An Application for Indicating Cognitive Competence as Measured by the Mini Mental State Exam

Sarah McQuoney

This dissertation was submitted in part fulfilment of requirements for the degree of MSc Software Development

DEPT. OF COMPUTER AND INFORMATION SCIENCES UNIVERSITY OF STRATHCLYDE

August 2019

DECLARATION

This dissertation is submitted in part fulfilment of the requirements for the degree of MSc of the University of Strathclyde.

I declare that this dissertation embodies the results of my own work and that it has been composed by myself.

Following normal academic conventions, I have made due acknowledgement to the work of others.

I declare that I have sought, and received, ethics approval via the Departmental Ethics Committee as appropriate to my research.

I give permission to the University of Strathclyde, Department of Computer and Information Sciences, to provide copies of the dissertation, at cost, to those who may in the future request a copy of the dissertation for private study or research.

I give permission to the University of Strathclyde, Department of Computer and Information Sciences, to place a copy of the dissertation in a publicly available archive.

(please tick) Yes [✓] No [ ]

I declare that the word count for this dissertation (excluding title page, declaration, abstract, acknowledgements, table of contents, list of illustrations, references and appendices is 20,515.

I confirm that I wish this to be assessed as a Type 1 2 3 4 5 Dissertation (please circle)

Signature: 

Date: 18/08/2019

Acknowledgements

I would first like to thank my dissertation supervisor Mr. William Wallace for his continuous guidance and support throughout the duration of my Master's dissertation, without whom the project itself would not have been possible. I would also like to thank Mr. Konstantinos Liaskos for his invaluable support and guidance throughout the whole of my Master's year.

Finally, I would like thank my parents for their inviable support and encouragement throughout the duration of this thesis and my years of study.

Abstract

In today's information society, where most of the population is heavily reliant on technology it is not surprising that the digital health sector is growing exponentially due to many realising the value that technology has in facilitating the current healthcare system. The information society has also meant that governments are having to adapt legislation and adjust their ideologies to reflect today's technology driven culture. Once such example of this is the change being made to current legislation regarding last the creation of a last will and testament. A start-up company hoping to take advantage of these legislative changes approached the University for expert advice concerning an application they aimed to build – a mobile application that is used to make last a will and testament. It became clear that an assessment of competence was needed for such an application to exist.

The need for a competence measure led to the main basis of this thesis: create a proof of concept that will test the cognitive competence of an individual. This dissertation takes a psychological paper based cognitive impairment examination and attempts to implement this digitally into a mobile application. The final aim of which is to create a digital version of the Mini Mental State Examination that is ready to be equivalence tested in future to determine if it could be used in practice.

The numerous ethical implications surrounding the implementation of a cognitive impairment test are discussed in detail as well as the methodology used to design and build such an application. The outcomes of in-depth expert evaluations and acceptance tests are discussed and used to demonstrate that the proof of concept built is ready to be evaluated further in future to determine the equivalence of the digital version of the MMSE compared to the original paper based version to see if it can be used in practice.

It is important to consider not only the use of this for an application that allows users to make a will but the scope of such a system in relation to the healthcare system and management of those suffering from cognitive dysfunction within the digital healthcare sector.

Table of Contents

1.Introduction

During the past half-decade, there has been an exponential growth in the digital health sector. This is no surprise considering the information society that we live in - technology has become integral in everyday life, thus, it could be argued that digital health is the next phase within our culture - especially considering how much money and time can be both saved and made from healthcare and wellbeing apps. This rise in healthcare based applications are clearly an attribute of the information society that we live in today, but this rapid growth is facilitated by both an e-economy in which technology based healthcare can save costs and notable technology and software companies such as Apple and Google becoming increasingly interested in this sector bringing out cardiology diagnostic and fall detection[1] and deepmind respectively. The attention these notable companies bring to the digital healthcare sector undoubtedly motivates others to follow suit and encourages consumers to partake in the use of such technologies. Since the past half-decade there have been over 153,000 new digital applications available from both the Apple Store and Google Play[2]. This brings the total to higher than 318,000 applications[3], as well as, 340 wearable health tracking devices globally[4] and it does not seem to be slowing. Studies indicated approximately 200 wellbeing and health centred applications are being added to application platforms each day[5]. Due the continued progression of this sector the FDA have even brought forward an incentive called the Digital Health Action Plan that aims to minimise guidelines for applications to meet the specifications needed for approval in terms of health apps and systems[6], consequently facilitating and encouraging companies and developers alike to build health, medicinal and wellbeing apps for the mass majority. This allows America to meet consumer demands for such technologies and benefit from the positive impact this will have in the long run, both governmental and citizen alike. Those who are most likely to partake in using such applications and technologies are those in early adulthood, followed closely by the aging population. This was announced by the Rock Health digital health consumer adoption survey[7] – arguably the part of the population that can benefit most from these types of web based and phone based applications. This is consistent with more apps being developed and aimed at the aging and elderly population, for example: Dthera Sciences are currently building a medicinal

