochlear implant monitoring, which are combined into the overall project goal.

1.2 Behaviour Change Interventions (BCIs)

In human psychology, numerous models have been devised which attempt to theorise and model human behaviour to allow for a better understanding of habitual development. These analyse a broad range of influences on motivations, such as cognitive processes (social psychology), sociology and anthropology (particularly with respect to human tendencies), but studies generally reach a mutual conclusion: the foremost deciding factor in an individual's actions is determined by the balance of their self-determination to resist, polarised with their predisposition to adopt a particular manner of behaviour; in other words, how well a person is equipped to offset the development of habitual actions, particularly those with damaging effects. (Morris, et al., 2012)

To combat this, health organisations such as the National Health Service (NHS) make use of the concept of Behaviour Change Interventions (BCIs), which they define as "*a structured way to deliver advice… arranging follow-up support… [and] equip people with tools to change attitudes and handle underlying problems*" (Powell & Thurston, 2008). This manifests itself in techniques such as helping people adversely affected by their own behaviours to recognise the potentially harmful consequences (including risks to both physical and mental health) of their actions through one-on-one contact with a psychologist, in turn continuously assessing their readiness to change and providing feedback, advice and resources to motivate the necessary adjustments to their lifestyle.

In order to standardise these BCIs, the National Institute for Health and Care Excellence (NICE) lays out a set of principles for health-related organisations (including the NHS) and behaviourists regarding the application of BCIs; these suggest that BCIs are applicable to all forms of behaviour (such as smoking, unhealthy dieting, or even extended bereavement and classroom behaviour), may be applied in many different contexts to dissuade a broad range of behaviours, and should share a general structure which operates on the mantra that early prevention of poor behaviours amongst participants is easier than curing them later (NICE, 2007). This is achieved by means of a cyclic reinforcement loop: the psychologist collects data from the participant, analyses it, assesses it with respect to goal completion, and then sets new goals for the next meeting, incentivising these gradual habitual adjustments through praise when progress has been made, while discouraging any activity which would set the participant back.

However, BCIs in this physical format carry a number of disadvantages, primarily due to their delivery and the resulting resources they consume. Time and equipment is required for psychologists to elicit participant data and set goals, which in many contexts requires the participant to be present at the assessment (and thus they may have to travel). Appointments must hence take place during the psychologist's working hours, with only a limited number of appointments per day feasible. Furthermore, the effect of the cyclic intervention model is limited in some contexts as it is constantly operating in a retrospective format (relying on the participant's honesty in review), meaning that it may not help to suppress 'in the heat of the moment' instincts (for example, when a participant is tempted to make an impulsive decision) or the temptation to lie out of guilt, and thus the lack of immediate disincentive may, even if temporarily, encourage the flouting of a CBI programme.

1.2.1 Digital Behaviour Change Interventions (dBCIs)

Digital Behaviour Change Interventions (dBCIs) proffer a more personalised, pervasive and reactive set of affordances in the context of interventions, particularly given the recent proliferation of personal computing devices. They are defined by Hargood, et al. (2014) as "*large-scale interventions conveniently delivered to users via the Web*", acting as a digital representation of the typical psychologist-participant interaction; as such, they may manipulate user input, digital sensors and even context-sensitive data, particularly on mobile devices (for example, location tracking).

The potential advantages of these over traditional BCIs are numerous. Firstly, the participant's typical reliance on the professional resources of psychologists, such as time and equipment, is reduced greatly, a convenience for both parties as participants no longer need to regularly attend physical appointments and are instead able to use the dBCI in their own time and at their own leisure. Furthermore, dBCIs may make use of machine learning techniques to better personalise their programmes to their users, potentially setting more realistic goals or being more adaptive to patterns of participant behaviour, in turn making better use of their responses. The use of context-aware data only augments this, allowing mobile devices to provide instant disincentive interventions (notifications) in cases where their programme success is threatened (such as by encouraging healthy eating if it senses the participant is shopping in a supermarket).

In order for the BCI framework to be effective across widespread communities, therefore, its digital equivalent should be proliferated. Hargood, et al. (2014) proposes a framework called "UBhave" which serves as a platform for creating, presenting and distributing mobile dBCIs through an accessible and generic Web-based architecture, toolkit and Android application, thus offering the advantages of dBCIs to the general psychologist audience and lending them sufficient flexibility to be applied in an eclectic range of contexts. It was hence suggested to be a perfect partner project for automating a number of cyclic process areas regarding user behaviour, such as the testing of cochlear implants.

1.3 Cochlear Implant Users in the UK

In the United Kingdom alone, there were over 10,000,000 people with some degree of hearing loss as of 2011. Of these, over 800,000 suffer from severe to profound hearing loss (see section 2.2.2 for definitions). The total number of people with hearing loss is predicted to rise to around 14,500,000 by the year 2031 and assuming the same proportion of those are at least severely deaf, that would mean 1,160,000 sufferers of severe or profound deafness. (Action on Hearing Loss, 2011)

Cochlear implants are a special form of hearing aid used by those with severe or profound hearing loss. In 2011, while the number of people eligible in the population exceeded 150,000, only 6000 had yet been fitted with a cochlear implant, with 500 more being fitted per year (Action on Hearing Loss, 2011). This rate of implant surgeries is largely limited by the cost, both in time and money, of the follow-up treatment for patients.

In the week following the implant operation, patients will have three check-ups to fine-tune the frequency levels in the hearing aid and ensure everything is working correctly. These check-ups continue with decreasing frequency over time as patients become more accustomed to use of the aid. After a few years, check-ups will occur only every 1-2 years, assuming there are no major changes in hearing ability.

The major obstacle with these check-ups is that there are only 23 centres in the UK that have the equipment to adequately test the aids, meaning many patients have to travel very long distances to reach their nearest test centre. For example, the centre in the Institute of Sound and Vibration Research (ISVR) at the University of Southampton covers patients all the way to the Scilly Isles, a distance of around 300 miles, which can take around 7.5 hours with the ferry. (Agyemang-Prempeh, 2011)

There are two main issues that arise from these conditions in long-term care. Firstly, having travelled such a distance, it can be found that nothing has changed in the patient's ability to hear and their aid is working as expected. In this case, the time and resources of the centre were used unnecessarily, in addition to the time the patient spent travelling to and from the centre, and could have been better used on another patient. Secondly, a patient's implant may deteriorate in the months following a check-up without the patient realising, leaving the patient unable to hear as well as they should until their next scheduled check-up; the patient could potentially live with a faulty aid for over a year.

If there were a way for patients to keep track of their hearing ability when away from the centres, even if crudely, to establish deterioration in hearing, appointments at centres could be better organised to focus on treating only those who have shown deterioration, solving both stated issues with the current system. (Agyemang-Prempeh, 2011)

1.4 Project Definition

From drawing parallels between the demands of cochlear implant monitoring and the affordances of Digital Behaviour Change Interventions, it soon became apparent that the UBhave framework would be a suitable host for a telemedicine approach of allowing patients to monitor the operation of their cochlear implants.

Most prominently amongst the advantages of adopting UBhave in this context were the pre-existing pervasive properties of its mobile-based framework, which directly addressed the two major problem areas identified with the current physical appointment system. Firstly, the waste of time and resources incurred by appointments returning wholly positive results (and were therefore unnecessary) would be addressed by removing the need for patient and centre staff to meet physically, instead replacing this interaction with a self-administered dBCI-based mobile application test which would be able to transmit health-related data and user feedback (such as those contained on the diagnosis questionnaire filled out during appointments) to centres remotely, leading to a more efficient and convenient process.

Furthermore, if implemented with the graphical UBhave intervention editor, the test may even be adapted or fine-tuned at a later date by centre staff without any prerequisite programming knowledge, a significant advantage over the creation of a bespoke application. Although it was not expected that a test taken on a mobile device would yield hugely accurate results able to be used for any kind of implant diagnosis, it was hoped that it would still reduce the likelihood of a patient booking an unfruitful appointment, identifying those truly in more need of the time and hence increasing the efficiency of the appointment system within centres.

Addressing the concern that implant users could potentially unknowingly harbour a faulty device in between appointments, it was suggested that the typical cyclical model of a dBCI would, in many cases, mitigate the adverse effects of unidentified deterioration within implants through provision of a regular and consistent means by which to remotely test them. As a self-applied test, patients would be able to monitor their own implants remotely on an ad-hoc basis, or indeed receive regular “notification” reminders of the need to take it (for example, every month) should they wish. The framework also holds the further advantage of facilitating implementation and delivery to patients through its Web-based server, allowing the dBCI to be easily distributed and operated through a simple touch interface.

It was therefore envisaged that, should the pre-existing UBhave framework be extended to the point where it might support the necessary functionality to support a dBCI representative of a regular hearing test, both the generic functionality of UBhave and cochlear implant centres might benefit.

1.5 Overall Project Goal

In accordance with its intended purpose and context, the project thus ultimately aimed to develop a prototype permitting people with cochlear implants to test the proper functioning of their devices remotely and use the results to judge their next course of action accordingly.

To achieve this, it would thus be necessary to extend specific areas of the UBhave framework, in particular the pre-existing intervention editor and mobile client application, and manipulate the resulting tools to compose a dBCI which might provide an accurate representation of a typical hearing test. The project therefore commenced with a literature review undertaken to better grasp the state of the pre-existing framework and its underlying principles, including those of similar systems and cochlear implants as a whole, the results of which are located in the next section (Chapter 2).

Chapter 3 goes on to analyse the results of this background research with a view to providing a comprehensive specification for the proposed intervention, encompassing the group’s background research to acclimatise to, and gain experience within, the pre-existing codebase, cochlear implant monitoring methodologies and the UBhave framework as a whole.

Chapter 5 discusses the design decisions made on this basis, particularly those related to the models adopted in extending the current framework which Chapter 6 later details the iterative implementation of.

Chapter 4 then discusses the tools, techniques and methodologies employed by the group over the course of the project to coordinate resources, manage time and communicate effectively to achieve the specified goal in direct cooperation with the client, the ISVR centre.

Chapter 7 features an account of the testing undertaken throughout this extensional coding and the subsequent manipulation of the UBhave framework to ensure functionality within their web-based and mobile contexts, before Chapter 8 incorporates an end-user study evaluating the effectiveness of these efforts, the resulting mobile application itself, and indeed the project as a whole.

Finally, Chapter 9 concludes with an overall reflection on the consolidation of dBCI authoring with remote cochlear implant monitoring, suggesting future work which might be undertaken within both fields to further their potential.

2 Literature Review

2.1 Digital Behaviour Change Intervention (dBCIs) Systems

2.1.1 The UBhave Framework

In order to acclimatise to the pre-existing state of the UBhave framework before shared control was assumed over at least a portion of its development, a light background and literature review of its associated theory was undertaken to gain a better understanding of its ancestry, architecture, current applications and overall scope.

The most saliently relevant source of information, a paper contributed to and recommended by the Project Supervisor, detailed a comprehensive summary of the theoretical UBhave framework and architecture as a whole (Hargood, et al., 2014), illustrating which elements had been fully implemented when viewed alongside the pre-existing project (as discussed in Section 3 and in turn allowing inference of which areas to develop further.

The summary hence described the overall objective of UBhave: to provide a generic and accessible medium through which behavioural psychologists may create, present, store, distribute, and receive results from, mobile dBCIs, without the prerequisite of much technological knowledge (for example, proficiency with programming code). This was achieved through a central server storing dBCIs, written via a Web-based intervention editor (derived from a related project, *LifeGuide* – see Section 2.1.2) and output as .JSON ‘intervention definition files’ for ease of distribution (Figure 1).

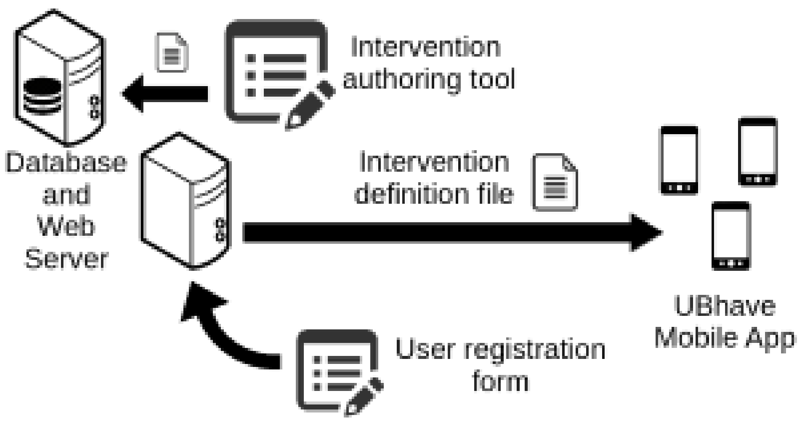

Figure 1. The architecture of the UBhave Framework (from Hargood, et al., 2014).

From here, dBCIs were intended to be downloaded to Android UBhave mobile clients and interpreted from their encoded format to a fully functioning application able to upload results and relevant data from subsequent usage, taking full advantage of the particular affordances of mobile dBCIs in doing so (such as their personalisation and reactive tailoring of intervention content to user contexts, like locations). The framework also describes itself as one of the first to incorporate mechanisms not reliant on self-reporting, instead manipulating data based on actual user behaviour, suggesting that the context of use should be at the forefront of any design decisions made as part of the project.

Furthermore, the paper highlighted and contrasted the affordances of previous Web-based projects in the field of dBCIs like *LifeGuide* with the demands of using digital interventions in more mobile contexts, with the foremost differences originating from UBhave's more reactive and pervasive approach, insinuating that content control flow could be carefully managed when constructing the hearing test application (and thus would not be linear). The need for intervention content and interaction to be suitably condensed to the limited screen space of a mobile phone was also pointed out, and manifests itself in the analysis of Section 3 and thus the subsequent design of the hearing test application, with intervention architecture restricted by the editor to forms able to be rendered on a mobile screen.

With a firmer understanding of the UBhave framework in place and recognition of which elements were already operational, detailed analysis of the system could take place, in turn permitting the specification of both necessary and desirable extensions with respect to the project's overall goal of implementing a remote hearing test mobile application.

Additionally, partner resources in the multidisciplinary collaborative project also emphasise UBhave's core goal to remain a holistic and generic platform (Lathia, et al., 2014) which implemented a core dBCI structure (Figure 2), a consideration to be taken into account when designing extensions to the intervention editor in case it was adjudged that bespoke features needed to be added (which may flout this principle). The case for the project to remain interdisciplinary during development was also presented strongly, given the cited fundamental importance of sound psychological theories in the creation of effective dCBIs, implying that the main non-functional requirement while developing the project should be maintaining accessibility for all psychologists as end-users.

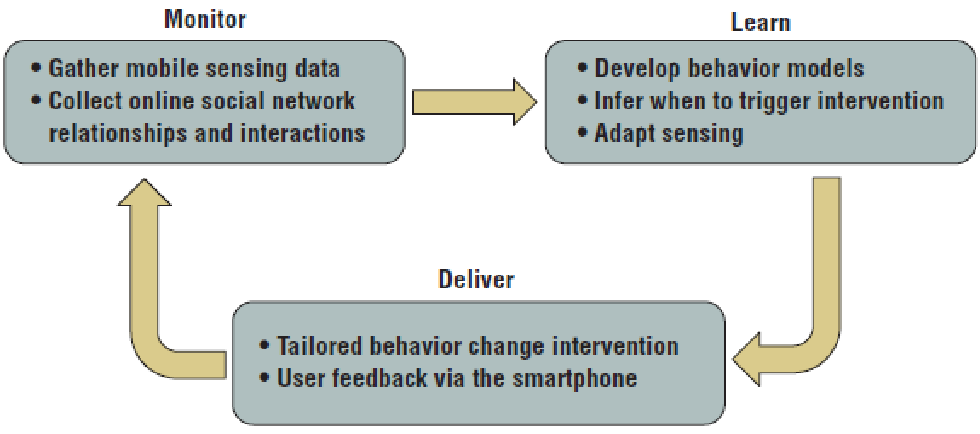

Figure 2. The core structure of a digital behaviour intervention-based application on smartphones (from Lathia, et al., 2014).

Furthermore, developers of the framework highlighted the influence of associated systems in the overall design of UBhave, particularly its parallels with, and loaning of resources from, the *LifeGuide* and *Emotion-Sense* systems, as well as the *My Personality* project cited on the official UBhave web page, insinuating that these ought to be investigated. (UBhave, 2011)

2.1.2 Associated Systems

It was therefore deemed necessary to investigate the project's associated systems in order to further contextualise UBhave's presence in the dBCI landscape.

The most frequently cited influence within UBhave-related literature was that of *LifeGuide*, which Hargood, et al. (2012) reveals is the parent project of the framework by co-designing and developing a hybrid intervention, in turn demonstrating how tasks such as intervention authoring were more intuitive on a larger device or PC, but actual intervention deployment was more convenient on a mobile and pervasive application (particularly when combined with notifications), as in Figure 3. This revealed the fundamental relationship between the two projects, and hence demonstrated the intended functionality of any elements in UBhave whose implementation was not yet complete.

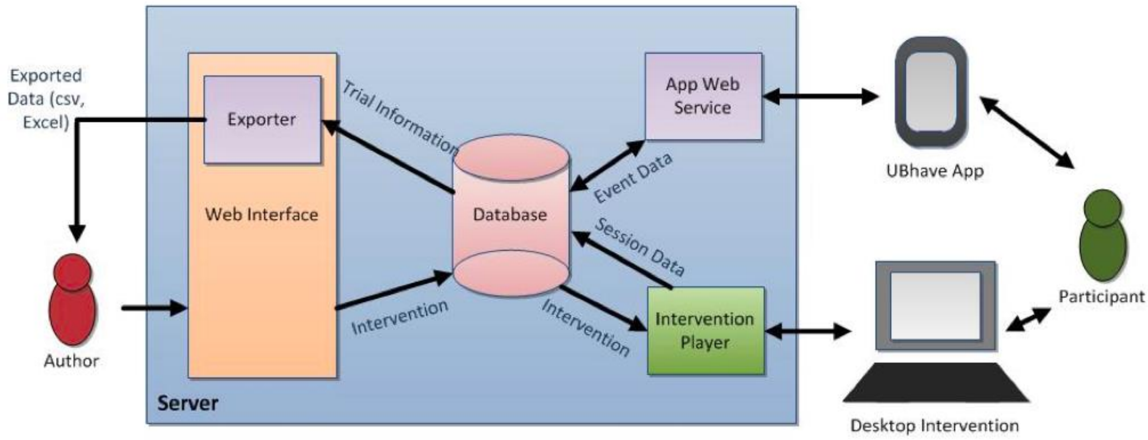

Figure 3. The hybrid UBhave framework, demonstrating the relationship between its Web and mobile-based elements (from Hargood, et al. 2012).

Furthermore, it was found that the Web-based mobile intervention editor under development for UBhave was largely inspired by the *LifeGuide* equivalent, which allows similar functionality for all Web-based interventions (Hare, et al., 2009). Also of particular interest within this framework was the web-based management interface used to collate and view data received from their interventions, a similar tool for which did not yet exist in UBhave, but which might prove useful should development time permit.

The most important feature of this editing tool was its accessibility, prominent in this project because of the need to maintain ease of use for a non-specialist audience. This was achieved through implementing a system of graphical content construction (Figure 4) and English-like syntax as its representation of intervention content control flow, allowing intuitive navigation to be programmed without the need to use any complex programming languages (Yardley, et al., 2009), and thus bearing in mind the project's target audience through its design (which should be mirrored by any extension made to the editor as part of this project).

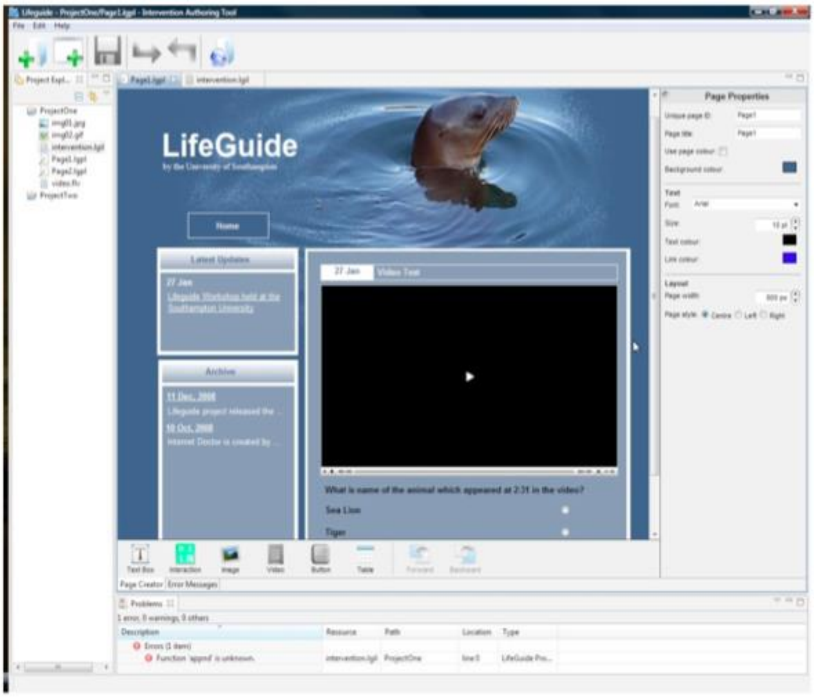

Figure 4. The *LifeGuide* authoring tool (from Yardley, et al., 2009)

Additionally, the *LifeGuide* project also incorporates and encourages community interaction within its users in the form of both an internet message board (for collaborative intervention development) and a supporting 'manual' manifested as a Wiki. This augments the level of help available for non-specialist psychologists and researchers in implementing interventions, and was to prove the inspiration for the project's own supporting resources (Southampton, University of, 2014).

Another project officially associated with the UBhave framework is that of *EmotionSense*, a collaborative smartphone application developed by the Universities of Birmingham and Cambridge, which aims to passively monitor the use of the device and, through a combination of behavioural and social signals with speech recognition, ultimately infer the user's mood through machine-learning techniques, with the overall goal to lessen reliance on self-reporting in interventions (Lathia, et al., 2014).

Although this usage of sensory signals was not necessarily directly applicable to the construction of a hearing test intervention, its implementation in other applications is indicative of the operation and potential potency of the reactive elements of the UBhave framework, many of which were in various states of completion at the time of the group's initiation into the project.

Further literature emphasised that, similarly to *LifeGuide*, end-user programmability and run-time adaption (according to user context) should be at the core of the project, as control over the complex machine-learning algorithms manipulated by *EmotionSense* could be dictated by a simple, first-order logic declarative language (Rachuri, et al., 2010).

The final associated project with UBhave is *My Personality,* a Facebook application developed at the University of Cambridge, which offers its users the opportunity to take real psychometric tests or to have their personality assessed on the provision of their profile data (Cambridge, University of, n.d.). This represents an approach not directly applicable to UBhave in terms of its social network integration, but a potential extension to the framework which has been adopted by multiple alternative systems (Section 2.1.3) due to its community-induced motivational influence (with the results automatically shared on profiles for users to compare to those of their peers – Hagger-Johnson, et al., 2011).

2.1.3 Alternative Systems

Finally, alternative digital intervention-centred systems were investigated in order to provide comparative approaches towards increasing the effectiveness of interventions in a variety of contexts, highlighting potential extensions that, although out of scope, should be held in consideration during the development of the continually evolving project.

As in the case of *My Personality*, several existing intervention systems manipulate aforementioned social network integration to motivate user conformance to their programme through appealing to users' competitive instincts and desire to share achievements. This was seen by Little, et al. (2013) as a particularly effective tactic in designing behaviour change interventions for teen markets and, consequently, future users of the technology. Although such competitive motivations are unlikely to pertain to users seeking to perform a mobile cochlear implant test, it is possible they should be considered as a strategy for publicising the existence of interventions through UBhave in the future (for example through having the option to automatically broadcast a status or when positive feedback is received following a test, which would naturally attract attention on a social network).

An example of such integration within an intervention structure, albeit fairly loosely, is *EnergyWiz*, a mobile application which aims to socialise energy-related feedback by prompting users to compare their power saving with one another and, consequentially, motivate more responsible use of energy (Petkov, et al., 2013). This application was constructed via a "*theory-driven design approach*" which aimed to deduce motivational strategies manipulative of social influences, particularly those on online networks, borne of users' needs to evaluate the extent of their energy-saving accomplishments through comparison to others, in turn using this in place of the 'feedback' element of the typical intervention structure.

Conversely, an alternative method was employed by the *Stroppy Kettle* project, also with the goal of reducing inefficient energy use (Cowan, et al., 2013). Whereas *EnergyWiz* promoted the incentive of competitive self-evaluation, *Stroppy Kettle* manipulates a strong disincentive – namely that of reducing a user's kettle's performance if regularly overfilled - as an alternative methodology of intervening in a negative habitual scenario and thus ensuring conformance to a programme of reducing wastage. Although UBhave features no direct equivalent, its notifications (for example, reminders to input certain data) could perhaps be considered to fulfil such a role in the future, such as in the instance where a user has procrastinated filling out a survey due to their lack of progress on a particular front, in turn inducing a sense of guilt and hence a disincentive-based motivation to participate more openly in the future.

Alternative methodologies of delivering these interventions were also explored, such as using SMS messages to assess progress and notifications with teenagers in both sexual health (Merrill, et al., 2013) and obesity (Woolford, et al., 2011) interventions, both of which recommended this functionality, but warned that their content be tailored carefully to carry positive and optimistic tones to avoid misinterpretation and demotivation; when designing the hearing test, therefore, such pragmatic linguistics should be taken into account.

Finally, more experimental intervention models encountered included those which promoted anticipatory mobile notifications based on previous habitual behaviour and machine-learning techniques (Pejovic & Musolesi, 2014), concluding that these represent the future of pervasive dBCIs and thus should be incorporated into the framework. Some discussed the privacy concerns of pervasive intervention application (with actors wearing cameras as part of their programmes in the study conducted by Doherty, et al., 2013), a salient reminder of the sensitivity of the data being handled by UBhave, and the need for security to be at the forefront of design thinking, although this mostly falls outside of the proposed project scope.

2.2 Cochlear Implants

One way to treat severe to profound deafness is to surgically implant a special type of hearing aid directly into the final component of the ear - the cochlea. This acts as a replacement for all components up to and including the cochlea, leaving only the auditory nerve and brain to act naturally.

2.2.1 The human ear

The human ear is comprised of a number of sections, often summarised into three functional components: the outer, middle and inner ear. The outer ear is the externally visible section, consisting of the pinna and external auditory canal, terminating at the eardrum. The middle ear is a small air-filled cavity containing three bones, the ossicles, spaced between the eardrum and cochlea. The inner ear comprises of the cochlea used for hearing, and semi-circular canals used for balance. The cochlea is a two-chamber tapered spiral tube around 3.5cm long filled with liquid. The inner tube contains the organ of corti, an arrangement of around 17,000 small branched-hair structures called stereocilia. The stereocilia protrude into the liquid in the cochlea and are connected on the other end to the auditory nerve. (Action on Hearing Loss, 2013)

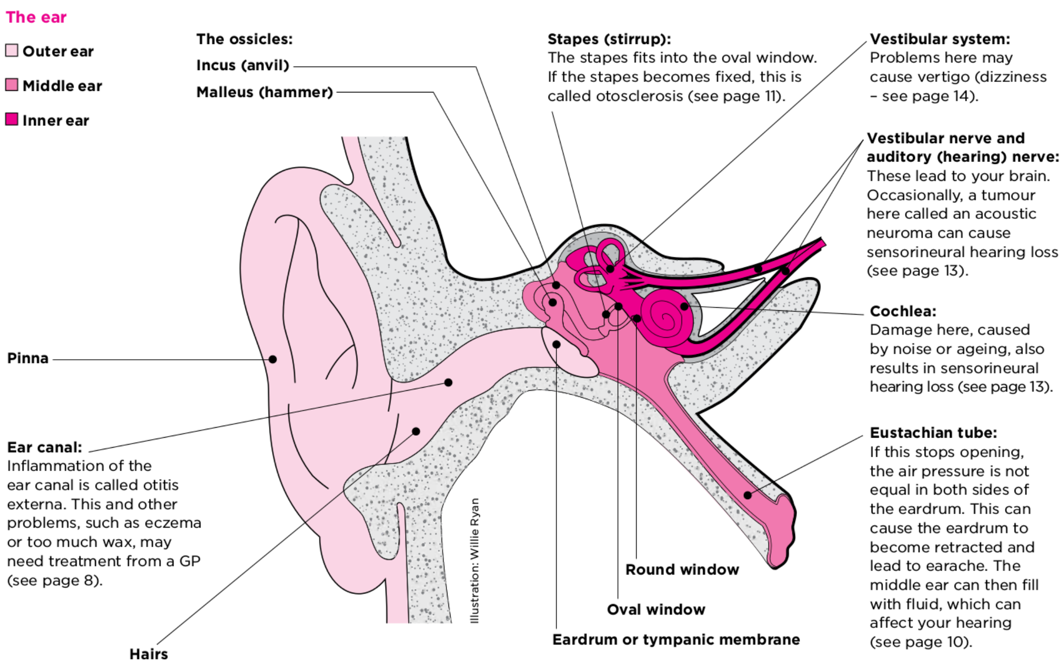

Figure 5. Internal structure of the human ear (Action on Hearing Loss, 2013)

To process sound, the pressure waves are channelled into the ear by the pinna, causing the eardrum to vibrate. This vibration is carried by the ossicles, concentrating the vibrational energy into the oval entrance of the cochlea. The vibrations pass through the inner-cochlea, are picked up by the stereocilia, which send a signal on the auditory nerve to be processed by the brain. Due to the tapering of the cochlea, different frequencies of pressure wave (sound) produce maximum amplitudes at different points along the cochlea's spiral. High frequencies peak near the base (where vibrations enter) of the cochlea and low frequencies peak near the apex. This allows the brain to differentiate between frequencies of vibrations. (Agyemang-Prempeh, 2011)

2.2.2 Hearing loss

Hearing loss can be caused by any section of aforementioned process failing. There are four main recognised types: conductive, sensorineural, mixed and central deafness. Conductive hearing loss occurs through failure of the outer or middle ear; sensorineural hearing loss stems from issues in the inner ear, mixed hearing loss is a combination of conductive and sensorineural hearing losses and central deafness is the inability of the brain to interpret signals sent on the optic nerve, even if all sections of the ear are functioning correctly. (Agyemang-Prempeh, 2011)

Four levels of hearing loss are commonly referred to. Each of these levels is defined as the quietest sound one can hear in their best-functioning ear. Those with *mild* hearing loss can hear nothing below 20dB, those with *moderate* loss have a hearing threshold of 40dB, while *severe* and *profound* losses refer to 70dB and 95dB respectively. (International Standards Organisation, 1991)

Action On Hearing Loss use the term "deafness" to cover all different levels of hearing loss, however there is a further important distinction to make: the difference between those born deaf (ear did not form correctly) and those who have been *deafened*, meaning they were born and learned to speak with functional hearing, but have since become severely or profoundly deaf. This can occur gradually, such as through ageing, or suddenly, such as through physical trauma or severe illness.

The most debilitating part of hearing loss is the inability to understand communication by speech. This problem is further exemplified when the sufferer is not able to see the speaker (e.g. whilst looking elsewhere at another task or on the phone). For this reason, speech is what many hearing aids, including cochlear implants, focus on boosting for the user.

2.2.3 Cochlear implants

Cochlear implants bypass the outer, middle and inner ear components, directly stimulating the auditory nerve from within the cochlea. This makes them a viable solution to each of the four main types of hearing loss other than central deafness, since the process from the auditory nerve onwards is unaffected. However, they are specifically focussed on enabling the recognition of speech, so mixes of sound such as music may still be illegible. Due to being speech-focussed, only those who had developed speech, then been deafened or children who have not yet developed speech are considered suitable candidates for cochlear implants. (Action On Hearing Loss, 2012)

2.2.3.1 Design

The device is comprised of a removable external component worn behind the ear and an internal component which is surgically implanted under the skin in the patient’s head.

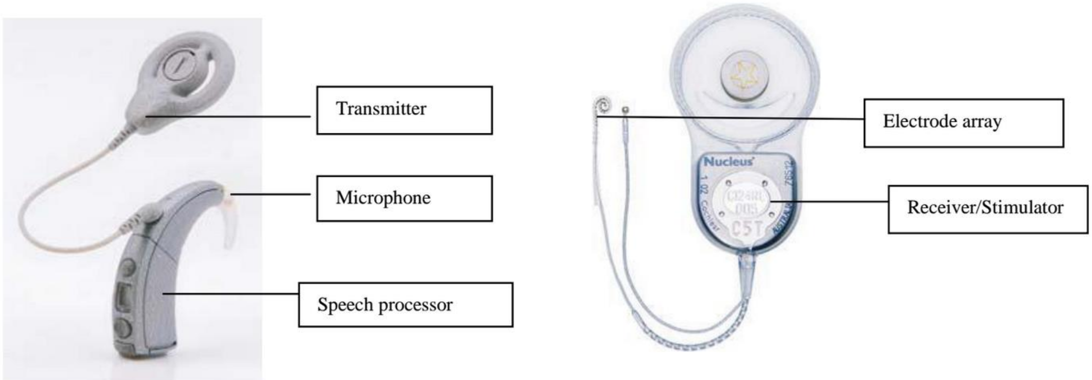

Figure 6 - Inner (right) and outer (left) components of a cochlear implant (Agyemang-Prempeh, 2011)

The spiral electrode array of the internal component is inserted directly into the cochlea of the patient to form direct connections to the auditory nerve with frequency information spread out as close as possible to the natural cochlear function. The large, circular part of the implant contains a magnet which is used to hold the corresponding part of the external component in place. This keeps the transmitter and receiver as close as possible to one another, minimising the energy required to send signals. (Agyemang-Prempeh, 2011)

2.2.4 Function

The process to hear using the implant is as follows:

- Sound is detected by the external component's microphone
- This raw audio input is processed using the on-board speech processor
- The processed audio signal is transmitted from the transmitter, held in place by a magnet
- The internal component's receiver receives the signal
- The signal is converted to electrical stimulations in wires corresponding to the frequency components of the sound
- Each wire passes its individual frequency signal to the auditory nerve where it terminates in the cochlea

Since the electrical impulses cannot be made as precisely as in a fully functioning ear, the final signal sent on the auditory nerve will be unfamiliar to the patient at first, so every patient will need time to learn what each perceived sound means, regardless of whether they were deafened or deaf from birth. Each aid will also need to be tuned to ensure the levels of each frequency sent to the auditory nerve make the sound as understandable as possible to each patient. Testing and tuning (see section 3.2) is therefore frequent soon after the implant operation, while the patient is still getting accustomed to the new sensation, and continues less frequently as time goes on. (Agyemang-Prempeh, 2011)

2.3 Implant Testing/Noise Tests

The triple digit test was developed jointly by the Institute of Sound and Vibration Research at the University of Southampton (who are one of the end customers for this project) and Action on Hearing Loss (formerly the RNID). Rather than a pure tone test it is speech in noise (SPIN) test. A Speech in Noise Test calculates the ability of the patient to comprehend speech over a varying level of background noise. Whilst this has the advantage of not requiring exact knowledge of the sound output level and thus can be used on near any hardware, the ability to recognise speech over background noise is equivalent to the skills needed to converse with people in the real world. (Vermeire, Katrien, et al.) Showed that improving performance for a speech in noise test to cochlear implant patients resulted in a significant improvement in quality of life for both young and old patients.

The aim for the hearing test interventions is for the application to be compatible with the users own smartphone and headphones. Because different volume levels on different combinations of mobile phones and headphones produces different volume levels, any test we use cannot rely on knowing the volume of the sound output.

Whilst (Swanepoel, 2014) have been successful using smartphones to produce calibrated output as a low cost alternative to audiometry equipment, their approach relies upon using a specific smartphone and headphone pair. This approach is much less practical and cost effective than being able to utilise the smartphone and headphone combination which patients likely own.

As specified by (Lutman, 2006) the triple digit test is performed by playing a voice speaking three single digit numbers one syllable in length (possible values of one, two, three, four, five, six, eight and nine in the English version) over noise varying in loudness.

After each set of three digits is played the patient is asked what the digits were. As the noise is varied an algorithm estimates the ratio of signal to noise in which the three digits are correctly recognised 50% of the time.

3 Analysis/Specification

Before starting design or implementation, it is necessary to specify who the target users are with this project. It is also important to discuss the existing technology the project will be based on, mentioning areas for improvement. Keeping these areas and target audience in mind, a number of requirements can be drafted to be referenced in the evaluation before finally making methodology decisions for the project.

3.1 Stakeholders

The primary stakeholders of this aspect of the project are two-fold. The user interacting with the digital intervention itself will be cochlear implant users. They will use the application to answer questions regarding their implants e.g. details of any discomfort they might have due to the implants. They will also use the application to request spare/new implant parts and most importantly, take the hearing test, which will determine if they need to come in for a formal check-up. The ages and technical expertise of these patients may vary greatly so a simple interface is necessary with clear and complete instructions to allow them to use the application with ease.

The second group of stakeholders are the doctors and psychologists who will use the intervention editor to create different interventions, or this intervention. They will have less variance in age but accomplished technical expertise cannot be expected. Therefore, they will need a user-friendly interface to easily create the interventions, using the newly added features in addition to the already existing features. They may also require helpful guides in case they need to understand all aspects of the feature.

As this project is ongoing, further development will be carried out after this project's changes are implemented. Therefore, it is imperative that the next set of developers working on this project easily understand both the existing features and any new additions; they should be able to quickly understand the structure and use of new features without needing to re-write the code it. They may also, like the users of the editor, benefit from a helpful guide.

3.2 Patient Check-Up Appointment Observations

As part of the analysis of existing procedures, each author was invited by the client to observe a cochlear implant patient check-up appointment. The five patients observed were of varying ages and hearing abilities and had been using the implants for differing periods of time. This variation allowed the application design to keep in mind a wider range of possibilities than if only one test had been observed or if all patients observed were similar.

3.2.1 General Check-Up

At the beginning of an appointment, the audiologist goes through a standard questionnaire to establish how the patient feels their implant and hearing have been recently. They establish any perceived degradation or improvement in hearing by the patient, physical discomfort due to the hearing aid and any relevant change in health circumstances since their last appointment. The patient's usage of the aid is then recorded, including how long they use it each day, what (if anything) is preventing them using it more and how long the battery tends to last. Finally, any components of the external section of the aid that the audiologist, based on what the patient reports, believes may not be fully functional are changed and the patient is asked if an improvement is perceived. If there is no perceivable improvement, the old component is reinstalled to avoid changing what the patient is used to, since the aids tend to be extremely sensitive to changes.

The full questionnaire used can be found in Appendix 0.

3.2.2 Hearing Test

After the general check-up had been completed (including the fitting of necessary new/replacement parts) the appointment moves on to a hearing test. This test is designed to track any change in hearing ability *without* any hearing aid between appointments. The hearing test is split into three sections: pure tone audiometry, speech recognition with lip-reading and speech recognition without lip-reading.

3.2.2.1 Pure Tone Audiometry

Pure tone audiometry is used to assess which audio frequencies a patient can hear at which volumes. The audiologist leaves the soundproof room to go into the adjacent observation room. The audiologist can observe the patient by means of a one-way mirror, leaving the patient free from visual distraction or prompting. Single-frequency tones are then played after random delays and at precise volumes. Whenever the patient hears a tone, they press a button. This allows the audiologist to establish which tones and volumes are audible to the patient and which are not.

3.2.2.2 BKB Speech Recognition With Lip-Reading

Next, the Bamford Kowal Bench (BKB) test is performed with lip-reading visual aid. Short pre-recorded sentences are played with a recording of the speaker’s face displayed on screen. The patient then has to repeat the words they think were spoken. The sentences spoken are designed specifically to include phonemes in different combinations, to establish which parts of speech a patient struggles with most and which they are able to recognise best. For many patients with profound hearing loss, their responses will be mostly based on lip-reading rather than the audio itself. This test is therefore the closest to real life of the three tests performed in the appointment.

3.2.2.3 BKB Speech Recognition Without Lip-Reading

The final audio test without the assistance of a hearing aid is a repeat of the previous test, but with the screen showing the speaker’s face removed. This test is therefore to establish the ability of the patient to comprehend speech based solely on the audio component. This is the most similar test to the Triple Digit Test, since both require the person being tested to identify speech with no visual aid. As with the previous test, the results concern groups of phonemes rather than full sentences. Since many sentences can therefore be used to test the same components, patients cannot learn and remember the test sentences; audio is the only available information.

3.2.3 Processor Tuning

The final part of the appointment is tuning the speech processor on the external section of the hearing aid. The audiologist connects the aid directly to the computer, on which processor profiles can be made. A number of profiles can be loaded onto the hearing aid for use in different scenarios or as backups (e.g. the normal old profile and a new profile) in case any changes made turn out to be detrimental.

Each profile is a frequency-volume mapping dictating how much to amplify each frequency heard. The mapping of the current “normal” profile the patient uses are loaded and adjusted based initially on the results of the prior tests. Each time a frequency mapping is changed, a tone of that frequency is played through the patient’s implant at both the old and new amplitudes to assess which is preferable. The new tuning is also tested by simply talking to the patient and establishing whether an improvement in speech quality is heard. The new mapping(s) generated are loaded onto the implant’s speech processor, allowing the patient to switch between profiles whenever they feel is necessary.

3.2.4 General Notes

An important observation to note was that some patients with profound hearing loss struggle to understand any speech at all without the visual aid of lip-reading, even with their hearing aid. Such is the reliance on this technique that one patient even reported difficulty understanding one author’s speech due to him having a moustache. Resultant of this reliance on lip-reading, some patients will receive no benefit from a Triple Digit Test (or any similar visual-free test), so not all patients would be able to benefit from a telemedicine solution as proposed. Despite this, the majority of patients would register at least somewhere on the scale when taking a Triple Digit Test, making the test viable for comparative use in most cases.

3.3 Existing Architecture

3.3.1 Intervention Structure

Interventions are distributed as JSON files, with some additional resources such as logos and themes. An intervention consists of ‘activities’, ‘functions’, ‘conditions’, ‘variables’ and ‘triggers’.

Examples of activities are ‘menu’, ‘survey’ and ‘diary’. Each activity has additional information associated with it based on that activity type. For instance, a menu contains a list of references to other activities in the intervention. Conditions are either logical (‘and’, ’or’) with subconditions or are comparisons (‘=’, ‘>’, ‘<’, ‘>=’, ‘<=’, ‘=/=’) between variables and values. Activities can optionally have navigation conditions, where the activity will only be displayed if the condition is met.

Functions are described as a condition and an action. The actions are only executed if the condition holds. Actions involve setting or incrementing variables or calling subroutines (which are also functions). Functions can be set to execute when an intervention is launched or after an activity is completed.

Triggers describe a context for when certain activities should be started. Contexts include things such as time and location. For instance, the user might be prompted to complete a survey only when in a certain location detected by GPS.

The JSON schema has two different versions which mostly differ in how they identify the type of various intervention activities. Version 1 uses integers, while the new version 2 schema uses strings.

A simple example intervention JSON file is shown below.

```
{
 "applicationName": "My Intervention",
 "front": "c5528",
 "functionPool": {},
 "modelVersion": 2,
 "triggers": [],
 "content": [
   {
     "id": "c5528",
     "type": "menu",
     "label": "Main Menu",
     "content": {
       "items": [
         {
           "id": "c5551",
           "type": "survey",
           "label": "Colour Survey",
           "content": {
             "questions": [
               {
                 "question_id": "colour",
                 "title": "What's your favourite colour?",
                 "text": "I want to know!",
                 "type": 1,
                 "choices": [
                   { "choice": "Blue", "detail": "Good choice!" },
                   { "choice": "Other", "detail": "Blue is only colour!" }
                 ],
                 "details": []
               }
             ]
           }
         }
       ]
     }
   }
 ]
}
```

Figure 7. An example of a simple JSON intervention

3.3.2 Existing Editor Codebase

The editor used for creating mobile interventions is a web-based editor written in Coffeescript - which compiles to Javascript - using jQuery, Bootstrap and Backbone.js. The editor produces an intervention file in the JSON format described above. While it only supports version 2 of the JSON schema, a tool exists which can convert between the two versions. The editor is designed to be accessed using the UBhave server described in section 3.3.4 below, allowing quick deployment of interventions.

Backbone.js is designed to be used to maintain a persistent state in a model-view-controller (MVC) style, using objects called *Models* and *Views* (a *View* combines the notions of view and controller in MVC). Within the editor, Backbone *Models* are used to remember the structure of the intervention. This provides an easy means to convert the intervention into a JSON file: by converting each *Model* to JSON individually and combining them.

The editor was developed by a student, Chris Baines, over the summer. It has a responsive and intuitive interface but since the project is still in its initial stages, it can be sometimes found to be somewhat buggy and incomplete. Chris has continued to provide support and fixes over the course of the project.

It should be noted that the JSON format used for intervention files is more expressive than the editor itself. The limitations in the editor are deliberate to make it easier to understand, such as presenting a ‘tree’ structure to the intervention developer rather than the real graph structure within the JSON file. These limitations mean that it could be necessary to manually edit the JSON files themselves in order to use certain features.