[1] Sarsby, S. (2019). *Guest Article: The rise of digital therapeutics and what this means for healthcare professionals - AT Today*. [online] AT Today. Available at: http://attoday.co.uk/guest-article-the-rise-of-digital-therapeutics-and-what-this-means-for-healthcare-professionals/ [Accessed 2 Aug. 2019].

[2] Basw.co.uk. (2019). [online] Available at: https://www.basw.co.uk/system/files/resources/basw_55937-1_0.pdf? [Accessed 2 Aug. 2019].

[3] Basw.co.uk. (2019). [online] Available at: https://www.basw.co.uk/system/files/resources/basw_55937-1_0.pdf? [Accessed 2 Aug. 2019].

[4] Basw.co.uk. (2019). [online] Available at: https://www.basw.co.uk/system/files/resources/basw_55937-1_0.pdf? [Accessed 2 Aug. 2019].

[5] Basw.co.uk. (2019). [online] Available at: https://www.basw.co.uk/system/files/resources/basw_55937-1_0.pdf? [Accessed 2 Aug. 2019].

[6] Forbes.com. (2019). *Digital Healthcare Growth Drivers In 2019*. [online] Available at: https://www.forbes.com/sites/greglicholai/2019/01/07/digital-healthcare-growth-drivers-in-2019/#2f8367011dba [Accessed 2 Aug. 2019].

[7] AdvancedMD. (2019). *The Rise of Digital Healthcare - AdvancedMD*. [online] Available at: https://www.advancedmd.com/learn/rise-digital-healthcare/ [Accessed 2 Aug. 2019].

instrument that aims to relieve and moderate of Alzheimer's Disease[8] and MedCoach, an app available on both iOS and android platforms that aids in medication management[9].

The information Society has also forced governments to modernise legislation. In a culture where information and data is wealth, the governing bodies must be able to facilitate this growth through modernising its ideologies and in turn, its legislation to incorporate the mass technologies needed to transfer such data efficiently, securely and quickly. This can be seen through new data protection laws such as the General Data Protection Regulation (GDPR) coming into effect to monitor and manage the safety of the publics personal information. Not only this, the government must keep up with the advances that technology is currently making and cater for a population who rely more and more on web based and phone based applications to aid their daily life; this can be seen through the changes currently proposed for the act of creating and managing ones last will and testament. The legislation surrounding will making in the UK is currently undergoing change in order to mirror the technological society that we currently live in. At the moment, the UK law regarding last will and testament is governed by the Wills Act 1837[10]. An outdated precedent that is based on a society far different from our own currently in terms of the way society is governed as well as modern medicine and disease[11]. Changes that are being made to this legislation are in development presently and include:

"The emergence of increasing reliance upon digital technology[12]" (Lawcom.gov.uk, 2019).

The Law Commission also have a booklet that states numerous changes in relation to wills that will make the process of making one easily accessible and transparent for all individuals residing within the UK - one of which states that the public should be able to make a will using a computing device[13] . These changes are needed to sustain the prevailing reliance on software today.

Lifeium, a Glasgow based start-up company hope to take advantage of these factors: the rise in the digital health sector and the new legislation regarding making last will and testaments in the UK. They have approached Strathclyde University for expert advice concerning the mobile phone based application they are interested in developing: An automated will writing application – a niche in current market that will have the scope to benefit many UK consumers. This application will aid the government with their present vision for will writing;

---

[8] Digitaljournal.com. (2019). *Dthera Sciences to Provide Corporate Update at the Digital Medicine and Medtech Showcase - Press Release - Digital Journal*. [online] Available at: http://www.digitaljournal.com/pr/4064364 [Accessed 2 Aug. 2019].

[9] iYogi. (2019). *10 Best Medical Apps for Seniors*. [online] Available at: http://www.iyogi.com/editors-pick/10-best-medical-apps-for-seniors.html [Accessed 2 Aug. 2019].

[10] Lawcom.gov.uk. (2019). *Wills | Law Commission*. [online] Available at: http://www.lawcom.gov.uk/project/wills/ [Accessed 2 Aug. 2019].