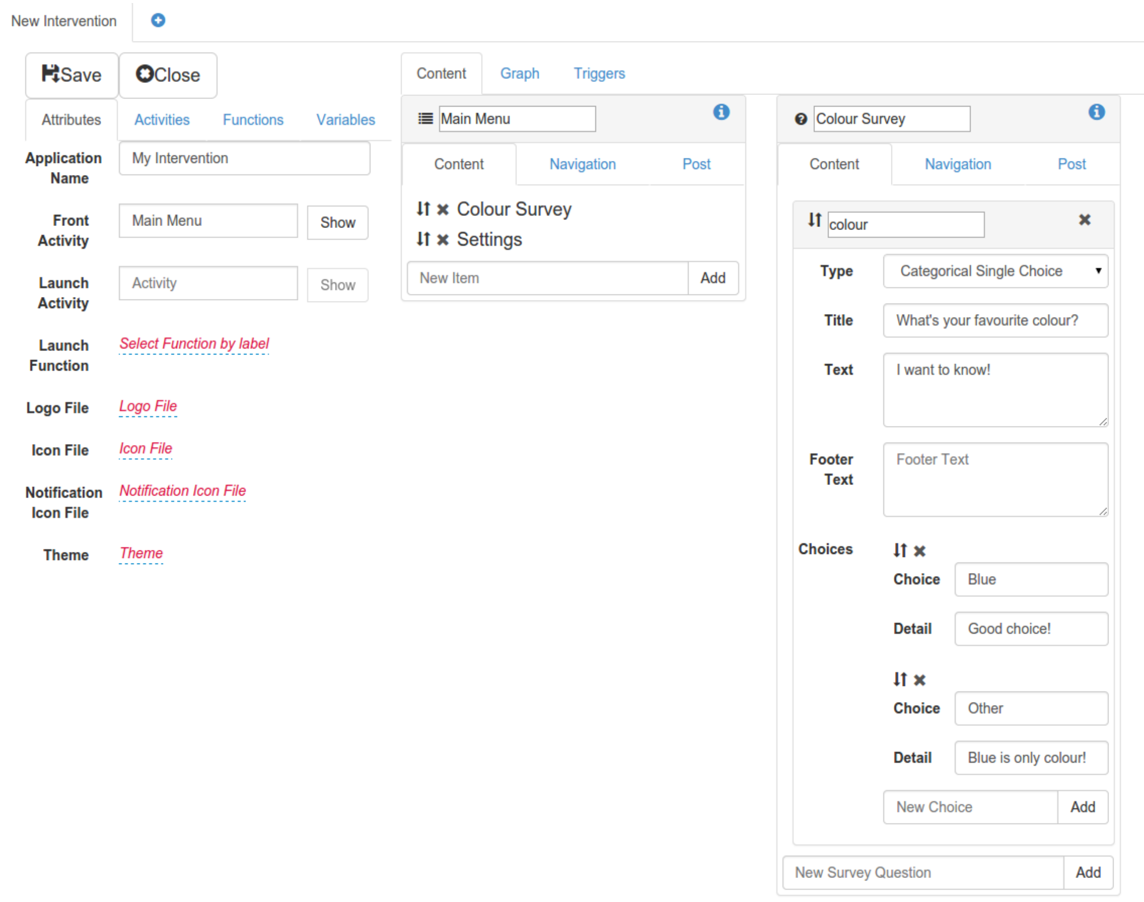

Figure 8. The intervention editor

3.3.3 Existing Client Codebase

There also exists an Android application to run the intervention files generated in JSON from the intervention editor. This application can either download the JSON file plus resources, such as images and media files, from the remote server, or have these files pre-loaded, in an .apk file to be installed and run. When the application starts, the *DynamicApplicationController* class parses the JSON file, extracting the name of the intervention with any other icons or themes attached, which are then displayed on the main menu of the application. In the next step, it opens the first content object in the array of contents, checking the type of activity. Depending on that, the relevant activity *Controller* object is then created and passed over the content. This *Controller* parses the content JSON and fills the activity models with the relevant information. It is also responsible for handling the flow of the activity, taking various actions depending on the request code returned, which could be asking to return to the main menu, or notifying the controller that its activity has finished.

The information in the model objects is parcelled so that it can then be sent to the display classes for that particular activity; this is done by a *Loader* class. Once the *StaticActivity* class receives these objects, it displays these on the screen to the user in ways determined for each activity. Once a certain activity finishes, the *ActivityController* returns control to the *DynamicApplicationController*, which can then either run the next activity in the array (this would be in the case of having a *Sequence* activity) or take the user back to the main menu, if present. Apart from that, the application regularly connects to the remote server, uploading user answers from survey questions, if they exist, while also logging in other usage data.

There are also classes present to parse and interact with the functions and navigation attributes of the intervention. These generally extract the information from the JSON file, and store the variables and values set by the user in an easily retrievable and changeable global look-up table. Additional complex features also exist such as making use of the notification triggers set by the intervention author as well as determining, with machine learning techniques, what the best time might be to notify or remind the user to perform a certain task with the help of the application.

Pictured below are some of the screenshots taken of different activities as displayed on the Android application.

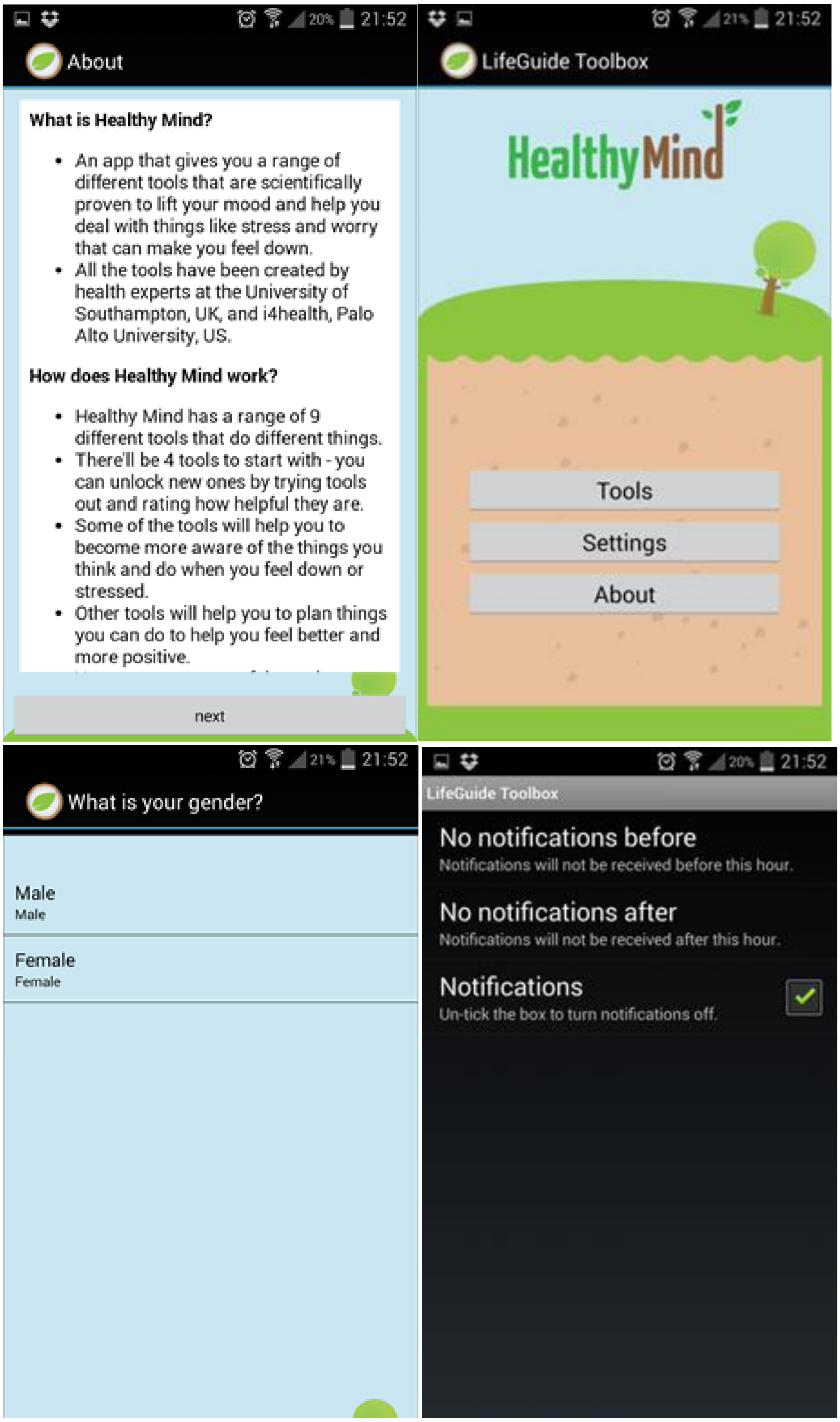

Figure 9. A number of Android application screenshots (From left to right) (i) an Info activtiy (ii) a Menu activity (iii) a Survey activity question (iv) a Settings activity

However, this application is still in active development so continuous work is being done to improve the code structure as well as optimising different procedures and methods. Additionally, while there exist methods to retrieve media files from the resources folder, there doesn't exist any sort of functionality to play these audio files. This implies that in its current state, the application cannot run an intervention containing a hearing test with audio files needed to be played.

3.3.4 Existing Server Codebase

In order to support interventions deployed via the cloud the UBhave framework has a server component. The server allows users to create and edit interventions using the dynamic editor. The server is written using PHP and supports uploading resources to be used in interventions. It uses MongoDB as its database, this is because as a NoSQL DBMS it can make up part of a distributed system for interventions with very high loads in order to support large scale digital behaviour interventions.

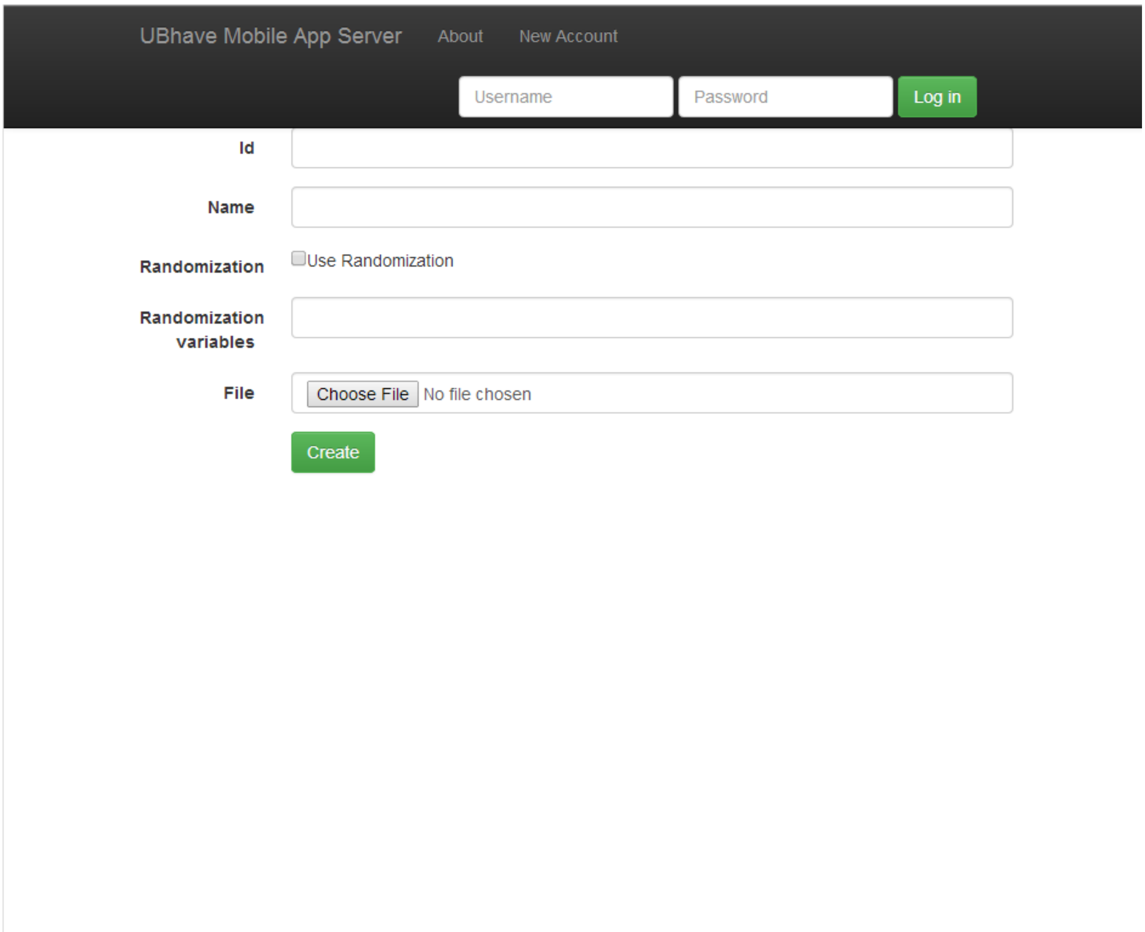

Figure 10. Screenshot of the server application page

The screenshot above shows an example of creating an intervention with the Mobile App Server. After creating the intervention it can be edited using the dynamic editor which is integrated into the server as a git submodule. The server also supports randomization for clinical trials, but this feature is not required for the project..

3.3.5 Triple Digit Test

The exact process used in the Triple Digit Test varies between implementations. The unchanging factors in the test are as follows:

- A single round of the test plays three monosyllabic digits along with noise, with volumes arranged so as to produce a particular signal to noise ratio (SNR), measured in decibels.
- A candidate enters the three digits they think were spoken.
- A round is marked correct (passed) if all three digits are correctly identified and incorrect otherwise.
- Multiple rounds are played with differing SNRs.
- The result of the test, the Speech Reception Threshold (SRT) is the SNR at which the candidate gets 50% of rounds correct.

The remaining details that vary by implementation include:

- What SNR to start with
- What range of SNRs to include
- What precision (smallest step) of SNRs to use
- How to navigate through the different rounds
- When to end the test
- How to establish the 50% SNR threshold from the results

3.4 Requirements

From the analysis it appears the most significant group are the cochlear implant users. These users need an Android application with a simple interface, allowing them to carry out the three different functions discussed above.

The requirements of intervention application are:

A. Allow users to answer cochlear implant questionnaire.
B. Allow users to request spare/new parts for their implant device.
C. Allow users to take a hearing test.
D. Play media files with varying audio to model a hearing test.
E. Analyse user responses to pinpoint a user's Speech Reception Threshold.
F. Show result of the hearing test to users.
G. Provide a simple user interface.
H. Follow good user experience practices.

The other group also requiring attention consists of the doctors and psychologists working the editor to create interventions, who would benefit from guidelines and support. Lastly, the developers who will work on the system in the future should be taken into consideration.

The requirements of the intervention editor are:

- Provide functionality to allow user to create the aforementioned intervention for cochlear implant users

- Provide features to allow user to create suitable test to measure hearing ability
- Allow these features to be used in other conditions
- Provide guidelines and helpful explanations to using these features
- Have a simple user interface
- Follow good user experience practices

3.5 Scope

With functional and non-functional requirements for both the intervention application (via the Android client) and Web-based editor now in place, it was necessary to determine and define a suitable extent of scope for the project in conjunction with these results and the initial project description supplied by the original client, a representative of UBhave, at the start of the project (Appendix A). Although at the time this description was supplied the additional client of the ISVR centre was not in place, the time and resources available for development still needed to be assessed in light of the renewed goal of developing a mobile intervention application.

However, given the open nature of the initial description and on the basis of early meetings with the Project Supervisor, where it was suggested that time might be split equally between development of the framework and Web-based authoring system and its eventual hearing test application, the focus of work remained unconfirmed. It was ultimately decided that the overall goal of the project would define its minimum scope, allowing it to be considered a success in the case that an intervention representing the hearing test was produced, but solely on the condition that it was achieved through the intervention editor (thus reconciling our two initial project objectives).

It naturally followed, therefore, that extensions to the editor and Android client went on to be made through iterative development in an agile-inspired spiral development model on a largely as-needs basis, with implementation content dictated by the demands of the target intervention application. The most salient example of this was the addition of media file support to both the editor and client, so that they might eventually be included in the construction of the hearing test intervention and thus contribute towards the success of the project in its limited timeframe.

Any further extensions or bug fixes of the authoring system and Android client would be considered outside of the overall project scope, but with the tool being used to produce the mobile intervention, were still relevant and useful in the context of the final result.

3.6 Proposed Solution

The intervention editor will allow users to create a complete intervention for cochlear implant users with the provided features. The questionnaire and item requests will be completed with the already existing features while the newly-added features will allow the user to successfully model a hearing test with the use of audio files. Should the user run into trouble while designing the intervention or get confused with any feature, helpful explanations should be present to answer questions.

The intervention application will be a simple Android application which runs the intervention created on the editor, providing the user with three options: answer questionnaire, request an item or take the hearing test. On each of these options, the required activity will start and provide the prompts highlighted. The hearing test will play the audio files with the determined settings and perform real-time analysis to calculate the user's hearing proficiency, providing them with relevant advice.

This project will create the custom intervention using the editor and run the resulting intervention on the intervention client.

3.7 Decisions

As this project was started in the summer, decisions about programming languages, storage, frameworks have already been made. This project will be adding extensions using those choices. Instead, this section will focus on the chosen tools and software methodology.

3.7.1 Tools

The development of the intervention editor was carried out with the help of the Sublime Text 2 text editor, which provided useful syntax highlighting and sophisticated editing tools. Google Chrome was used to view changes made to the editor as well as debugging the code to fix errors.

For the Android application, the Eclipse IDE was used to work on adding the required additional features and for debugging purposes. To run the Android client, the authors used their personal Android devices.

3.7.2 Software Methodology

An iterative approach was taken with this project. Initially, the project was divided into three iterations. The first iteration comprised of adding the required features necessary to model the noise test in a very basic format and also adding functionality to the client to run this activity. This allowed a better understanding of how to improve the initial design and compensate for any limitations present on either of the systems. The second iteration then aimed to improve on these initial designs with knowledge gained from the initial iteration and complete the proposed design on both, the intervention editor and the intervention client. The third and final iteration consisted of using these features to create and run the custom cochlear implant intervention, which is later evaluated. After each iteration, requirements and design were reviewed.

4 Project Management

4.1 Team Communication

In order to coordinate the team, a private Facebook group was made. Because all team members own smartphones the Facebook notifications can be viewed in any location. Also, because some team members kept slightly nocturnal working hours they could view a record of what was said at any time. In addition the team used a shared Google Drive: when any documents were made or used by the team they were uploaded here.

The group also kept regular meeting with the project supervisor Mark Weal to discuss progress with the project. This was planned in addition to weekly team meetings that were organised for every Monday afternoon without Mark. Prior to these meetings, an agenda was passed around to all team members highlighting the points of discussion; at the end of the meeting, the written minutes were added to the Google Drive.

4.2 Time Management

During the planning phase a Gantt chart was constructed to predict time on each task. Then, at the weekly meeting the Gantt chart was updated to show project progress. During Semester out of four modules each team member was scheduled to complete, two were timetabled for this project and two were timetabled for individual modules. Thus each team member aimed to spend half of their time on their other modules and half of their time on this project.

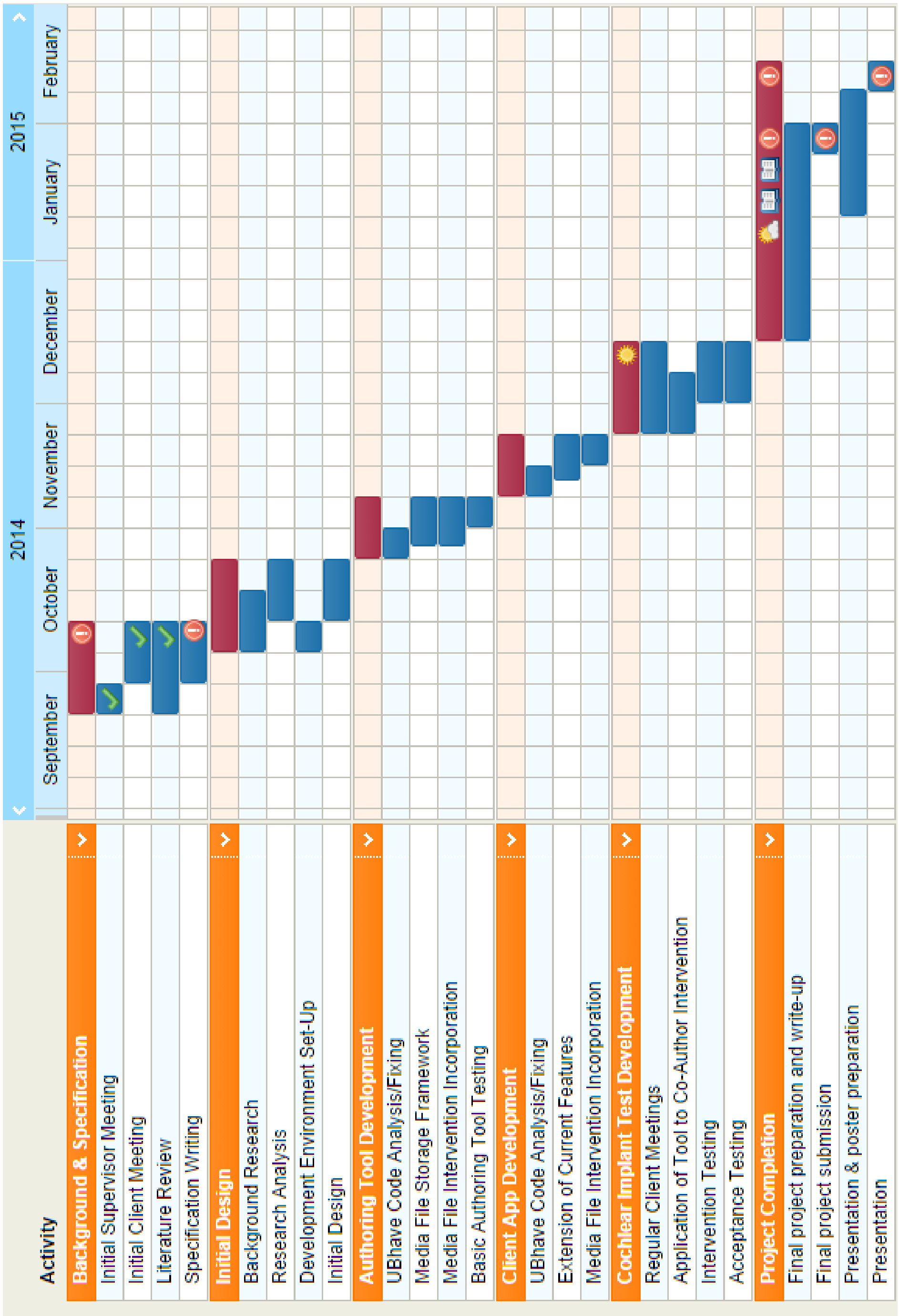

Figure 11. Initial Gantt chart

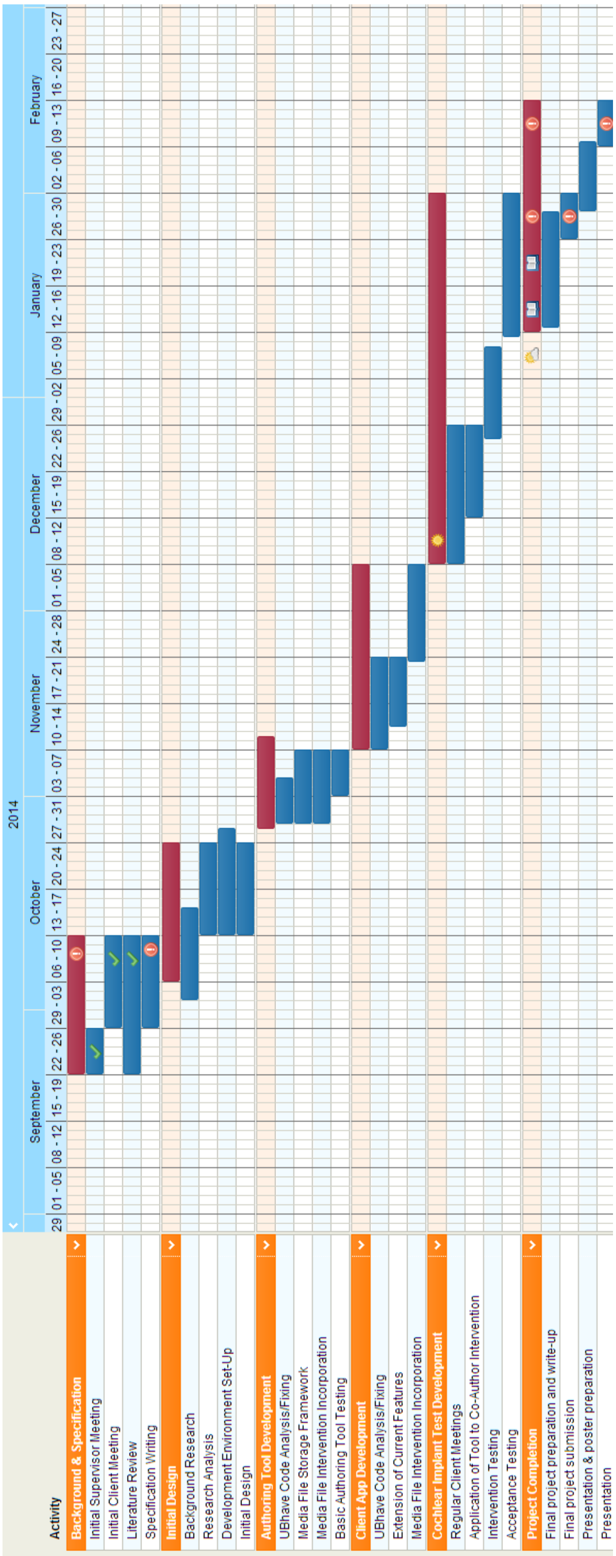

Figure 12. Final Gantt chart

After comparison of the two Gantt charts, it can be seen that the team took a month longer to conclude the project; the initial Gantt chart was made with the intention of completing all development before the Christmas holidays and allow for focus on the report for the latter stages. However, due to unforeseen circumstances, a few team members were rendered unavailable which meant that work could not be carried out at full capacity during the semester. Moreover, it should also be notes that a great deal of initial effort went into getting familiar with the systems of the project, and overcoming this extreme hardship was also greatly time consuming.

The delays caused by the problems mentioned above led to a cascading effect which pushed everything a few weeks forward, which led to finally completing the implementation of the project at the end of the Christmas break and overlapping report writing and evaluation being carried out. Because team members were busy with exams in early January they were unable to find the time to work on the report. In hindsight it was unwise to assume the report could be written in exam weeks, this delayed the start date of the report writing process.

Nevertheless, the initial project plan was designed to be extremely flexible, with the assumptions of possible hiccups and hitches occurring. This allowed the team to plan a conclusion of the project before Christmas and hence was able to make up for lost time with the additional month left free with the first project plan.

4.3 Project Contribution

Because the project was developed over many different systems it was vital to allocate team members according to their strengths. To do this a skills audit was run where each team member identified a series of skills at which they were adept and also the fields they were interested in. Two team members (Ben and Felix) had experience with machine learning, whilst not a field directly applicable to the project, it suggested the ability to write complex code and analyse large data sets.

- Ben
  - Machine Learning
  - Audiology
  - Medical computing
- Felix
  - Machine Learning
  - User Interface Design
- Robin
  - User Interface Design
  - Report Writing
  - Customer interaction
- Michael
  - Data Visualisation
  - Web Development
  - Software Testing (worked as a tester for mobile app company)

- Ali
    - Web Development
    - Data Visualisation
    - Automation
    - Team management
    - Android Development

Using these skills, each team member volunteered to take on an aspect of the project. This meant that none of the team members were unhappy with their allocation, as it was of their own choosing, allowing for greater cohesion and teamwork. There was also a slight rotation policy implemented such that if a team member wanted to work on another aspect of the project, they could easily do so. This would help them increase their knowledge in another field and also decrease the chances of the project failing if one team member became unavailable; since almost everyone rotated around, they could fill in for each other effectively.

Task	Skills Needed	Member Allocated
Project manager	Team Management	Ali
Client developer	Android Development	Ali
Server Developer	Web Development	Michael
Editor Developer	User Interface Design	Felix
Tester	Testing	Michael
Hearing Test Research	Audiology, Medical computing	Ben
Documentation	Writing	Robin
Customer Contact	Customer Interaction	Ben
Report Editing	Report Writing	Robin

Table 1. Initial and major project allocation and task division.

The overall division of sections on this report can also be seen below:

Members	Sections
Ben	Introduction, Literature Review, Analysis, Design, Evaluation
Felix	Analysis/Specification, Design, Implementation, Evaluation
Michael	Literature Review, Analysis, Project Management, Evaluation, Conclusion, Abstract
Ali	Analysis/Specification, Design, Implementation, Evaluation, Conclusion
Robin	Introduction, Literature Review, Analysis, Project Management

Table 2. Division of section writing between authors

4.4 Project Costs

During development it was clear that the team would need android devices in order to be able to run and develop the LifeGuide client. Whilst it would have been possible to use the budget to purchase phones for development, some team members owned several Android devices. In order to keep things simple and save resources, these spare Android phones were lent out to members without Android phones.

4.5 Project Tools and Techniques

To access the code all team members were added to the existing Bitbucket hosted git repositories for the UBHave project. By using git it was possible to create new development versions of the projects to allow for merging into the main codebase later. Because of the decentralized architecture of git, the repository was stored on all team members' devices, providing a very reliable backup mechanism. As all commits could be seen by all team members, everyone could keep track of code changes.

The client was written in Java with the Android Development Kit running on Eclipse. Whilst it would have been possible to use the newer Android studio for android development, when development started it was still in beta and used an incompatible build system.

A development server was provisioned running the server and editor components. Because it was only used for testing only a modestly specified virtual machine was needed.

4.6 Client Interaction

Our client Helen Cullington is clinical scientist specialising in cochlear implants. An initial meeting at the start of the project with Helen, Mark Weal and Charlie Hargood where the project goals were discussed, Helen explained the background of Cochlear Implants and Charlie and Mark explained details of the UBhave framework. The team then produced a formal specification (A) which was shown to Helen and approved by her.

Vital to the development of the intervention was each team member attending one of cochlear implant observation sessions set up with Helens help.

In addition to the User Assessment Test we intended to run some tests against a small number of cochlear implant patients. However, we would need a complex ethics approval to work with real life patients especially as the patients would have impaired hearing ability. Thus we used Helens assistance to submit an ethics application through the Institute of Sound and Vibration Research, as they have extensive experience with these kinds of studies. Unfortunately after submitting the application the response from the ethics board was delayed and we were unable to carry out these tests in time.

5 Design

After establishing requirements, work began on designing the structure of the system. All the possible uses for the features were determined and many different solutions were considered. Finally, a design was chosen for our selection.

5.1 Use Cases

5.1.1 Mobile Intervention

The uses for the application are simple. The user can either answer a questionnaire, take a hearing test or request spare/new parts. Each of these cases will also result in data being uploaded to the server, whereas taking the hearing test will also involve playing different audio files.

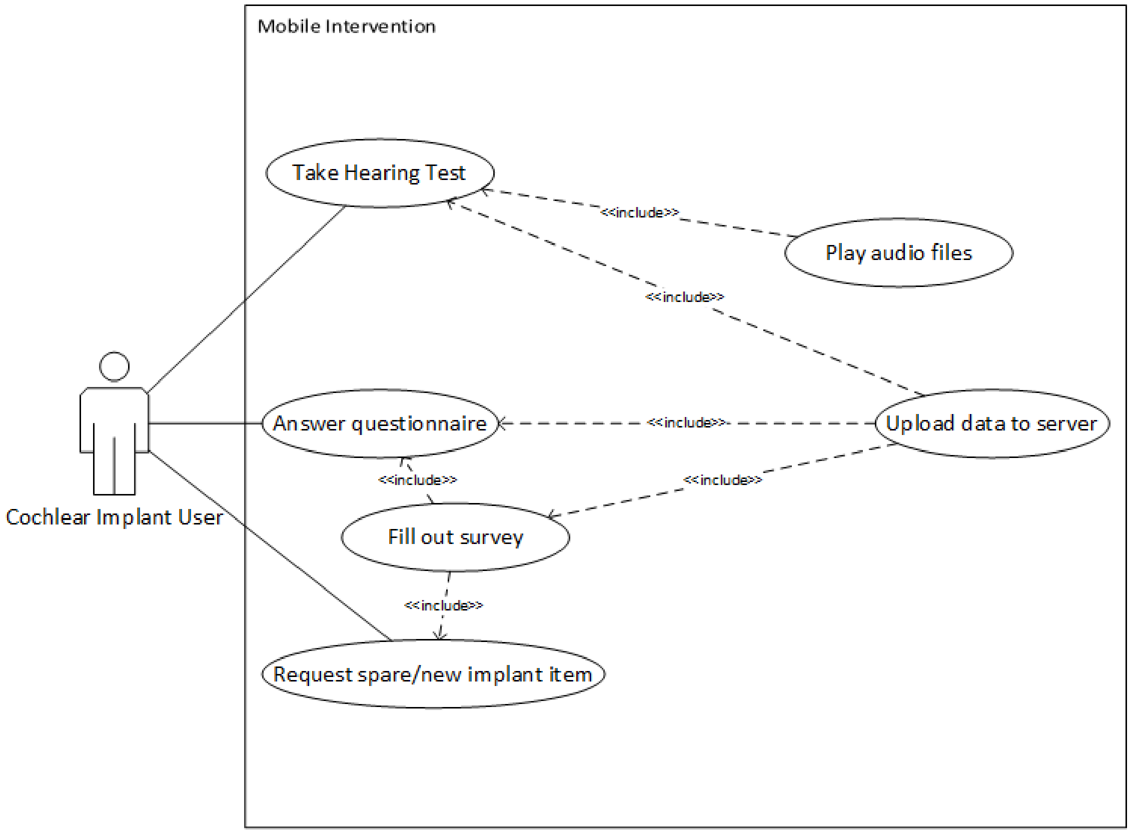

Figure 13. Use cases for the mobile intervention application

5.1.2 Intervention Editor

The uses cases for the editor relate to the new media activity. A user should be able to create such an activity and add media items to it, setting their properties.

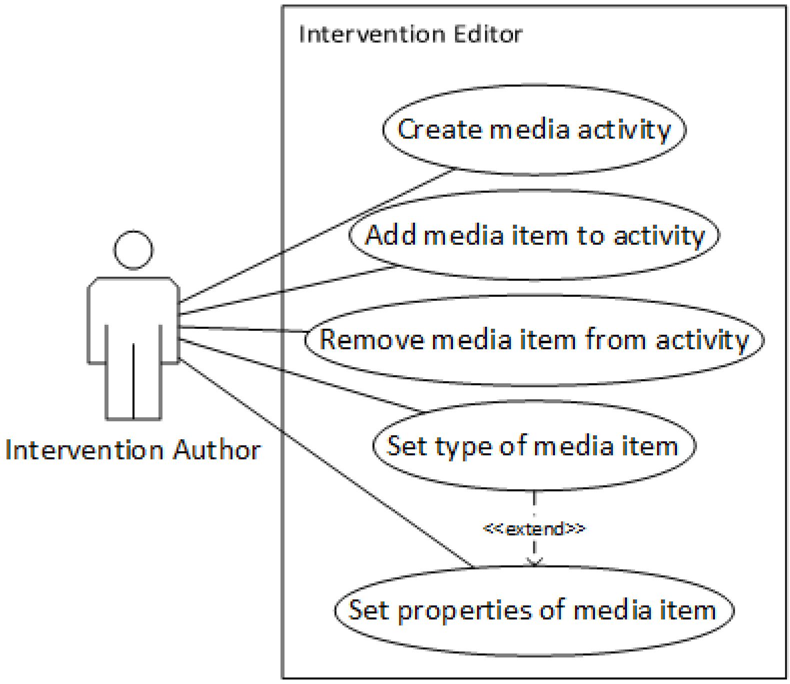

Figure 14. Use cases for the intervention editor

5.2 Modelling

5.2.1 Activity

Initially, creating a bespoke activity was considered which would specifically tend to the client's needs. This meant that a new 'Hearing Test' activity would be created, allowing users to add a number of media files, which could be randomly played with different volume settings, and the application would dynamically tweak these volumes and calculate to zero in on a hearing level. However, it was argued that such an activity would only ever be used once, defeating the purpose of a generic framework. Moreover, there may not exist features or functionality in the target devices to calculate extremely accurate values, the alternative was a solution that is general enough to easily cater to the needs of the client while also allowing others to utilise it. The solution should have a strong foundation, allowing it to be easily extended in the future.

Therefore, it was decided to create a generic 'Media' activity that allowed users to specify the file that they wanted to be played. This activity fits the criteria, as the intervention would be playing the audio file consisting of both the noise and digits being pronounced. Moreover, this activity would also remain useable to other intervention authors who might want to play another type of audio file in their activity for their own purposes. This way, the hearing test intervention can utilise other already-existing features available in the intervention editor framework: it can use the Survey activity to display questions, Info activity to display prompts and introduce information and use the powerful functions and conditional navigation features to model the hearing test logic.

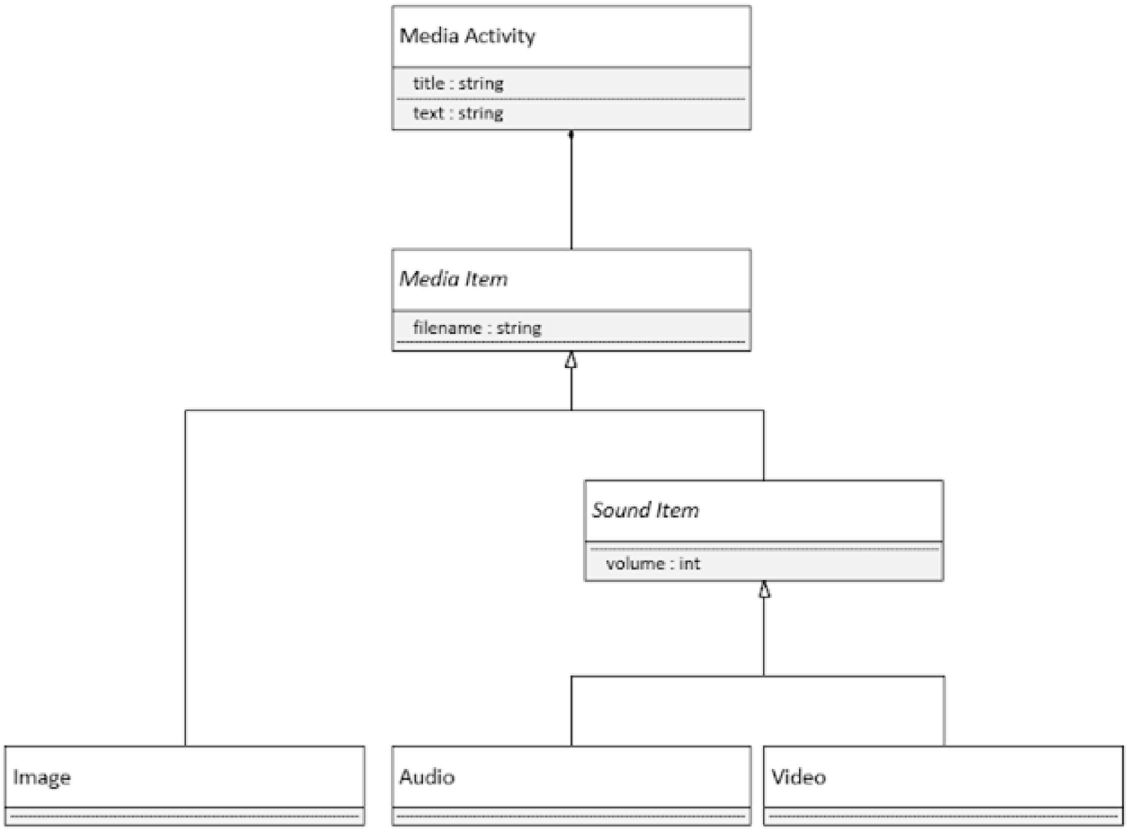

Figure 15. Class diagrams for Media Activity

The class diagram above gives the general way the media activity will be modelled in both the client and editor. A media activity contains several media items. Media items may contain a volume, if they are audio or video. The JSON representation used for intervention files does not support the notion of classes, so the approach in this case will be to record the 'type' of each media item and include a volume field based on that type.

5.2.2 Intervention

For the cochlear implant intervention there are three different features to model. The first feature is adult follow-up questionnaire, which involves asking questions to better understand and attempt to pinpoint any problems which may have led to problems with hearing. The questions will be taken directly from the existing paper questionnaire provided, but with some added improvements. These improvements are conditional questions depending on the user answers; as the current questionnaire is in a paper form, they ask the user to answer 'Yes' or 'No' to a number of questions and provide details if any of those questions have 'Yes' for an answer. Instead, the framework's conditional navigational powers can be used to add an addition detail question after each of these questions and otherwise skip it. This allows for an easier to understand and shorter questionnaire as well as have specific details for each type of question, allowing for even more accurate pinpointing of the problem at hand.

The second feature to implement is item request. Studying the aforementioned questionnaire, it can be seen that it is limited to only 6 items. Moreover, this questionnaire is only filled during a visit to the ISVR centre, meaning that if the user requires another piece before or after the check-up, they may not be able to contact services as quickly as possible. By adding a feature to request new/spare items, the user is able to easily request as many items as they may require. Moreover, conditional navigation can again be applied to check the type of processor the user may have and show them information corresponding to that specific processor.

The third and most significant feature to be implemented is the hearing test. This will be done with the help of the Survey activity and the new Media activity. In the next section the modelling of the hearing test will be discussed.

5.2.3 Hearing Test

The implementation of the Triple-Digit Test used by the RNID is "a closely guarded secret", however the client of this project shared the Matlab implementation used by ISVR. While this cannot be directly converted into an implementation that could be used in the application design, it gave a more detailed idea of how the test can function. That implementation was designed as follows:

- Start at high SNR (high volume digits, low volume noise)
- If two rounds at the current SNR are passed, SNR is decreased (harder to hear)
- If a single round at the current SNR is failed, SNR is increased
- At the start, increase / decrease SNR by 8dB
- If the direction of change of SNR has changed (last round was increased, this round was decreased or vice versa), halve the SNR step size unless it is already down to 2dB
- The test ends when two reversals have occurred *after* the step size has reached 2dB or when a total of 60 rounds have been run
- The mean and standard error of the SNRs at the final two reversals are then taken as the score

5.3 Wireframes

5.3.1 Intervention Editor

The intervention editor wireframes reflect the user interface of the existing activities. There is a wireframe for both iteration 1 and iteration 2 of the implementation.

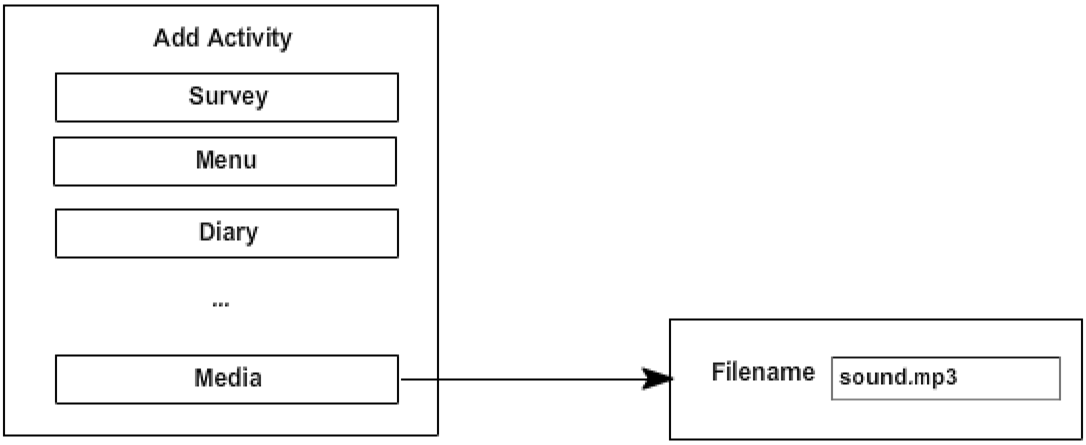

Figure 16. Initial wireframe diagram for Media Activity

This was the initial iteration design, which, as discussed in the Analysis section, was to allow for quick implementation and discovery of any hindrances. The final design is provided below.

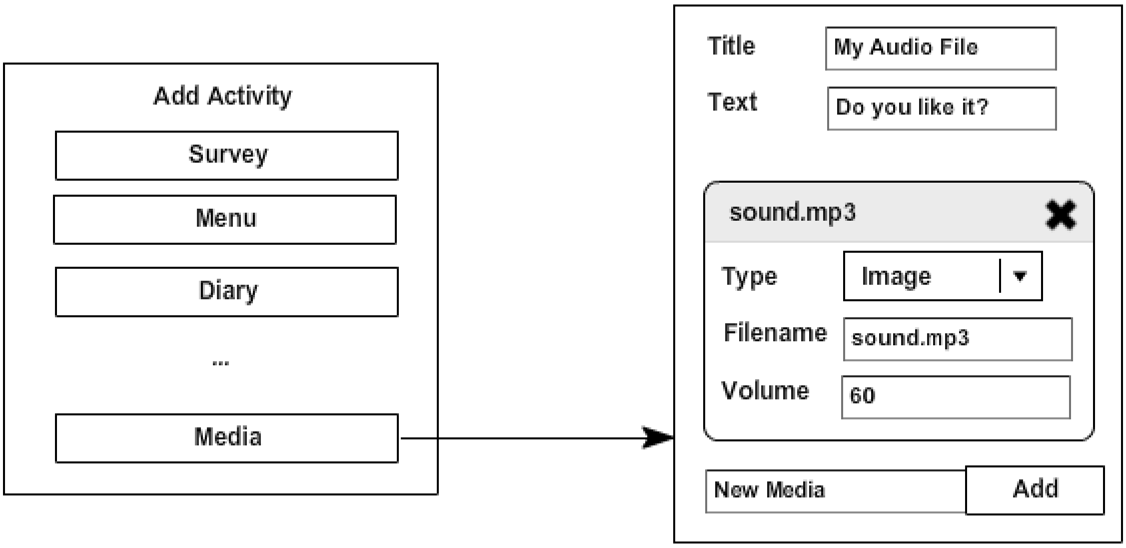

Figure 17. Final wireframe design for Media Activity

This design easily conforms to the standards set in by the rest of the features. Moreover, it also provides a clean interface to the user to allow them to easily add the required information. New media files are only added when needed, which doesn't clutter the interface. Lastly, volume can easily be manipulated by the user which allows for tweaking of the separate audio files.

5.3.2 Intervention Client

When designing the display of the application, designs patterns already in place for the existing activities should be followed. Moreover, it should be kept in mind that the majority of users will generally be older than 40, meaning they are likely not as technologically capable as the average user. This means that the design must be kept extremely simple for users to understand and follow, with a clean user interface and absolutely no clutter: only information the user needs to concentrate on is displayed and no other distractions to avoid confusing them, which is beneficial to not only older users but also all potential users of this activity. These thoughts allow the creation of the following simple design.

Figure 18. Wireframe mock-up of Media activity on Android device

This simple rendition of the Media activity allows the user to only focus on the play button and the attached information text displayed on the screen. This prevents the user from losing their focus, so they can quickly read the information and easily play the audio file using the big ‘Play’ button centred on the screen.

6 Implementation

This sections documents the path taken to build the system. It covers some of the underlying factors which influenced any decisions made and shows the evolution of the ideas behind the project while making the best system possible.

6.1 Initiation

To begin development it was first necessary to become familiar with the existing tools and code available to the team: the editor, server and mobile client. These are all fairly large code bases and so getting to grips with them took some time. None of the team members had any experience with Coffeescript or Backbone.js and only some had significant experience with Javascript, so team members had to learn these prior to adding or changing anything in the code.