[11] Lawcom.gov.uk. (2019). *Wills | Law Commission*. [online] Available at: http://www.lawcom.gov.uk/project/wills/ [Accessed 2 Aug. 2019].

[12] Lawcom.gov.uk. (2019). *Wills | Law Commission*. [online] Available at: http://www.lawcom.gov.uk/project/wills/ [Accessed 2 Aug. 2019].

[13] Lawcom.gov.uk. (2019). *Wills | Law Commission*. [online] Available at: http://www.lawcom.gov.uk/project/wills/ [Accessed 2 Aug. 2019].

making it computer based and transparent. There are similar online applications available at the minute that have been a proven success, allowing the government to achieve what they are currently trying to. Although, the application Lifeium are currently looking to build has much merit and usefulness for the mass majority, it comes with many ethical and legal issues. The main legal issue being coercion; where one could force another to use the app for their own monetary gain going unnoticed by forcing people to unwillingly make them executor of the will or leave them large sums of money. The main ethical issue being that of cognitive competence; ensuring all individuals who make use of the online app are of able mind and understanding. For these purposes, I will be building a proof of concept for Lifeium's will writing platform that can demonstrate the capabilities of measuring competence through a mobile platform. To do so, I will be making a digital version of the Mini Mental State Examination(MMSE) (Folstein, Folstein and McHugh, 1975), with the future hopes of reaching a digital equivalent. I have chosen to use the MMSE over other psychological paper based competence test for numerous reasons, those of which will be discussed in the next section of this paper, the literature review.

2.Literature Review

2.1 MMSE Review

There are numerous psychological tests that have been developed to assess patients cognitive function and indicate if there is any impairment and to what extent. These include tests such as the CLOX test (Royall, Cordes and Polk, 1998) which involves patients being instructed to draw a clock with the hands pointing to a certain specified time. Patients are then scored out of 15 based on whether the time is correct, if the minute hand is longer than the hour and the order of the numbers on the clock face[14]. Although this is an accurate measure of competence found through numerous studies which prove both the reliability and validity of this test such as (Royall, Cordes and Polk, 1998), (Pinto and Peters, 2009) and (Shulman, 2000) who all have found significant results from using the test, it proves challenging when looking to transform it into a digital format. This would require a very large screen such as an iPad or tablet, as well as sophisticated touchscreen technology. Even when such things are accessible, the results of the test lend themselves well to subjectivity. It begs questions such as how long must the minute hand be longer than the hour hand for it to count as a point? How round must the clock be to represent it as a clock? When creating a proof of concept such as a competence test it is important to keep in mind that these tests typically have a trained clinician carrying them out who can manoeuvre much ambiguity between the patients answer and the scoring system using their common-sense knowledge and years of experience. When making these into a digital version, the application takes the place of an experienced clinician which can raise may issues surrounding subjectivity and ambiguity of drawings. Similar clock drawing tests, however, are often used in conjunction with the Mini Mental State Examination with results suggesting they have significant and reliable results when measuring potential cognitive impairment as shown by (Schramm et al., 2002), (Cacho et al., 2010), (Shulman, 2000) and (Yildiz et al., 2018). These findings, therefore, suggest that

[14] Nccdglobal.org. (2019). [online] Available at: http://nccdglobal.org/sites/default/files/content/clox.pdf [Accessed 6 Aug. 2019].

the MMSE is a suitable cognitive assessment to use for this proof of concept to evaluate if an individual is competent enough to go forward in writing a will without a lawyer present.

The Mini Mental State Examination (MMSE) developed by (Folstein, Folstein and McHugh, 1975), is a commonly used paper based psychological test that measures potential cognitive impairment in individuals. The MMSE is a reliable and validated cognitive competency test that is still used by clinicians today to assess their patients and monitor any cognitive decline over long periods of time. The examination is comprised of 6 different sections, each evaluating different cognitive functions: orientation, registration, attention and calculation, recall, language and copying. It is scored out of 30, with 3 subsections: no cognitive impairment is a score between 24-30, mild cognitive impairment is a score between 18-23 and severe cognitive impairment is a score between 0-17. The MMSE is a suitable test to use for this proof of concept due to continued success as an accurate measure of cognitive function shown by numerous empirical research projects. The MMSE complies with a clinical diagnosis of the existence of cognitive deterioration (Folstein, Folstein and McHugh, 1975). As (Kurlowicz and Wallace, 1999) affirm that the MMSE is efficient in distinguishing between those who suffer from impairment of their cognition and those who have healthy cognitive functions, it can also adequately assess any deterioration of cognition over periods of time when regularly administered. It is important to consider the findings of (Kurlowicz and Wallace, 1999) as the ability to reliably separate those who are competent and have a full understanding of potential consequences of their monetary actions and those who should be recommended to seek legal advice when doing so, is the whole crux on which this proof of concept is based on. Further reinforcing the appropriateness of using the MMSE for this thesis.

This proof of concept is not limited to the elderly population - anyone of any age may want to make a last will and testament, however, it is important to consider that the elderly generation are most likely to have complaints when it comes to healthily functioning cognition. For this reason, the MMSE again proves itself a useful tool to use: those with cognitive dysfunction may find it difficult to concentrate on tasks for long periods of time (Folstein, Folstein and McHugh, 1975) so implementing a digital version of a long-winded paper based test for cognitive impairment would be inappropriate and potentially skew the scores of those taking the test via this proof of concept. One of the motivating factors when creating the MMSE was to have an examination that is easily and quickly completed (Folstein, Folstein and McHugh, 1975) accounting for those who have yet to be diagnosed with cognitive dysfunction that cannot be adequately responsive for long periods of time. Not only does this ensure the MMSE is a suitable tool to use for this thesis to account for all generations using the application in future but it also lends itself well to the will making app Lifeium are looking to build. In terms of usability, when creating an application for will making users will not want to spend long periods of time completing other tasks beforehand; this has potential to lower usage and user satisfaction of the app.

Moreover, the MMSE has proven to be a viable option for this thesis through recent research where it has been implemented through telecommunications. Telehealth is a corporation that adopts telecommunications such as video technology to provide healthcare outside of a

clinical setting[15]. Due to growth and success in recent times of telehealth it was possible to test the reliability of the MMSE using this provider. This was investigated by (McEachern et al., 2008) who reviewed the scores of individuals who competed the MMSE in person and via telehealth. The outcome was significantly successful and scores were consistent between both methods. Research such as this is significant for this proof of concept as it demonstrates the ability of the MMSE to measure cognitive functions across multiple scenarios, lending it well to be used for the application I am building. This furthers the argument that the MMSE is the choice cognitive examination to use for this thesis. The MMSE, however, is not the only versatile cognitive ability exam that has proven to work consistently across multiple platforms. The Graduate Record Examination (GRE) that measures reasoning skills and critical thinking has shown promising results for measuring the same abilities from the paper and pencil form and the computerised version (Mead and Drasgow, 1993).

It is important, however, to consider and acknowledge the short comings of the MMSE before continuing. Like most psychological tests of cognition, the MMSE has some properties that leave it open to misinterpreting cognitive impairment and for any clinical diagnosis should be used in conjunction with other examinations. The examination focuses substantially on literacy skills, numeracy skills and verbal abilities for example: writing a sentence, repeating a series of object names, spelling a word backwards and subtracting 7 from 100 over 5 times (Kurlowicz and Wallace, 1999). It is vital to recognise the short comings that would be a result of using the MMSE as well as the numerous advantages. These include possible inaccurate results due to individuals having poor literacy or numeracy skills causing the proof of concept to recommend creating a last will and testament with a lawyer not because of any cognitive disturbance but a lack of ability to complete the test properly. Moreover, it is also possible that an induvial will fall below the no cognitive impairment score due to a lack of ability and understanding in regards to technology and mobile phone applications rather than cognitive impairment. It is crucial in general then to recognize that the MMSE should not be the sole examination used to diagnose any individual with a clinical cognitive disturbance in a healthcare setting (Folstein, Folstein and McHugh, 1975), instead it should be used alongside other diagnostic tests to ensure accurate results not based on any literacy verbal or numeracy bias. With regards to this thesis, that does not aim to clinically diagnosis any individual with a cognitive impairment - rather ensure accurate cognitive competence where failing to do so will only result in advising one to seek out legal assistance when creating their will. This does raise ethical implications such that any individual should not become aware of a potential cognitive disturbance using this proof of concept. To ensure this is not the case, it must be acknowledged that there are many factors that can skew the results of the MMSE as mentioned above, causing the need for other examinations to be administered in conjunction. Users will be advised before and after completing the digital implementation of the MMSE that this is by no means a clinical diagnosis and the application itself by no means aims to do this. It is only a way to ensure competence of an individual before significant decisions are made. The examination results can be altered due to many external factors and the failure to pass is not necessarily an authentic representation of their cognitive competence. It only suggests that the user should seek legal representation as a more suitable

[15] https://www.who.int/sustainable-development/health-sector/strategiestelehealth/en/

way to change or make their last will and testament and is not indicative of cognitive impairment.