6.1.1 Tutorials

Figure 19. CoffeeScript and BackboneJS tutorial

The team made use of numerous resources available on the internet to learn and understand CoffeeScript and BackboneJS. To get started, a brief introductory lesson was taken on Tuts[1] to understand the basic features of the language before moving on to further explanations as available on the main CoffeeScript website[2] and Treehouse[3]. Lastly, a small tutorial[4] was taken which combined CoffeeScript and BackboneJS which involved creating a small model, rendering a view for each model and implementing list items. This helped the team gain practical experience with the language. After these tutorials, the team continued to improve their grasp on the languages by working on the editor itself and trying out different functions to see how they work on the web application.

Figure 20. Implementation of Coffeescript and BackboneJS tutorial

6.1.2 Prototyping

After the team had an understanding of the languages and libraries a simple survey was developed in the editor, hosted on the server and then tested on the client in order to understand the capabilities of both the interventions and the existing tools.

[1] http://code.tutsplus.com/tutorials/rocking-out-with-coffeescript--net-17027

[2] http://coffeescript.org/

[3] http://blog.teamtreehouse.com/the-absolute-beginners-guide-to-coffeescript

[4] https://adamjspooner.github.io/coffeescript-meet-backbonejs/

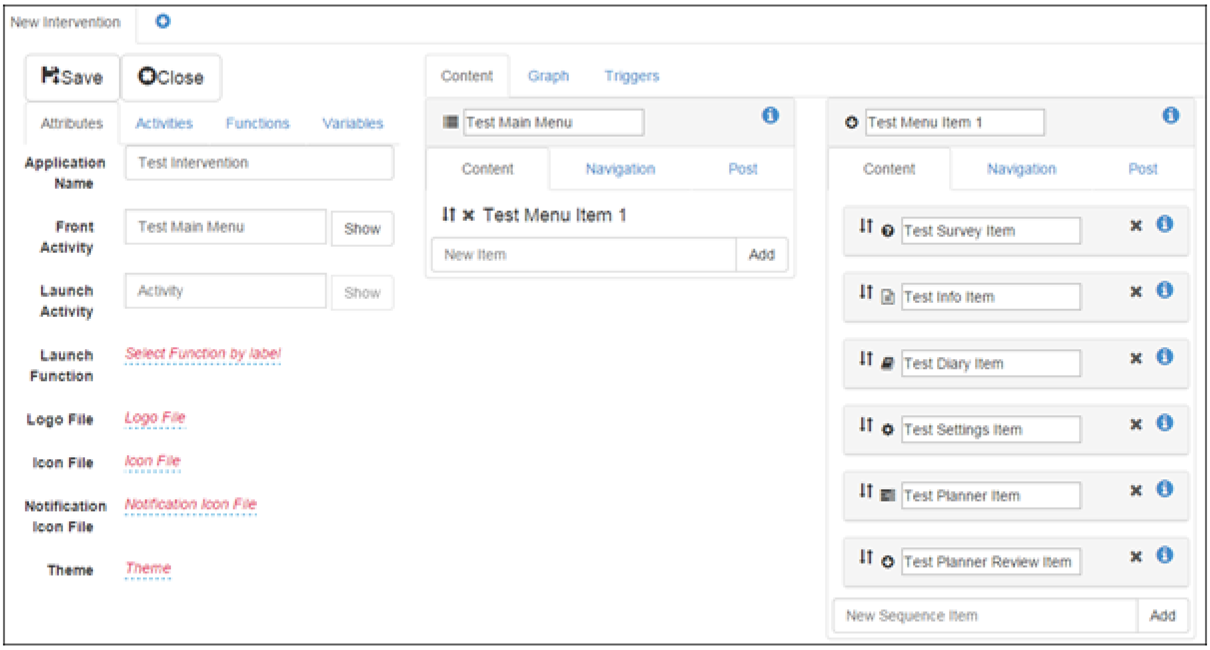

Figure 21. Screenshot of test activity created in intervention editor.

This foray into prototyping led the team to discover a number of features which had small bugs in them and those which had not been fully developed yet. This has been discussed in the generic improvements section later on.

6.2 First Iteration

Having worked through a number of tutorials to get up to speed with the framework languages and libraries, work on the intended implementation began. However, to allow for review and prevent overly ambitious changes, a very basic version of the Media activity was implemented initially. This meant setting the foundation and working through any potential bugs generated and fixing these before adding the remaining changes in the second iteration.

6.2.1 Editor

In the first iteration, a new activity was introduced to the JSON schema (both versions 1 and 2) called ‘media’ with a single filename field. Support was added for this in the editor by examining how other activities were implemented and using the same classes and methods. This meant that the new activity had consistent appearance and behaviour with the existing activities.

6.2.2 Client

To handle our media activity, other activity classes in the Android application were examined, and the general structure was replicated. The media package was divided into three parts:

1. *ubhave.dynamicapplication.media*, containing the controller to parse the JSON
2. *ubhave.dynamicapplication.media.data*, containing the models for our data

3. *ubhave.dynamicapplication.ui*, containing code to display the media activity and play the audio file.

The media controller parses the data and constructs a *Media* class out of it, which essentially contains the name of the audio file. This is then parcelled so that it can be sent to the *StaticMediaActivity* class, where a *MediaPlayer* instance is created and passed the name of the audio file, which is used to import the resource (i.e. the audio file). A static generic title and text is added to the display, along with a button to play or stop the audio file. The result of this can be seen below.

Figure 22. A single Media Activity instance on the intervention client

6.3 Second Iteration

The first iteration was successful without encountering any significant problems. This meant work could continue on the second iteration of the implementation, involving improving the initial models to fit the final model design. This was carried out on both the intervention editor application as well as the client application.

6.3.1 Editor

A single 'media' activity was sufficient for simply playing audio files, but to play both the triple digit test spoken part and background noise required that interventions support multiple, simultaneous audio files at variable volumes.

Therefore, the JSON schema was extended such that a 'media' activity was comprised of 'title', 'text' and a list of media items. Each media item included a 'type' and 'filename', with the type being one of 'image', 'audio' or 'video'. In the case of audio and video a 'volume' field was also added. The new media activity could represent a triple-digit test using two audio files, one being noise and the other being the three spoken digits. The noise level can be adjusted by changing the volume balance between the two audio files.

The new list of media files was implemented in the editor by the same method used to record and display lists of survey questions. This gives the user the capability to add, delete and reorder media files just like survey questions, as well as allowing expanding and minimizing each media item to reduce the amount of information on screen at once.

6.3.2 Client

As the model for the *MediaActivity* was changed, the client had to be modified to handle the new one. Therefore, a new *Audio* class was created, which contained the filename plus the volume to play at. Moreover, the *Media* class was given a type attribute which determined the type of media added. In the case of an 'audio' type, an *ArrayList* of *Audio* files is created, to cater to possibilities of more than one audio file being played simultaneously. Title and text attributes were also added so that the user could choose exactly what needs to be displayed on this activity. This modified class is then parcelled and retrieved by the *StaticMediaActivity* class later on.

In the *StaticMediaActivity* class, the *Media* object is received along with all the audio files that are needed to be played. Since an instance of the *MediaPlayer* object can only play a single file at a time, an *ArrayList* of *MediaPlayer* objects is created, the size of which corresponds to the size of the *Audio* files *ArrayList*. Each media player is assigned an audio file to be played, plus the volume level at which to play the file. When the 'Play Audio' button is pressed, the client iterates through the *MediaPlayer* playlist, playing each audio file, resulting in the different audio files playing simultaneously.

6.4 Third Iteration

In the third iteration all features required to create the intervention were complete, so focus shifted to the intervention itself. This meant constructing the cochlear questionnaire, the item request and the hearing test using the intervention editor.

6.4.1 Cochlear Questionnaire

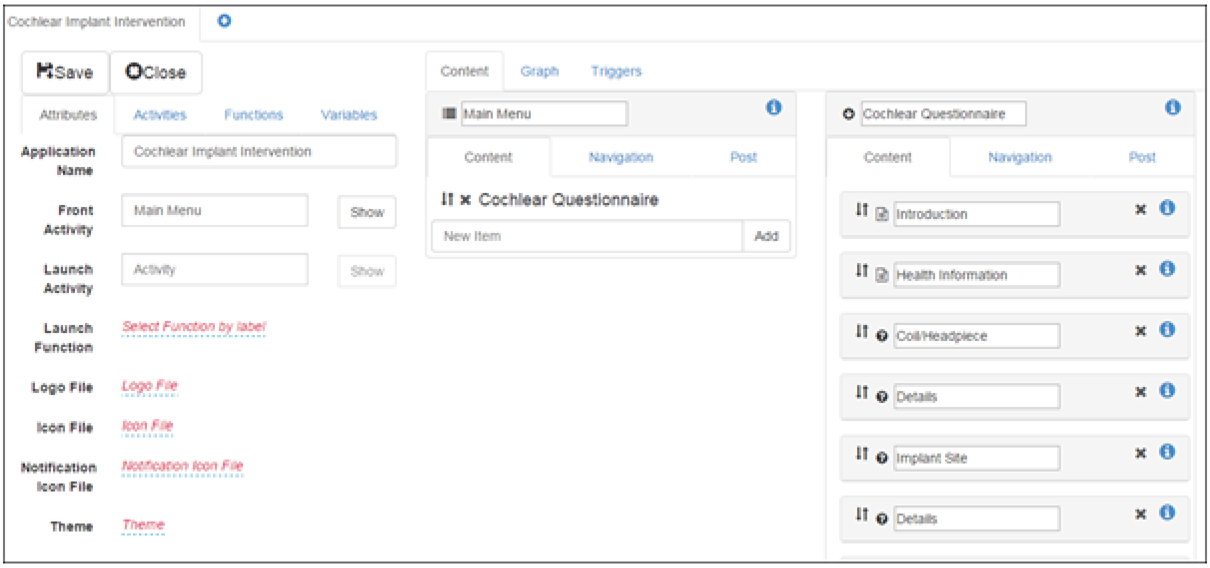

Figure 23. Screenshot of the cochlear questionnaire activity

As discussed before, conditional flow of content for the cochlear questionnaire was implemented, meaning the intervention would only ask the user to provide further details if they have a problem with the implant. This is showcased in the first question, which asks if the coil/headpiece is comfortable on the users heard. The next section, which is a details survey activity, is only navigated to if they user has answered ‘No’ to this question. This logic was applied to all the questions from the follow-up questionnaire which would have required further details.

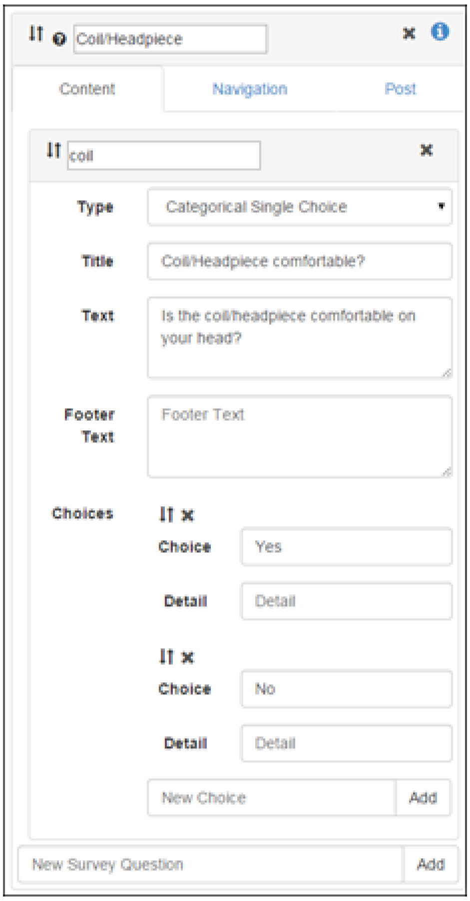

Figure 24. Screenshot of the coil/headpiece question

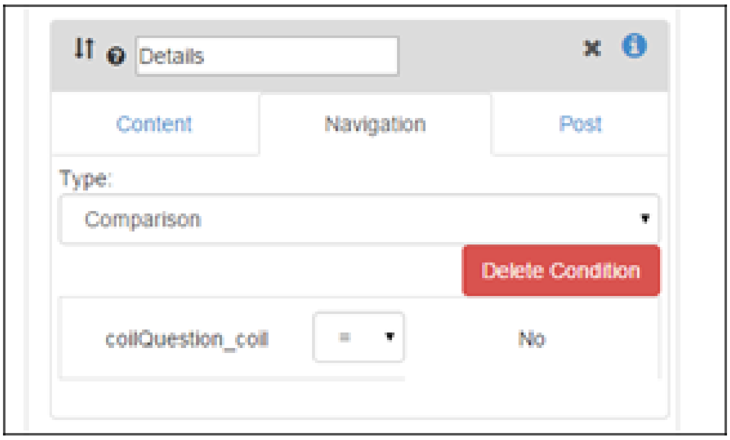

Figure 25. Screenshot of the conditions for the details question

6.4.2 Item Request

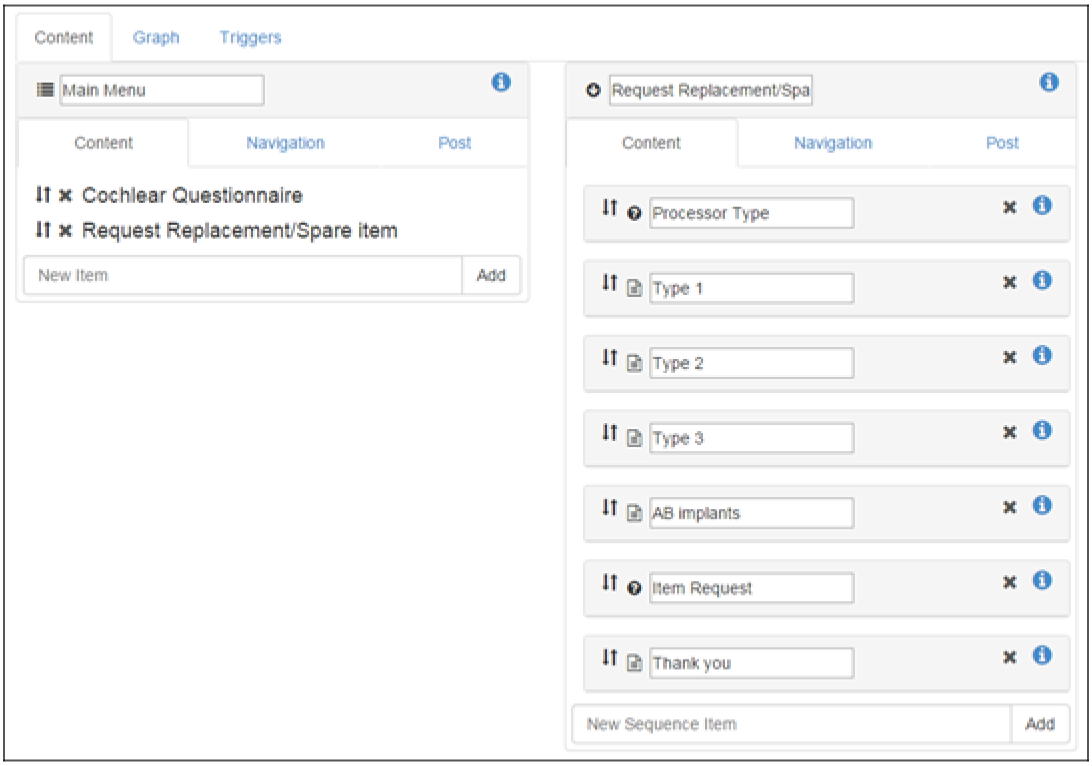

Figure 26. Screenshot of the item request activity

A similar logical and conditional navigation was also applied to the item request section. There exist a number of different processor types and those are to be handled differently. These were divided into three types and logic was applied to each type and corresponding to the processor type, the appropriate information activity was shown. Type 1 consisted of MED-EL, Cochlear and AB Neptune processor, type 2 consisted of AB Harmony and type 3 was the Neurelec processor. Out of these, AB processors requests are cannot be fulfilled by ISVR, so we only allow the user to put in a request if they do not have an AB processor, giving them directions to contact AB if they do.

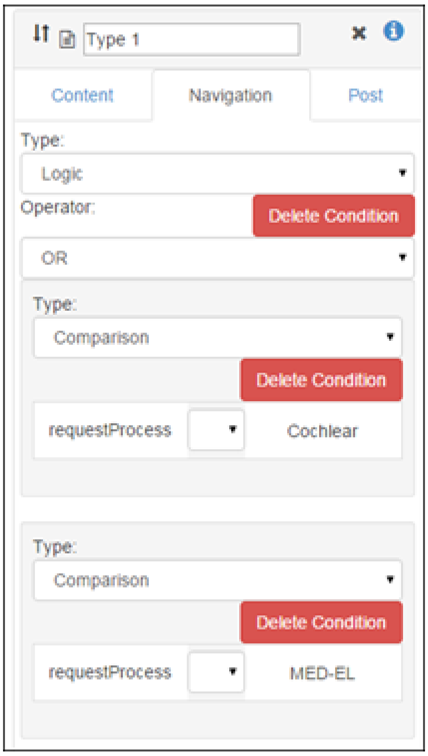

Figure 27. Conditional formatting on processor type

6.4.3 Hearing Test

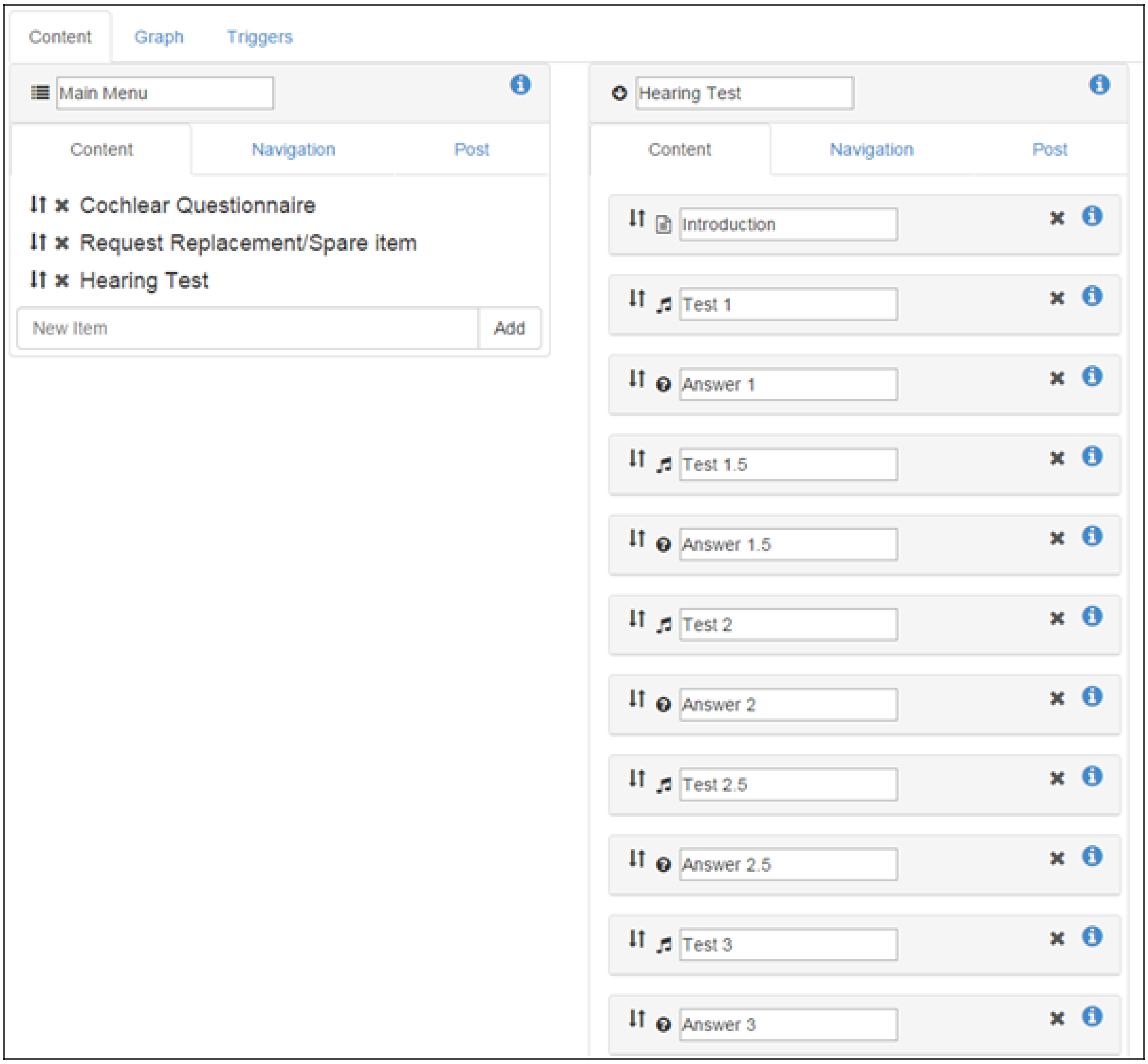

Figure 28. Screenshot of Hearing Test activity

As discussed in design above, a prototype of the triple digit test was initially developed. As this was a small prototype to be used, the number of tests was decreased to a maximum of 20. At the beginning of the test, a hearing level variable is created and set to 1, corresponding to each multiple of 10 for the volume of noise in our test. Each hearing level consists of two tests in succession. If the user answers either one of them correctly, the level is incremented once. If they are not able to answer either of the questions correctly, they move on to the result screen, where they are given the previous hearing level, since that was where they had at least 50% of the answers correct. This would be true since they needed at least 50% correctness in the questions for a particular noise level to progress to a higher one.

At the result screen, there are three thresholds, divided into groups of 1 – 3, 4 – 7 and 8 onwards. If the user noise level is between 1 and 3, they are told that they should come in for a check-up. If it is between 4 and 7, then they are told that their hearing is relatively okay and if the level is greater than 8, then they are told that their hearing is fine and they do not need to come in for a check-up.

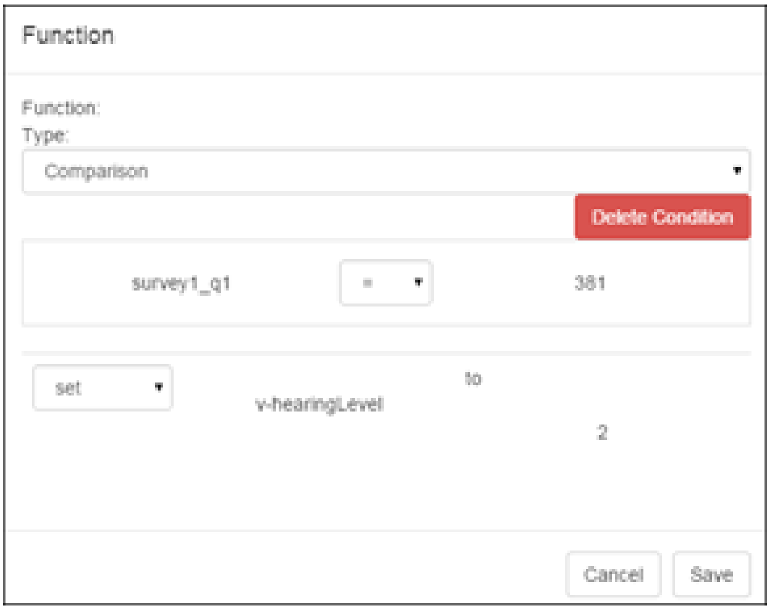

Figure 29. Function logic on hearing test questions

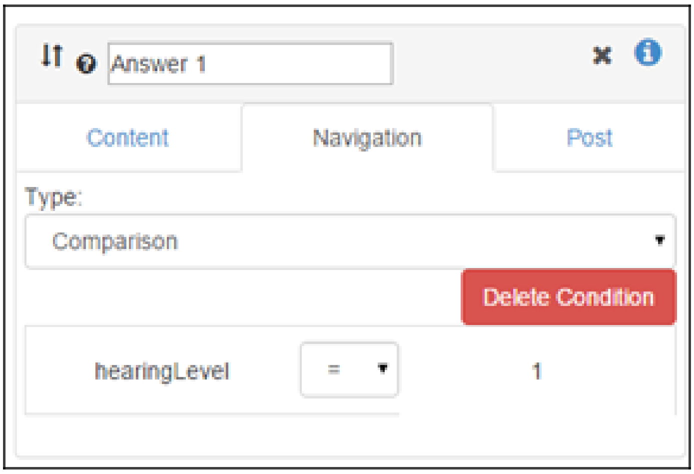

Figure 30. Navigational conditions depending on hearing level

6.4.4 Intervention Application

Ideally, the application should be easily available to be downloaded by users and run as-is, which also helps with the testing and evaluation. Therefore, the application consists of the intervention file plus the audio resources. The application was created by adding these resources to an Android project on Eclipse, generating an .apk file which runs the intervention.

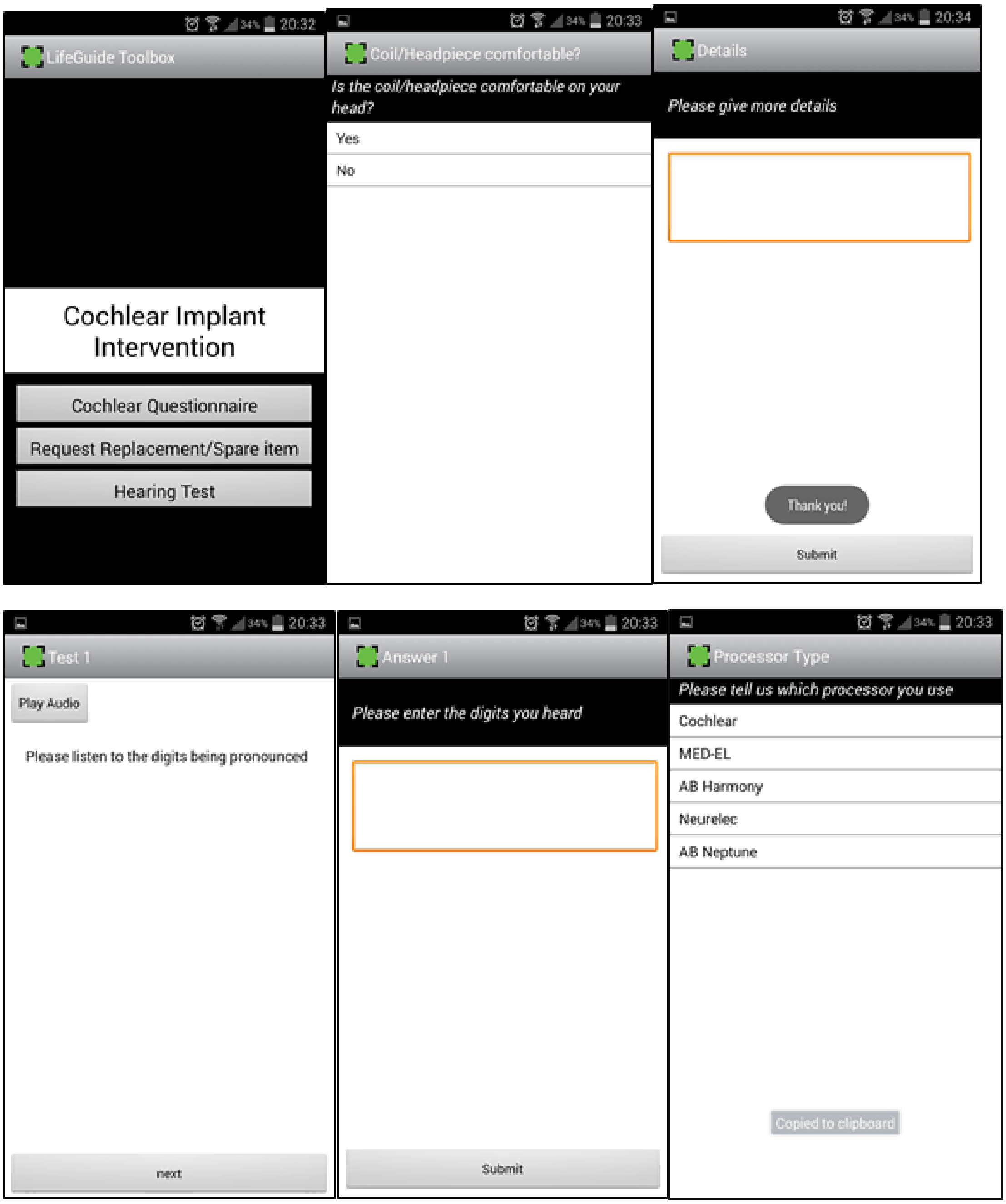

Figure 31. Screenshots from the Android client (i) Main Menu (ii) Question from Cochlear Questionnaire (iii) Details on the question (iv) Media Activity from Hearing Test (v) Answering a Hearing Test question (vi) Question from Item request

6.5 Documentation

Given the group's previous travails in attempting to acclimatize to development of the pre-existing codebase, and the large amounts of necessary background research and interaction with previous developers this incurred (slowing both parties' progress), it was decided that experiences and knowledge of it accumulated, particularly that which stemmed from its architectural theory and using the editor, ought to be documented. This would have the additional benefit of maintaining the forward momentum of the UBhave project beyond the Group Design Project, as it would not only permit future teams to be able to pick up previous work and theory quicker, with all collated information in one location, but also further appeals to our primary goal of making the system as accessible as possible to behavioural psychologists seeking to create their own dBCIs through the tool.

Discussion arose as to the best way to present this information, with suggestions such as an in-editor help overlay tool (both textual and graphical) as is featured in many applications. However, these were dismissed due to the depth of the editing tool itself, as a help tool may only serve to clutter an already-full screen. It was therefore decided that, in parallel with its associated *LifeGuide* project, the best course of action would be for one group member to document UBhave in a Wiki format (Figure 30).

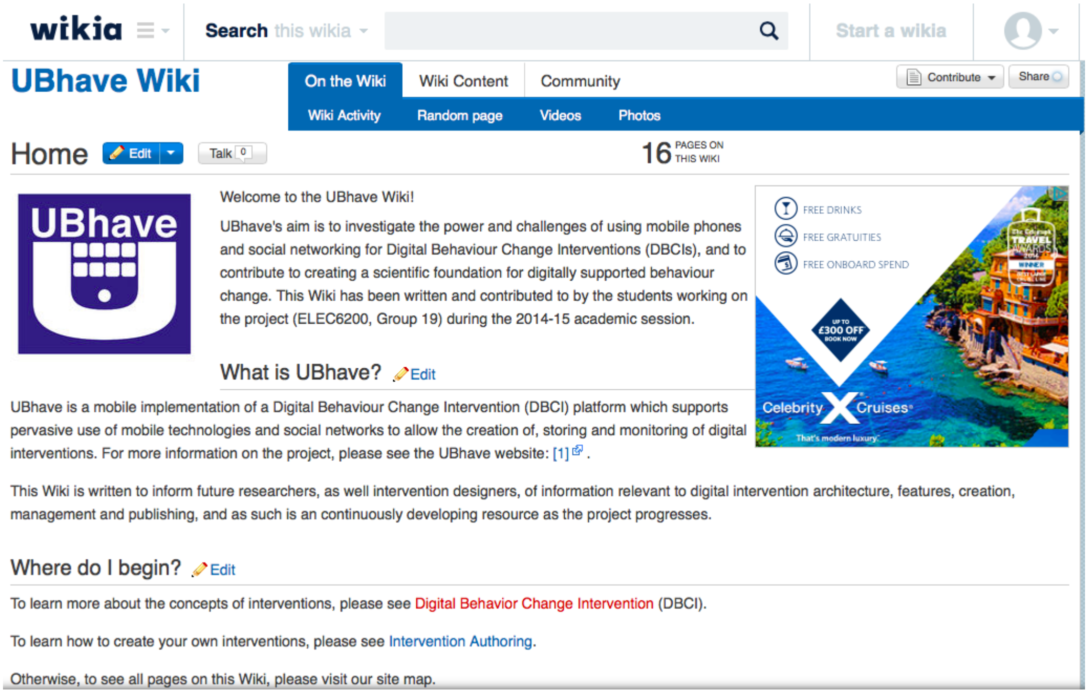

Figure 32. The front page of the UBhave Wiki under development (UBhave Wiki, 2015).

Structure of the Wiki at first was due to be in accordance with that implemented by the *LifeGuide* Wiki, from which inspiration was drawn (LifeGuide Wiki, 2014). However, initial attempts to write for the Wiki were frustrated due to lack of clarification of target audience; whereas some articles were read like helpful 'How-To' guides and were titled as such, for example 'How to create your first intervention', others were more akin to the typical theoretically-structured Wiki style, the equivalent being a subsection of the article 'Intervention authoring.'

This difference may only be minor, but its presence meant that the target audience of the documentation was often confused in early information gathering, leading to clunky and inconsistent presentation with some pages, for instance, intended to feature pictorial guides in contrast with those that were purely textual. It was therefore reconciled that the primary audience of the Wiki would be future developers of the project, as they might then be able to infer sufficient information from it to improve it and produce a more accessible set of documentation for behavioural psychologists and end-users in the future.

Additional problems also arose in the compilation of some knowledge, for example in identifying the function of several of the Activity types when online documentation was scarce. This was rectified through either contacting alternative developers on the UBhave project, or by using the intervention editor as a testing tool, creating 'dummy' interventions to test these individual sections of functionality on a mobile device, and hence infer their purpose.

Although currently incomplete due to prioritization of report-writing towards the end of the project, information for the Wiki was thus collated across its duration on the writer's personal system, and continues to be formatted suitably and contributed to the Wiki at the time of report submission. Expected completion of the resource is therefore to be rapidly worked towards following submission of the report.

6.6 Generic Improvements to the framework

As many aspects of this project had been rapidly developed over the summer and numerous were still under constant development, a decent amount of time was spent fixing errors and improving the framework. Errors were found generally when creating dummy interventions for practice and exploring the features of the editors. Whenever possible, the whole application was debugged in a step-by-step process, narrowing in on the particular bug breaking the system and quickly fixing it.

However, in the times that this was not possible, the authors endeavoured to add issues faced to the project bug tracker. This meant that if it was not viable to fix the problem, other developers working on the system were made aware and would manage to solve these problems as quickly as possible.

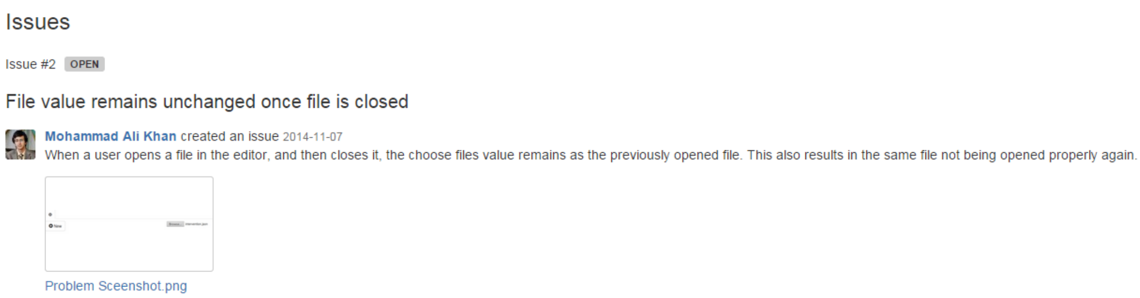

Figure 33. Adding issues to the bug tracker

7 Testing

With the implementation complete, it was necessary to verify the newly-extended systems. This was to ensure that the added features had not disrupted other previously working components and would not fail if pushed rigorously to the limit.

7.1 Methodology

The system relies on both the UBHave client, the intervention editor and the implant intervention itself. However, the two systems in use to create, manipulate and access the intervention were the former two, these were the systems tested with a number of techniques.

7.1.1 White Box Testing

During the development of the features in the client and editor applications, white box testing was thoroughly carried out to ensure that the application took the right steps to deal with the new features. In case of the intervention editor, the Chrome browser debugger was used to step through the added methods when they were called to ensure that the correct actions were being taken. A similar approach was applied to the client application, this time using Eclipse to step through the process of parsing a Media activity, creating audio classes and playing the audio files on the screen.

7.1.2 Black Box Testing

While white box testing ensures that the logic in the program is correct, black box testing was further employed to verify the end results of our applications.For the intervention editor, this generally meant studying the generated json file to make sure none of the attributes were misspelt and that the json object was correct. For the intervention client, accurate flow of the intervention was verified. This meant that an intervention file, such as the cochlear implant intervention, was loaded into the client application and it was checked that the correct menu items were displayed and that activities were shown in the expected order.

7.1.3 Integration Testing

Since these features were being added to an existing application with loads of already-present components, it was imperative that the new features do not disrupt the functionality of other components. This led to a reasonable amount of integration testing, most of which involved creating other activities like a Survey activity in combination with a Media activity in an intervention and then running this intervention on the client. This ensured that all the components previously added could easily work in tandem with the newly created ones.

7.2 Intervention Testing

Because a bug in the intervention could result in a patient going untreated and significantly reduce their quality of life, full coverage testing for the intervention was implemented. For every screen and action available within the intervention the expected result was shown, and its success was recorded. The testing methodology was a form of White-Box top down testing. The tests were carried out manually to ensure full compliance. The final developed intervention passes every test. The hearing test (the only section of the intervention which responds dynamically to freeform input) was tested with correct, boundary and erroneous data. The test tables containing all 48 tests are shown in appendices D, E and F.

7.3 Intervention client testing

Whilst developing the application a number of bugs were encountered in the client. In order to discover more the client was tested against some example intervention JSON files. These example files were shared between the authors. If the interventions failed to function properly, the faulty module was identified using the debugger.

The media playback facilities of the client were tested using erroneous data (an empty file and an incorrect filename), boundary data (a zero length audio file) and correct data (a correct audio file). All these tests were passed.

7.4 Test Outcomes

As can be seen from the test outcomes in appendices D, E and F all the tests carried out passed with flying colours. A few of the tests failed, but causes of these failures were quickly discovered and eradicated. These tests were then run again, passing with ease.

However, it must be stated that while technical testing can ensure that the product has few bugs and meets the specification, it cannot guarantee that users will be satisfied with the end product. Thus in addition to technical testing a detailed User Acceptance Test and evaluation were carried out, which are discussed in the next section.

8 Evaluation

To assess whether the application sufficiently fulfilled the project requirements, user evaluations were required. Initially two rounds of user acceptance testing (UAT) were planned, one with students and one with ISVR patients. Unfortunately the latter was not possible due to problems obtaining ethics approval, but the former was successfully completed, giving valuable results. This section shall therefore focus on the student-based user acceptance test.

8.1 Aims

In the evaluation, user-based requirements for the intervention application (detailed in section 3.4) were assessed to evaluate how successfully they were fulfilled. The relevant requirements are provided again here for convenience:

a. Allow users to answer cochlear implant questionnaire
b. Allow users to request spare/new parts for their implant device
c. Allow users to take a hearing check
d. Show result of the hearing check to user
e. Provide a simple user interface
f. Follow good user experience practices

For requirements a-d, the evaluation aimed to assess not just whether they were met (this could easily be established through testing) but rather how easy users found those tasks. Requirements e and f are subjective, so can only be assessed through UAT.

This way, our aims can be divided into

- Effective working of application
- Simplicity/Appeal of the user interface

8.2 Methodology

Volunteers were found from within the school of ECS and friends of the authors. This demographic (students, mostly computer scientists) is therefore much more accustomed to mobile technology than many actual hearing test patients would be, especially as one of the most common causes of hearing loss is ageing. For this reason, particular care needed to be taken with questions based on ease of use, seeing as a UAT with cochlear implant patients proved infeasible.

The application was compiled into the Android .apk format so that it could be easily distributed to volunteers with Android devices. A Google Form was created (Appendix G) which detailed each task the volunteers should complete and provided questions for them to fill in, providing the authors with unbiased feedback about the app. Requirements a, b and c each had an associated action to perform in the evaluation, with d, e and f covered implicitly. The information gathered from the participants was both quantitative (rating various aspects) and qualitative (describing what they liked and disliked).

8.2.1 Tasks

Volunteers were first asked to download and install the Android application, then perform three tasks on it, before finally filling in the user experience questionnaire. The three tasks correspond to the first three requirements, a-c:

a. Select the “Cochlear Questionnaire” option on the app and fill it in with the dummy data provided
b. Select the “Request Replacement/Spare” option on the app and fill it in with the dummy data provided
c. Select the “Hearing Test” option on the app and follow the instructions to complete the hearing test

These tasks served to assess first that each section of the app was functional (it is possible to complete the stated tasks) and second how easy and pleasant it was to navigate.

8.2.2 Questionnaire

The questionnaire for participants to fill in was split into two sections. The first section contained six Likert scale questions with options between 1 and 5, each clearly marked to show which end of the scale related to which answer. These answers covered the accessibility (ease of use), perceived fairness and general feel of the app. The second section contained five free-text questions for the participants to give feedback on problems encountered, likes and dislikes and suggested improvements to the app. These, while only qualitative, gave a deeper understanding of the strengths and weaknesses of our design. Finally, the questionnaire asked for an overall rating for the app.

The full questionnaire can be found in Appendix G.

8.3 Results

Seventeen volunteers participated in the user acceptance test, most using their own Android devices. Though the device each participant used was not recorded, this at least ensured that the functionality of the application was not reliant on the devices used to test the application during development.

The results of the UAT have been split into qualitative and quantitative sections. The quantitative results are summarised graphically for ease of understanding. The qualitative answers have been analysed and repeated themes reported here. All original response data is available in appendices HH0 (Quantitative) and I (Qualitative).

8.3.1 Quantitative

Seven quantitative questions were asked; the responses to them are summarised in graphs and short textual analyses below.

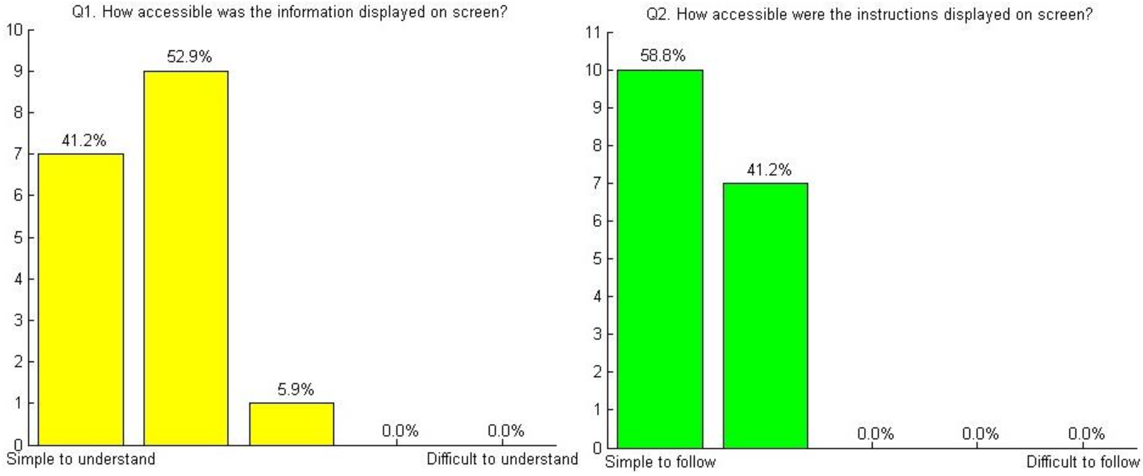

Figure 34. How accessible was the information (left) and the instructions (right) displayed on screen?

In terms of accessibility, the results in Figure 34 show that the participants found the information and instructions displayed on screen to be entirely sufficient, with all but one of the combined 34 responses being positive and the remaining one listed as neutral.

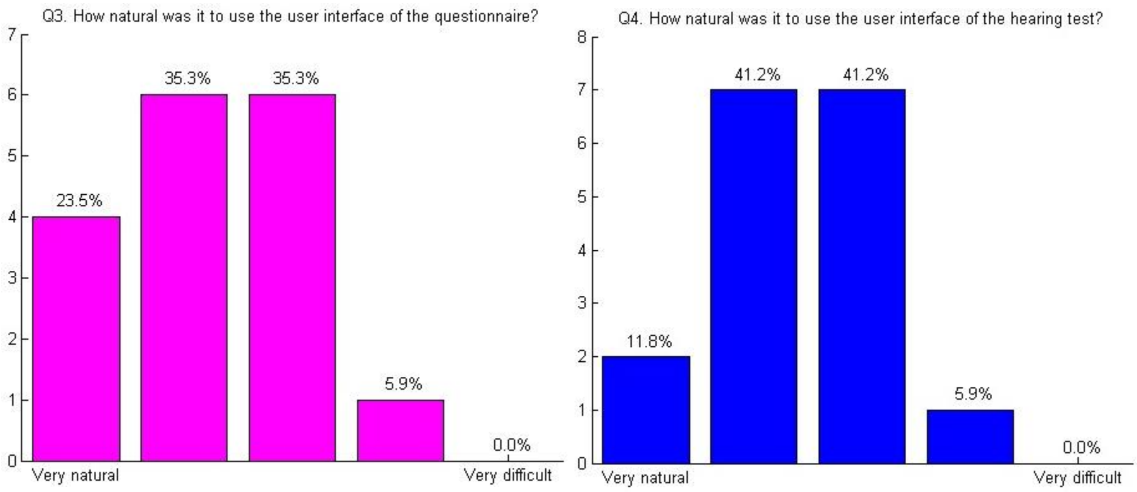

Figure 35. How natural was it to use the user interface of the questionnaire (left)

Therefore, nobody found the information or instructions difficult to understand or follow.

The design of the user interface saw a more diverse set of responses, though there was still not a single response of "very difficult" about either user interface (questionnaire and hearing test). Around half of responses were positive in either case, one negative response in both cases and the rest were neutral. This highlights an area which could be improved upon in future, starting with ascertaining what about the user interface seemed unnatural to them (see qualitative results).

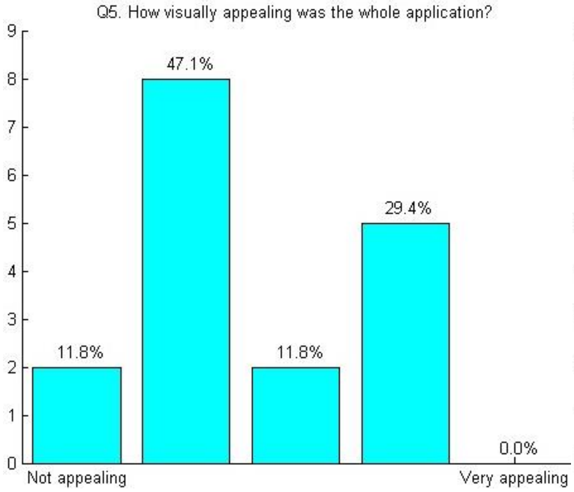

Figure 37. How visually appealing was the whole application?

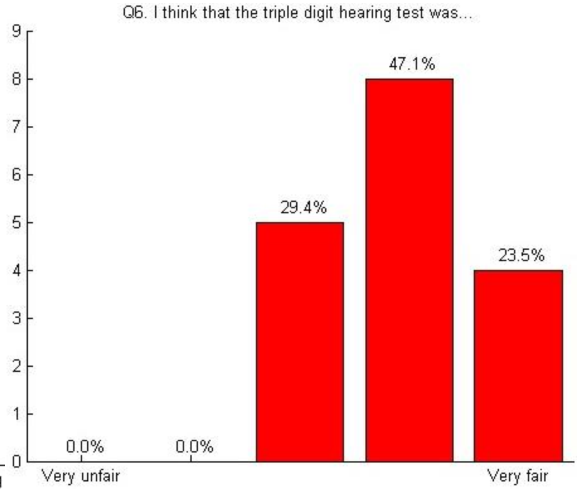

Figure 37 - I think that the triple digit test was...

The results from the question "How visually appealing was the whole application?" in Figure 37 are even more revealing as to what participants thought of the visual design of the application. In this question, less than a third of participants responded positively, with over half giving negative responses. This further reinforces that this is an area which needs to be addressed in the future.

The majority, around two thirds, of participants thought that the triple digit test was fair; the remainder giving neutral responses, leaving no negatives. Having spoken to some participants after the study, it was clear that many did not understand how severe the hearing loss of the target audience of the application was. If this had been made clearer in the evaluation instructions, ratings may have even been higher, since a common piece of feedback was that it didn't seem hard enough. Therefore, if a similar study is run in future, it would be useful to include a description of the level of hearing loss of the target audience (e.g. target audience cannot hear anything quieter than an average vacuum cleaner).

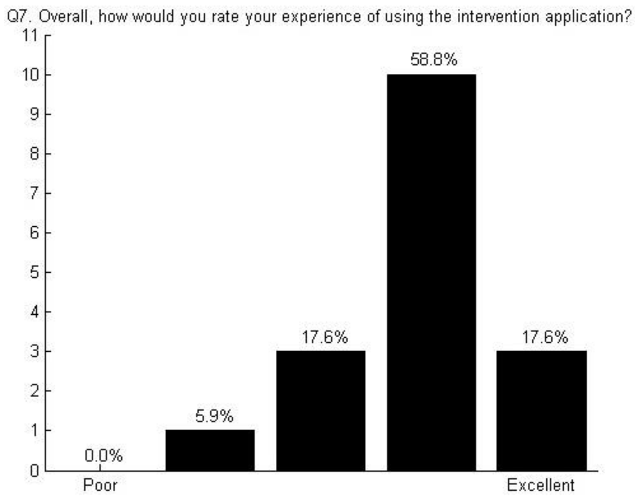

Figure 38. Overall, how would you rate your experience of using the intervention application?

Overall, the app was well received, with around three-quarters of participants responding positively to the question "Overall, how would you rate your experience of using the intervention application?"

However, concerns were raised in preceding questions, especially those concerning the user interface's visual design.

More detail about participants' views on the app were given in the qualitative, text-answer questions, analysed below.

8.3.2 Qualitative

A lot of the positive feedback reflected very well the requirements of the intervention. Users admired the 'simple interface' and 'clear instructions', stating it was 'quick to use' and 'responsive', which is good news as these both reflect requirements e and f and are important aspects considering the potential age of real users.

When asked about problems with the test a few points were repeatedly raised. Firstly, users were annoyed there was no progress bar or other sign of how long the test or questionnaire was. This might be a good addition to survey and sequence activities in the UBHave framework. Users were also surprised that their progress was not remembered when pressing 'back' and that it was very easy to accidentally return to the main menu.

Users were also irritated by text entry. Whenever a user had to enter the three digits, the full keyboard would appear as opposed to a keyboard showing only the digits 0-9. They were also irritated that the keyboard obscured the 'next' button, meaning they had to manually hide the keyboard themselves. This may prove to be a very big problem when used with elderly patients, who will likely have trouble typing numbers and will not know how to hide the Android keyboard. The first problem can be addressed by introducing a new type of survey question that only accepts numeric input and displays only the numeric keyboard. The second problem can be addressed by moving the 'next' button up the screen. This could even occur dynamically whenever the keyboard appears.

Some users stated that the questionnaire wasn't 'visually appealing', the buttons were too small and there were 'lots of empty spaces'. These could all be improved by bigger, bolder buttons - enhancing both appearance and usability.

8.4 Analysis

Using our results, we can draw conclusions about our aims and see how well we have answered our questions. It must be said that we cannot draw generic conclusions due to the small number and specific type of participants.

8.4.1 Effective working of application

Since all the users were able to follow the given tasks, which meant answering the cochlear implant questionnaire, requesting items and taking a hearing check, we can say that we have met the requirements a-d for our application. This means that our application is effective and fulfils its intended purpose.

8.4.2 Simplicity/Appeal of user interface

In general, it seems that the design of the intervention and the framework are very clear: users thought both instructions and information were 'very accessible' and stated as much in their qualitative answers. From these results, we can say that our application's interface has found to be simple enough to easily navigate through. This is further enhanced by some of them commenting that the interface is simple. However, while users were somewhat positive about usability, they gave some worrying negative remarks with some functionalities of the application that may need to be addressed when used with real patients, such as introducing numeric text entry and making sure buttons are visible on screen even when the Android keyboard is open. This would need to extend to the UBHave framework for exclusively numeric text input. So while our application has a simple and easy interface, there is still room for further improvement.

In contrast, the visual appeal of the application does not seem evident. The quantitative and qualitative results both demonstrate the same trends. Users particularly disliked the appearance of the application, thinking it was too plain and there was too much blank space. Addressing this is something of a balancing act - introducing too many elements may reduce accessibility, which had a very positive response. However, introducing larger buttons and fonts may be a good way to improve the appearance and simultaneously increase usability. Native applications implement user interfaces where the layout responds to the screen size but since UBHave interventions are defined independent of display so as to allow simple editing, an intervention creator could not implement this.

8.5 Client Evaluation

While a complete user evaluation was not able to be carried out, client evaluation was completed. A meeting was arranged with Helen to come and look at the completed application. During this meeting, Helen was shown two sets of questionnaires and it was explained that the flow of content had been improved with conditional navigation. The two questionnaires were then answered to showcase this improvement and the client was extremely pleased with the result.

The client had also brought a colleague along, who was an audiologist as well as a cochlear implant user. This meant that after showcasing the hearing test activity, the colleague was also able to connect the auxiliary cable from her cochlear implant to the phone and take the hearing test. This test was taken on two devices and the application concluded that the colleague’s hearing was fine and she did not need to come in for a check-up.

Overall, the client was extremely pleased with the project. She felt that the project provided valuable proof of concept and was excited to continue it for the future. She also commented that the questionnaire had detailed knowledge of cochlear implants and found the conditional navigation a neat addition. Lastly, she complimented the team for the work they carried out on the project, reserving high praise for the professionalism and excellent communication skills displayed throughout the course of the project.

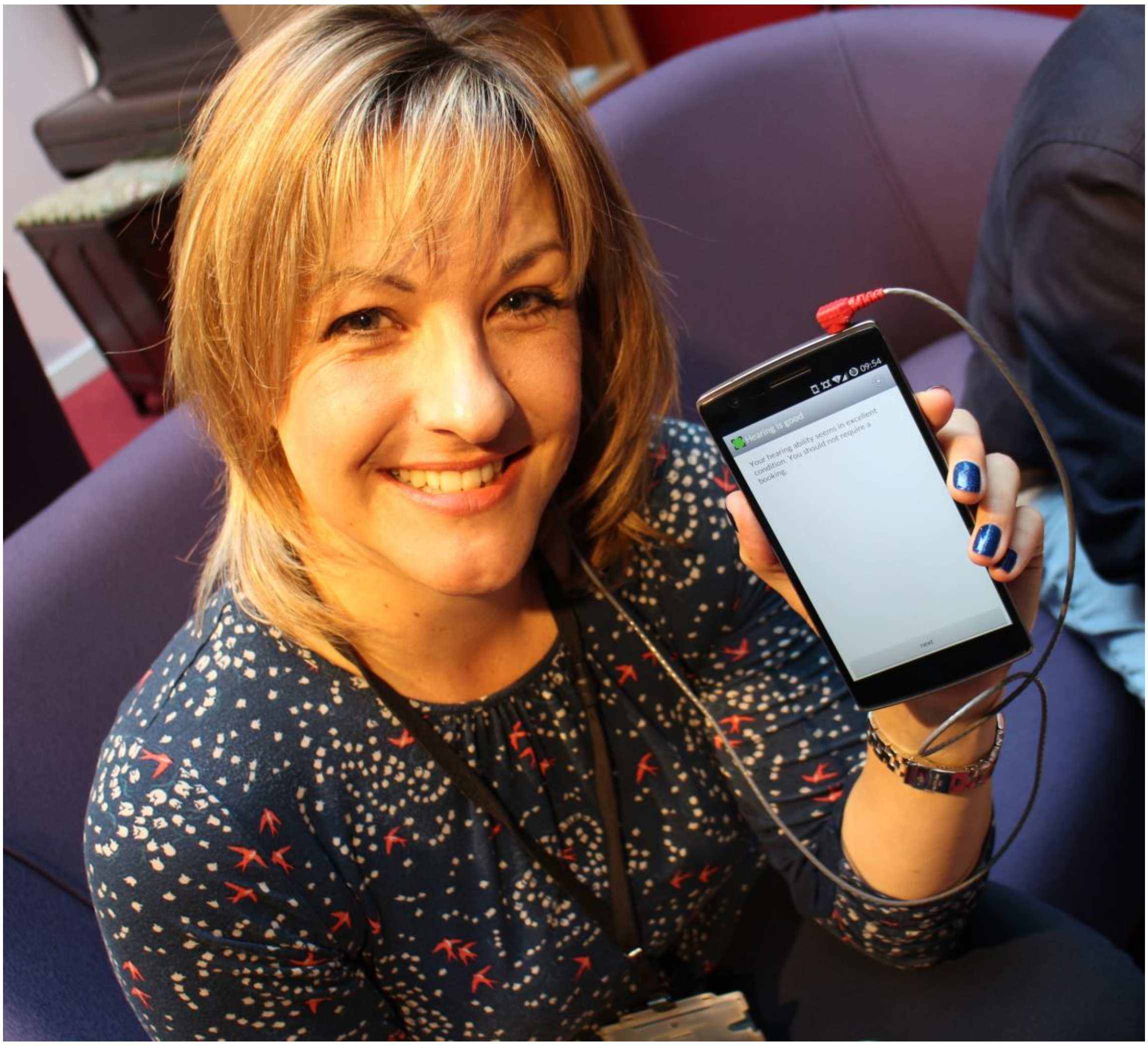

Figure 39. Cochlear implant user with the intervention

9 Conclusion

The team was assigned to extend an existing project started in the summer to create interventions for cochlear implant users. This project involved an intervention editor coded extensively over the summer holidays to reach a mammoth amount of code with powerful features. The team spent time getting up to speed with the development of the editor to fix errors left behind as well as increase the functionality to allow the users of the editors to create hearing tests. The team also had to rapidly understand and develop the intervention client to be able to carry out these hearing tests. After hard work on developing the platforms, the team finally created the intervention for the cochlear implant users. This took the existing questionnaires and optimised them to fit the needs of the cochlear implant users better, which were also further understood after undertaking numerous patient observation sessions. The completed application was packaged into an .apk and finally sent out for user testing, which received fairly positive reviews. Moreover, the client was able to test out the application and was pleased with the project.

9.1 Assessment of Completion of Goals

The main project goal was to create a Digital Behaviour Change Intervention that allows assessment of the hearing ability of cochlear implant patients to act as a telemedicine solution. This goal has been achieved, but it would have been useful to test the intervention against cochlear implant patients in order to verify its performance against patients hard of hearing rather than our test group of people with good hearing. However, the triple digit test has been verified in effectiveness by large scale clinical trials far more ambitious than it is practical for us to complete e.g. (Development of a telephone hearing test. 2006).

We specified and met three sub goals in order to achieve this main goal of:

- Extending the UBhave intervention authoring tool to allow users to insert media files. This was used to add the sound files for the hearing test
- Extending the LifeGuide client to support playback of media files. This was implemented.
- Making use of the extended authoring tool to create an intervention designed to test the cochlear implants on patients.

Due to developing the intervention on the UBHave framework the Interventions has support for the detailed data logging and analytics built into the UBhave platform. Thus when it is deployed to a clinical setting audiologists will be able to monitor and visualise patients using the intervention.

9.2 Future Work

This project added valuable extensions to an existing project, but there is always room for improvement. We will now discuss potential improvements for the future.

9.2.1 Bespoke Activity

While an effective representation of the hearing test has been successfully implemented, it would always be better to implement the original noise test itself. The team had decided to maintain the generality of the framework, but there remains a strong case for creating a bespoke activity for the hearing test itself.

The way to implement this bespoke activity would be to create another activity called *HearingTestActivity*. As discussed in the Design section, this would be then allow the user to give the activity a noise file and a number of triple digit audio files in the intervention editor. This would then be parsed by the Android client application where extensive code would need to be written to start at an initial hearing level/noise volume and dynamically increase or decrease it after every answer depending on its correctness. This is currently extremely difficult to with the UBhave framework, hence the use of a bespoke activity. Moreover, greater control could be exerted to make the increased as accurate in dB as possible. However, the major drawback of this approach would the compromise on the generality of the framework, and extremely client-heavy and client-dependant code. All things considered, it would be all right to compromise the generality, since the intention of the framework is to provide a clean and easy abstraction of the underlying code as well as catering to different users, who may have specific needs. With that perspective, this extension should be the next intended step.

9.2.2 Extension of Media Activity

Whilst the project created the notion of a generic media activity, only audio files were successfully implemented since there was no time to implement the other two media types. However, the foundation has been set to easily add these two media types, which means that this could be easily implemented in the near future. This would only add further variety of activities, allowing the framework to cater to an increased set of requirements.

9.2.3 User interface improvements

These improvements are basically the major ones suggested by the users from the undertaken evaluation. These would include allowing an input type for text-based answers in the survey activity. This would be implemented in the client application by only displaying the number pad to the user, thus eliminating the chance of the user entering invalid, useless data.

Another vital improvement, especially to cater to cochlear implant users, would be accessibility options. These should be added as a general list of settings to the client application which would allow the users to increase the size of the font as well as tweak contrast settings to suit their needs.

9.2.4 Improvements to Cochlear Implant Intervention

The intervention could be improved to produce a numerical score for the users hearing allowing them to compare their score over time. Once the intervention enters widespread usage, there would be a large body of data showing how the hearing ability of cochlear implants change over time. With the right patient consent and ethical approval, it would be possible to analyse the data for scientific purposes.

For example a researcher could compare how different models of cochlear implants behave. If it were shown that with a particular model hearing degraded faster or slower, it could allow better choice of cochlear implants or to better schedule check-up appointments with patients.

In addition if there is demographic information it would be possible to view which groups respond best to cochlear implant treatment, thus being able to prioritise the patients with the best outcomes for treatment.

Another possible plan would be to extend the pool of patients who use the intervention. The triple digit test is able to detect all kinds of hearing loss. The intervention could be used by the general population to screen for hearing loss, and be continually used as per the cochlear implant to detect changes in their hearing program.

As the triple digit test is available in multiple languages (Smits, 2005) it could be localised and use by other country centres to treat their patients. This may also apply to the United Kingdom to make the triple digit test target not only a language the patient speaks but a first language. According to the 2011 census 7.7% of the residents of England and Wales main languages are English or Welsh (Percentages of non-English speakers were not published). Support of Welsh may also be beneficial for patients in the long. However, it must be noted that for many of these suggestions would definitely require the use of a bespoke activity to ensure the smoothest flow.

Lastly, there might also be an argument to allow for different type of hearing tests. As was observed during the sessions discussed in the Analysis section, some patients may have extremely bad hearing and may not even be able to use the triple digit test for an accurate hearing check. These may only be able to distinguish between the types of sounds (‘sss’ and ‘sshh’, ‘aaa’ etc.) so they might require simpler tests, which could be implemented to cater to this niche subgroup.

9.2.5 Support for other mobile platforms

The intervention aims to be platform independent on mobile phones, and whilst the UBHave framework is built to use a platform independent file format, the only mobile client available is for Android. If a client for other mobile operating systems such as iOS or Windows phone was developed the interventions would be compatible with many more devices. As of November 2014 Android is reported as having 49.7% of the UK smartphone OS market share, iOS at 42.5% and Windows phone at 7% (Panel, n.d.). If all three platforms were supported, UBhave interventions would run on 99.2% of smartphones in the UK.

One approach to delivering cross platform compatibility would be to develop the UBHave client as a web application, this would also allow interventions to be deliverable as a web link rather than needing a client install. During his work creating the dynamic intervention editor Chris Baines produced a proof of concept simulation of the intervention client running within the editor, to allow rapid prototyping for interventions.

9.2.6 Advanced options

The UBHave editor currently supports basic programming via changing the state of shared variables. This system is built so that psychologists who do not have programming knowledge can create dynamic interventions easily. Some interventions that need more heavy duty programming create a fork of the client to implement custom activities, the obvious downside is if too many of these activities are merged into the main client it could lead to code bloat. As an alternative the LifeGuide client could be extended to support custom activities written using the web technologies of JavaScript, HTML and CSS. This would allow these extensions to be run cross platform. Moreover, this might make it possible to add more dynamism and alleviate the need for a bespoke hearing test activity since advanced custom code may be written to compensate for the specific requirements for the test. However, the major risk with this approach is the activities may use web APIs or expose browser bugs that only exist on some platforms and not others.

In order to mitigate the risk of running untrusted code, these activities could be executed within a web view on the client or if a browser application was developed they could be run within an iframe with the sandbox attribute. It would then be possible to share these custom activities, thus enabling intervention creators to integrate prebuilt activities within their intervention.

9.3 Reflection

Over the course of five months, the team managed to learn a fairly complex framework and add requested features to it. They worked with large code bases in languages we were novices in to add the required features without compromising the effectiveness and simplicity of the framework and the final delivery of the project was extremely well received by the client, who showered praise on the team. The group members gained valuable experience of working on a big group project and learnt valuable skills in web and software while designing our features, which were found was found by many users to be a good user experience. They also learnt priceless lessons of working in a group and greatly increased our understanding in producing effective results as a team. Lastly, we also succeeded in laying the foundations of a generic feature which can easily be extended further, having the potential to be utilised by users other than the project’s specific client.

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11 Appendices

A. Project Proposal

School of Electronics and Computer Science
Part IV Group Design Projects 2014/2015
Project Proposal

Note: The GDP is a substantial engineering design or feasibility study undertaken by a group of about four students. It carries 40 credits and, as a guideline, students should expect to spend about two thirds of their time on the GDP during the first semester in their fourth year.

Project Title:	Visual authoring of mobile digital behaviour change interventions
Proposer(s):	Dr Mark Weal
Research Group:	WAIS

Brief Summary of Project (150-200 words):

The UBhave project, a collaboration between Southampton, Cambridge and Birmingham, has been developing a framework for constructing mobile digital behaviour interventions. The interventions are represented as a JSON file and played on an Android App client. Interventions can include a range of components such as diaries, questionnaires, goal planners, information content. Interventions can be tailored based on user preferences and data and a notification system allows designers to target appropriate times to interrupt the participant.

This GDP project will develop a Web based authoring system that will allow behavioural psychologists to easily author novel mobile behavioural interventions. The project will use graphical authoring methodologies coupled with validation techniques designed around common intervention methodologies and patterns. The resulting tool will allow psychologists to create and trial their own interventions without the need for complex technical support.

More information about the UBhave project can be found at www.ubhave.org

If the project has an **industrial customer** (recommended), please provide the customer’s name, address,

telephone number and email: Professor Lucy Yardley (Psychology, UoS)
How many students is the project suitable for (typically 4,5 or 6)? 4-6
Will this project require laboratory space? **No**
What resources will be required: **Supplies (please specify): Estimated Cost £** 1. 2. 3. 4. Is project viability dependent on additional funds or resources (e.g. provided by the customer?) …………… **No** Additional funds/resources, if applicable, provided from (specify source): **Development mobile devices will be supplied by the UBhave project**

Please return forms by email to tjk@ecs.soton.ac.uk before Friday 30 May 2014. Include the text 'GDP Proposal 2014/15' in the subject line.

B. Project Brief

School of Electronics and Computer Science
ELEC6050 MEng Group Design Project

Project Specification and Plan

Title:

Mobile Intervention Authoring

Supervisor:

Mark J. Weal (mjw@soton.ac.uk)

Team Members:

Mohammad Ali Khan (mak1g11)

Michael Terry (mrt1g11)

Robin Johnson (rpaj1g11)

Felix Chapman (fc4g11)

Ben Jesty (bj1g11)

Customer:

Helen Cullington (hec@isvr.soton.ac.uk)

Project Specification:

One in one thousand babies are born deaf and many more become deaf as they age. Cochlear implants are electrodes inserted into the inner ear that allow patients to hear again.

It is necessary to test these implants annually, but this requires the patient to return to the Cochlear Implant Centre in Southampton, which can prove both costly and inconvenient given the distances involved.

Patients need a regular, inexpensive test to determine whether their hearing equipment has been damaged or their hearing has degraded. By building a telemedicine solution to remotely identify these problems, we can invite patients with defective implants to attend a thorough check-up. This allows patients' problems to be addressed quickly, while saving money on redundant annual tests.

The UBhave framework allows researchers to create dBCIs (Digital Behavioural Change Interventions) using a drag and drop authoring tool. They may then deliver these interventions to users using the LifeGuide Toolbox mobile application at particular or regular intervals.

We will build a dBCI to test the effectiveness of a user's cochlear implant without them having to travel to the Southampton Cochlear Implant Centre. The test will be comprised of multiple questions and a hearing test which forms to the Centre's specifications.

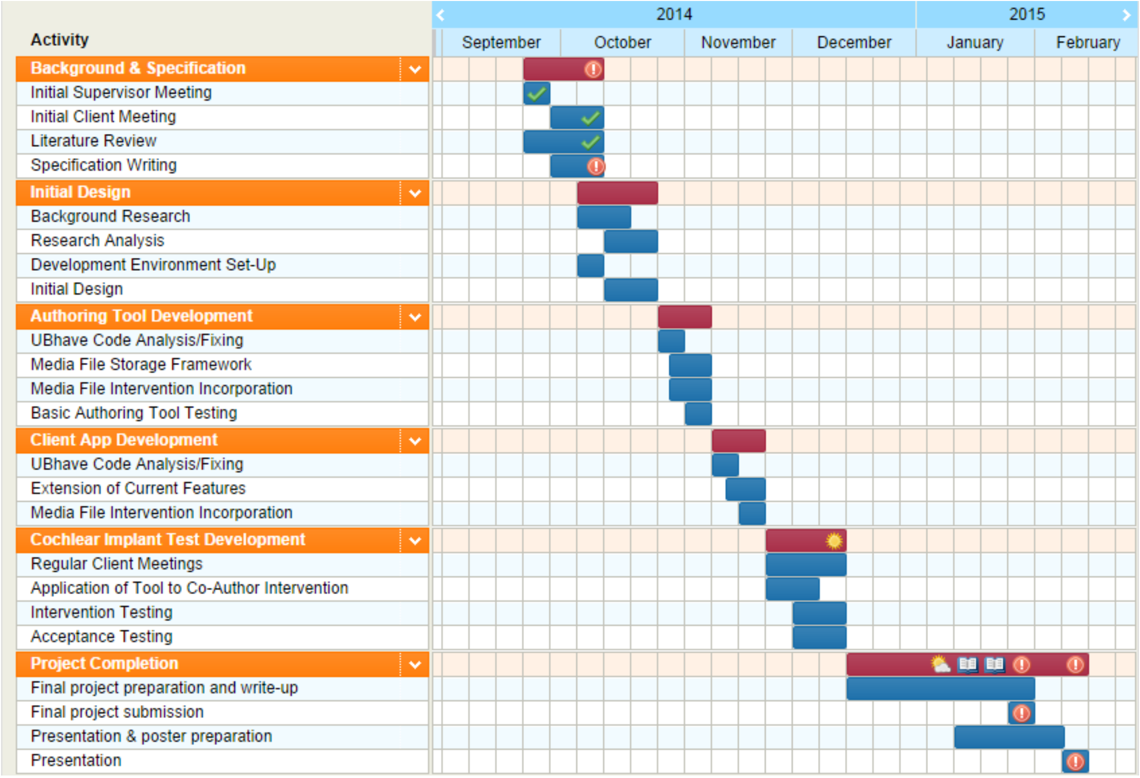
We want to be able to capture detailed analytics which can be used as feedback by our customer to measure the effectiveness of both the implant and the intervention. To achieve this we will integrate our dBCI with the pervasive logging capabilities of the UBHave platform.

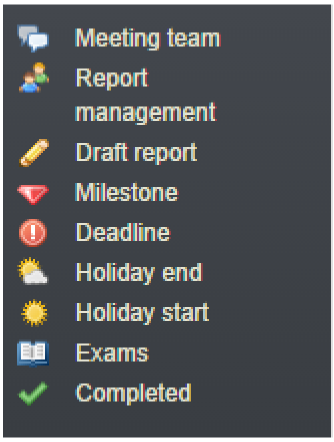
Therefore, the overall goal of this project is file:///C:/Users/mrt1g11/Downloads/Projectspecification.pdf to develop a prototype to allow people with cochlear implants to test the proper functioning of their device from the comfort of their own homes.

This can be partitioned into three main parts:

- Extending the UBhave intervention authoring tool to allow users to insert media files (such as sound and video).
- Extending the UBhave intervention mobile client application to play the aforementioned media files.
- Making use of the extended authoring tool to create an intervention designed to test the cochlear implants on patients.

For this project we have also constructed an initial Gantt chart, which may be found below:


Activity
2014
2015
September
October
November
December
January
February
Background & Specification
Initial Supervisor Meeting
Initial Client Meeting
Literature Review
Specification Writing
Initial Design
Background Research
Research Analysis
Development Environment Set-Up
Initial Design
Authoring Tool Development
UBhave Code Analysis/Fixing
Media File Storage Framework
Media File Intervention Incorporation
Basic Authoring Tool Testing
Client App Development
UBhave Code Analysis/Fixing
Extension of Current Features
Media File Intervention Incorporation
Cochlear Implant Test Development
Regular Client Meetings
Application of Tool to Co-Author Intervention
Intervention Testing
Acceptance Testing
Project Completion
Final project preparation and write-up
Final project submission
Presentation & poster preparation
Presentation


Meeting team
Report management
Draft report
Milestone
Deadline
Holiday end
Holiday start
Exams
Completed

C. Adult Follow-up Questionnaire

Health information

Is your coil/headpiece comfortable on your head? Yes ☐ No ☐

Does the implant site feel different, sore, hot or itchy? Yes ☐ No ☐

Have you had a significant bang to your head around the implant site? Yes ☐ No ☐

Does your speech processor cause soreness? Yes ☐ No ☐

Do you have ear ache or discharge from your ear? Yes ☐ No ☐

Do you have any new medical condition that you think we should be aware of? Yes ☐ No ☐

If yes to any of the above, please give more details…………………………………………………………………………

Use of implant and accessories

How many hours per day do you wear your processor? ....

If you don't wear your processor all your waking hours, can you explain why?

……………………………………………………………………………………………
………………………………………………………………..

Since your last appointment, is it more difficult to hear speech?

Yes ☐ No ☐

Since your last appointment, has anyone in your family or a friend said they think your hearing is worse?

Yes ☐ No ☐

Equipment

Please take a moment to examine your speech processor and check it fits together securely and is in good condition. If you have a remote control, is it working? If you require any replacement or spare equipment see attached spares sheet to request any items you need and return it in the SAE supplied.

If you have a Cochlear processor have you changed your microphone cover in the past 2-3 months?

Yes ☐ No ☐

If you have an AB Harmony processor, have you changed your T mic in the last 6 months?

Yes ☐ No ☐

If the answer to question 10 or 11 is 'No', please change it now. If you don't have any spares, please ask us to send you some if you have a Cochlear processor or contact AB directly if you have an AB processor.

Since you last appointment, has your battery life got worse? Yes ☐ No ☐

Are there any concerns you wish to discuss with SOECIC staff? Yes ☐ No ☐

If yes, what are those concerns? …………………………………………………………………………………………………

You can contact us at any time if you have any issues or concerns about your hearing on our Hot Line for processor problems, spares and replacements the number is: 023 80 584068 or you can email ais.repairs@soton.ac.uk

Please remember we do offer **hearing therapy** and **clinical psychology** services. You may want to access these services if you need help with tinnitus, adaptations to your work environment to help your hearing, or if difficulties with your hearing are having a significant impact on other areas of your life, for example your relationships or your mood. Please phone us on 023 80 593522 for more information.

If you are interested in learning about using accessories with your speech processor, please contact us as we run regular workshops.

Remember … it is your responsibility to keep us updated with your contact details, **including GP information.** Please return the attached contact sheet and let us know of changes in the future.

Thank you for filling in the questionnaire.

Depending on your replies, AIS staff may contact you for further clarification or organize an appointment. Please let us know the best way to contact you:

Letter	☐	Mobile (call)	☐	Typetalk	☐
Telephone	☐	Mobile (text)	☐		
Email	☐	Fax	☐		

Patient label

Please list the replacements/spares you need. Return this list to us in the enclosed SAE, and we will send you the items. (Once you receive the new items, please send the broken ones to us).

You should have a spare cable if you use a Cochlear, MED-EL or AB Neptune processor, a spare T mic and headpiece if you use an AB Harmony, and spare cables if you use a Neurelec processor.

Remember that we have a Hot Line for processor problems, spares and replacement parts. The number is: 023 80 584068 or you can email ais.repairs@soton.ac.uk

Item	Length	Colour	Ear	Notes

If you have an Advanced Bionics cochlear implant, you should contact the company directly for any spares you need (01223 847222, support@abforyou.co.uk).

If the spares do not resolve the problems, please get in contact with us again.

Remember to contact us if you need an MRI scan. This is regardless of which part of your body is being scanned. This is important as certain procedures need to be followed in order to prevent the movement or demagnetisation of the internal magnet.

D. Cochlear Questionnaire Tests

Question	Response	Expected Result	Success
Is the coil/headpiece comfortable on your head?	Yes	Next Question	YES
Is the coil/headpiece comfortable on your head?	No	Please give more details prompt	YES
Does the implant site feel different, sore hot or itchy?	Yes	Please give more details prompt	YES
Does the implant site feel different, sore hot or itchy?	No	Next Question	YES
Have you Had a significant bang Around the implant site	Yes	Please give more details prompt	YES
Have you had a significant band around the implant site	No	Next Question	YES
Does your speech processor cause soreness?	Yes	Please give more details prompt	YES
Does your speech processor cause soreness?	No	Next Question	YES
Do you have ear ache or discharge from your ear?	Yes	Please give more details prompt	YES
Do you have ear ache or discharge from your ear?	No	Next Question	YES
Do you have any new medical condition you think we should be aware of	No	User of implant and accessories section started	YES

How many hours per day do you wear your processor?	Free-form text below question	Response logged and next question shown	YES
Do you wear your processor all your waking hours?	Yes	next question shown	YES
Do you wear your processor all your waking hours?	No	Can you explain why not prompt?	YES
Since your last appointment, is it more difficult to hear speech	Yes	Next Question shown	YES
Since your last appointment, is it more difficult to hear speech	No	Next question shown	YES
Since your last appointment, has anyone in your family or a friend said they think your hearing is worse	Yes	Equipment Section shown	YES
Since your last appointment, has anyone in your family or a friend said they think your hearing is worse	No	Equipment Section shown	YES
Which processor do you have?	Cochlear	"Have your changed your microphone cover in the past 2-3 months" question shown	YES
Which processor do you have?	AB Harmony	"Have you changed your T mic in the last 6 months?" question shown	YES
Have you changed your T mic in the last 6 months?	Yes	"Since your last appointment, has your battery life got worse?" question shown	YES

Have you changed your T mic in the last 6 months?	No	“Since your last appointment, has your battery life got worse?” question shown	YES
Since your last appointment, has your battery life got worse?	Yes	“Are there any concerns you wish to discuss with SOECIC staff?” question shown	YES
Since your last appointment, has your battery life got worse?	No	“Are there any concerns you wish to discuss with SOECIC staff?” question shown	YES
Are there any concerns you wish to discuss with SOECIC staff?	Yes	“What are these concerns?” prompt shown	YES
Are there any concerns you wish to discuss with SOECIC staff?	No	Contact information screen shown	YES
Contact Preference screen	No answers selected	please select at least on answer, does not advance to next question	YES
Contact Preference screen	1 or more answers selected	Thank you screen shown	YES

E. Request Replacement/spare item Questionnaire Tests

Question	Answer	Expected Result	Success
Please tell us which processor you use	Cochlear	"What item do you require?" question	YES
Please tell us which processor you use	MED-EL	Thank you screen shown	YES
Please tell us which processor you use	AB Harmony	"You should have a spare T mic and headpiece for your processor. If you still require an item, please continue" shown	YES
Please tell us which processor you use	Neurelec	"You should have spare cables for your processor. If you still require an item, please continue" screen shown	YES
Please tell us which processor you use	AB Neptune	Told to contact Advanced Bionics	YES
What item do you require?	Freeform text	"Please tell us its length, if applicable." question	YES
Please tell us its length, if applicable.	FreeForm text	"Please tell us the colour you need, if applicable" question	YES
Please tell us the colour you need, if applicable	Freeform text	"Which ear is it for?" question	YES
Which ear is it for?	No answer selected	"please select at least one answer" stays on same screen	YES
Which ear is it for?	Left Ear	"Are there any other details you'd like us to know about this item?" question	YES
Which ear is it for?	Right Ear	"Are there any other details you'd like us to know about this item?" question	YES
Are there any other details you'd like us to know about this item?	Freeform text	Thank you screen shown	YES
Thank you screen	Next	Shown main intervention menu	YES

You should have a spare T mic and headpiece for your processor. If you still require an item, please continue	Next	User told to contact Advanced Bionics	YES
You should have spare cables for your processor. If you still require an item, please continue	Next	“What item do you require?” question shown	YES

F. Hearing Test Tests

Test	Type of Test data	Expected Result	Success
all tests are given no digits	Boundary Data	Test Terminates Early, user is told to attend a hearing test	YES
Test is filled normally(by a tester with good hearing)	Normal Data	Extensive testing is carried out, user is told hearing is good	YES
Test is entered with string not numbers. Test string of “cheese” used on each question	Erroneous data	Test continues but the question is logged as failed	YES
All questions are answered with incorrect digits	Normal Data	Test Terminates Early, user is told to attend a hearing test	YES
Test is answered with emoji symbols not number	Erroneous Data	Test continues but the question is logged as failed	YES

G. Evaluation Questions

Mobile Intervention Hearing Test

Mobile Intervention Hearing Test
Ethics reference number: ERGO/FoPSE/13089
Investigator(s): Felix Chapman, Benjamin Jesty, Robin Johnson, Mohammad Khan, Michael Terry

Please read this information carefully before deciding to take part in this research.

What is the research about?

Thank you for reading. This project concerns a fourth year Group Design Project conducted by five members of the School of Electronics and Computer Science (ECS) at the University of Southampton, revolving around the concept of Digital Behaviour Change Interventions (dBCIs). dBCIs are the deployment of Behaviour Change Interventions (BCIs), tools used by behavioural psychologists to lay out programmes of gradual behaviour change (for example, a weight loss programme), on pervasive devices, such as mobile phones, allowing for more portable, convenient and flexible (particularly in terms of context-sensitivity) applications of the concept.

One such proposed intervention is that which may be used to test the effectiveness of cochlear implant devices via a mobile phone application medium on a regular basis, allowing users to infer whether their device is operating at full capacity and hence establish the need to seek further assistance or book an appointment at their local clinic. and concerned with data controllers and the data controller registry.

Through extension of the existing UBhave (http://ubhave.org.uk) project, such an intervention has now been designed for a mobile phone application; we would now like to gauge the overall effectiveness of its user interface and experience through your invaluable feedback.

What will happen if I agree to take part?

There will be a task sheet provided to you from which you must carry out a number of tasks. An .apk file will also be provided to allow you to install this application and carry out the task. At the end of this, there will be a short questionnaire.

Are there any benefits in my taking part?

The feedback provided by you will be vital to the evaluation of the success of this project. You may also learn about the triple digit testing of cochlear implants.

Are there any risks involved?

There are no risks involved in taking part in this study.

Can I change my mind later on?

You are allowed to withdraw your participation at any time; if you wish to do so, please email Robin Johnson at rpaj1g11@soton.ac.uk or Mohammad Ali Khan at mak1g11@soton.ac.uk as soon as possible.

Will my participation be confidential?

You are promised unlinked anonymity in your participation.

How do I find out more about Digital Behavioural Change Interventions (dBCIs)?

More information about dBCIs, and the UBhave project on the whole, may be located at http://ubhave.org .

What happens if something goes wrong/I would like further information?

In the unlikely incident of any trouble, or for any further information, please contact Robin Johnson via rpaj1g11@soton.ac.uk or Mohammad Ali Khan via mak1g11@soton.ac.uk .

Participant Consent Form

If you are not satisfied with any of the conditions listed below, please inform the investigator.

I have read and understood the information sheet and have had the opportunity to ask questions about the study.

I agree to take part in this research project and agree for my data to be used for the purpose of this study.

I understand my participation is voluntary and I may withdraw at any time without my legal rights being affected.

Evaluation Form

Thank you for agreeing to take part. Please complete the following tasks listed below, then fill out the User Experience Questionnaire at the bottom of this page.

Tasks

1. Please download the apk file and install the android application on your phone. The link to the apk file is http://users.ecs.soton.ac.uk/mak1g11/gdp/LifeGuideToolboxClient.apk

2. From the menu, please select 'Cochlear Questionnaire.'

3. Please fill out the questionnaire to assess the current state of your hearing; for all questions referring to a cochlear implant, please refer to this answer sheet: http://users.ecs.soton.ac.uk/mak1g11/gdp/Questionnaire%20Answers.pdf

N.B. Please note that these results will not be recorded; you are asked to undertake the questionnaire so that you might be able to provide comprehensive feedback on the Intervention Application's usability.

4. Please return to the application menu and select 'Hearing Test.'

5. Please carry out the triple digit hearing test according to the information displayed on screen.

6. Please use the request replacement/spare menu option to request a few spare items. Please refer to the pdf referenced above for the items.

7. Finally, please fill out the User Experience Questionnaire below.

User Experience Questionnaire

How accessible was the information displayed on screen? (Simple to understand 1 - 5 Difficult to understand)

How accessible were the instructions displayed on screen? (Simple to follow 1 - 5 Difficult to follow)

How natural was it to use the user interface of the questionnaire? (Very natural 1 - 5 Very difficult)

How natural was it to use the user interface of the hearing test? (Very natural 1 - 5 Very difficult)

How visually appealing was the whole application? (Not appealing 1 - 5 Very appealing)

I think that the triple digit hearing test was... (Very unfair 1 - 5 Very fair)

Did you encounter any problems with carrying out the hearing test? If so, how? If no, please leave blank.

What did you like about using the application?

What did you not like about using the application?

What improvements would you make to the hearing test questionnaire?

What improvements would you make to the triple digit hearing test?

Overall, how would you rate your experience of using the intervention application? (Poor 1 - 5 Excellent)

H. Quantitative Evaluation Results

#	Timestamp	How accessible was the information displayed on screen?	How accessible were the instructions displayed on screen?	How natural was it to use the user interface of the questionnaire?	How natural was it to use the user interface of the hearing test?	How visually appealing was the whole application?	I think that the triple digit hearing test was...	Overall, how would you rate your experience of using the intervention application?
1	08/01/2015 15:08	2	2	4	3	2	4	3
2	09/01/2015 15:01	1	1	3	3	2	3	4
3	10/01/2015 13:21	2	1	2	2	2	3	4
4	10/01/2015 22:01	1	2	2	3	1	4	4
5	11/01/2015 14:00	2	2	1	1	2	4	4
6	12/01/2015 10:44	1	1	1	2	4	5	5
7	14/01/2015 18:41	2	2	2	3	4	4	3
8	18/01/2015 16:42	2	1	3	1	4	4	5

9	18/01/2015 22:26	1	1	1	3	2	5	4
10	19/01/2015 11:59	2	2	2	2	2	3	3
11	25/01/2015 16:18	2	2	3	3	4	4	4
12	26/01/2015 18:18	3	2	3	4	1	3	2
13	27/01/2015 17:18	2	1	2	3	3	5	4
14	27/01/2015 17:23	1	1	3	2	2	4	4
15	27/01/2015 19:00	1	1	3	2	2	3	4
16	27/01/2015 20:30	2	1	2	2	3	4	4
17	27/01/2015 22:40	1	1	1	2	4	5	5

I. Qualitative Evaluation Results

#	Did you encounter any problems with carrying out the hearing test? If so, how?	What did you like about using the application?	What did you not like about using the application?	What improvements would you make to the hearing test questionnaire?
1		It works.	Looks like old Android UI. Yes/no buttons are small. Number should be recorded using a number selector for when asking about number of hours. There seemed to be a character encoding issue on some of the screens displaying text. Couldn't make a request for a MED-EL.	There seemed to be a character encoding issue on some of the screens displaying text. Use appropriate field types. Bigger buttons for the yes/no questions
2	No issues that prevented me from carrying out the test.	Simple and concise.	Pressing the back button to go to the previous question meant that the previous input for that question was discarded and needed to be reentered. The interface was very minimal, the question layout could have been a lot prettier with more GUI components centred. The questionnaire	Input would be made much simpler by displaying either a smaller text box or three character input fields (linked so that on character input it jumps to the next cell and so that backspace clears the previous cell) which default to a number pad for input when tapped rather than the generic text input keyboard.

			may have worked better as a set of scrollable (up and down) pages with all questions visible at all times (which would make the back button problem less of an issue). Some of the input components could have been altered to better suit the input format.	
3		Intuitive, easy to understand.	The UI doesn't look very good.	Can't comment as I don't need hearing aid.
4		It complemented me on my hearing, no one ever does that	no visual aids and lots of empty spaces	only aesthetic ideas
5		The idea of having a hearing test and a diagnose, on the go, seems useful - however is there really a need of an application? Easy to order spare parts, rather than visiting the vendor's website and locating the particular part. The application is very simple to interact with, which in this particular case is useful. None of the pages show	I believe there isn't a need of an android application for a hearing test - as it would only be exercised once every few months. Even if you consider the accessibility of ordering any spare/lost parts. Plus some users might even have privacy concerns - this application needs to access my location, why would that be necessary in a hearing test is beyond my understanding! I think such tests can easily be included on the vendor's website - making it much	I think the questionnaire was pretty good: 1. It's easy to follow 2. Limited options (i.e. Yes or No) - makes it simpler However, once again if this has been targeted towards people who suffer from hearing disability (which in this case would mostly be elderly people) - it would be difficult for them to follow, due to: 1. Size of text 2. They might be unaware of their personal health - i.e. asthma, etc.?

		any excess information - making it very easy to follow the interface.	easier to access further information, this includes, device pictures (Mostly elderly people are associated with hearing loss and pictures are really useful than their description), price information, vendor's contact information, etc.	
6		Very quick and simple to use, inoffensive colour scheme, no problems	No explicit dislikes (details for improvements below)	When requesting replacements/spares, if there are a finite number of items which can be requested, it would have been nice to be able to select from a list/drop down of some sort. Similarly with the length, it would be easier to use a selector for length and units perhaps. A back button on questions might be useful.
7	No problems, but there was no background white noise on test 8, it was super clear and easy to hear, was that intentional?	Easy to use	next label had no capital - but Submit did?!?! Some weird unicode characters were displayed in the questionnaire and the "Request Replacement/Spare item" label doesn't quite fit in the box...	Fix above issues
8	Not really. It would have been nice to	Was simple to use	The keyboard hid the next button	Move the next button somewhere easier to hit

	know how many steps there still were to go.			
9		Simple interface.	The questionnaire had no guidance / explanation for the questions asked. I suppose that would be fine for people with the required knowledge / expertise. For the hearing test part, the interface seemed to need more work. After the sound finishes, the button doesn't change back to play sound. You can click next without actually listening to the sound (which happened by mistake). And when inputting the answer, the keyboard covers the submit button - which requires me to hide the keyboard first then click submit. I haven't tried "Enter", but maybe the submit button could come up with the keyboard? There seemed to be enough space.	See dislikes. Add some more help / guidance / info.
10	The play sound button is right near a button which took me back to	Simple to use	Not visually appealing	One should be able to resume previous hearing tests that have only been partially completed.

	the splash screen. I accidentally clicked this button a few times and had to start the hearing test again			
11	The "next" and "submit" buttons etc. were covered up by the keyboard when inputting data, meaning the keyboard had to be manually closed each time.	Simple layout	Multiple questions could have easily fitted on one page & keyboard/button issue	Either make buttons stay above keyboard or allow proceeding to next question using the keyboard. Number input box should be on same page as audio button. Number keyboard should be brought up rather than the standard keyboard.
12		Simple, not overly complicated	Design, all the blank space and small buttons, not knowing how long the hearing test was, having to scroll for the contact bit, having to use the full keyboard for numbers, boxes I could write my life story in (instead of drop down menus).	Design improvements, bigger buttons, less blank space and drop down menus for some of the user input areas.
13		Easy to test hearing	Not much data on each screen	More questions on one screen
14	I wasn't sure how to get rid of the keyboard once I'd	The Apllication was quick	The questionairre was a little bit lengthy	Make it a bit shorter

	filled the numbers in			
15		Was simple and quick to use.	No easy way to scroll between questions	Have the ability to review answers to questions at the end of the questionnaire.
16		Responsive, clear instructions.	The text boxes for the digits use the regular keyboard, not the numeric one!	Bigger text.
17		It is simple and straightforward application to use.	Nothing to dislike, as a fancy application with too much detail is not expected for such a procedure.	Not sure if the sound was bad for a reason, to test the hearing, or if it was just a poor quality. If the latter, that is an improvement to be made. Apart form that, again a simple and effective application.