2.2 Software that uses similar psychological examination review

Transforming psychological examinations, specifically those measuring cognitive ability, is not a new concept. There are numerous web based and mobile based applications that have implemented paper based psychological tests for different purposes. These digital equivocal applications of other psychological tests that are successfully administered via different software platforms indicates the potential success that is possible for this thesis.

CANTAB is an application that is typically used on an IPad or tablet, the purpose of which is to identify if an individual is suffering from a memory impairment. The FDA approved application[16] has been successful in diagnosing the symptoms of clinical memory loss in adults aged 50-90 years old while discriminating from the symptoms of depression[17]. CANTAB has also facilitated the diagnosis of dementia when used going from 39% to 46%[18]. The application implements the Cambridge Neuropsychological Test Automated Battery (CANTAB) and the Paired Associates Learning (PAL)[19] which have been found to detect memory deterioration and diagnose clinical memory disturbance (Junkkila et al., 2012). This application provides strong evidence that paper based psychological evaluation tests can be successfully implemented into a digital format without sacrificing validity or reliability of results.

The same can be said for Cognigram, which implements the Cogstate Brief Battery (CBB)[20]. This computer based application is extremely like the proof of concept being built for my dissertation. Its purpose is to track the performance of cognitive functions within the aging population. It has shown abilities to distinguish between symptoms of schizophrenia and cognitive function, successfully diagnosing impairments in sufferers of schizophrenia[21]. Reinforcing the idea that digital competence tests are valid and stable ways of measuring any potential cognitive disturbance.

Although these digital implementations have proven that it is possible to reliably and successfully measure cognition both for the purpose of diagnosis and for the continued monitoring of performance to track any changes over long periods of time. While they are able to distinguish between the cognitive impairment they were built to diagnose and other

[16] https://www.cambridgecognition.com/products/digital-healthcare-technology/cantab-mobile/
[17] https://www.cambridgecognition.com/products/digital-healthcare-technology/cantab-mobile/
[18] https://www.cambridgecognition.com/products/digital-healthcare-technology/cantab-mobile/
[19] https://www.cambridgecognition.com/products/digital-healthcare-technology/cantab-mobile/
[20] https://www.cogstate.com/cognigram-detects-cognitive-impairment-schizophrenia-patients/
[21] https://www.cogstate.com/cognigram-detects-cognitive-impairment-schizophrenia-patients/

health issues that may have similar symptoms to what is being measured. Each implementation only lasts between 5 – 15 minutes making them an efficient option to save both time and money when used in a clinical setting. These applications, therefore, give insight into the proof of concept that I am building as part of my dissertation project. Proving that it is possible not only to implement previously paper based psychological tests into a digital platform but if done properly they can be a valid, reliable, efficient and cost effective way of measuring cognitive functions. It is important, however, to acknowledge that the above-mentioned applications have all been designed and build to be administered by either clinical staff or support staff. Due to this, the application does not take the place of trained clinician or a person with life experience of dealing with such situations. The proof of concept I will building is designed to take the place of the clinical or a trained member of staff that has been cleared to administer such examinations. This could have implications and result in my application being less reliable in assessing the relevant cognitive functions the MMSE has been designed to measure, however, the competence test I am building is not meant for clinical use and this must be kept in mind. Although it may not be as valid a measure, it is merely a gage of competence from an individual before making any decision of consequence and it's not in any way meant for diagnostic purposes. For these purposes, the above empirical research strongly suggests that the MMSE is the best examination to digitise for my proof of concept mobile application; a measure of competence.

2.3 UK legislation regarding a last will and testament

In 2017 the UK law commission proposed numerous changes to the current legislation in place for creating and changing a last will and testament. They propose a complete makeover of the current act that has been in place since 1837 - Wills Act 1837. After significant research, there seems to be 2 major reasons for doing so: the current legislation is from Victorian times making much of it outdated specifically in terms of governmental, medical and technological advances that leave the current act insufficient in terms of imposing the law as it does not reflect current society and citizen needs. From this, comes the second major reason for the change: the poor and arguably alarming low statistics of citizens in the UK that have a will in place. These figures are realised by the Kings Court Trust report that as of 2018:

> "More than six in ten people in Great Britain (61%) do not have a Will"
> https://app.hubspot.com/documents/2632673/view/49938227?accessId=8b71ba (page 4)

Currently, the process of creating a last will and testament includes an adult of age 18 years and above who is cognitively competent. It must be signed and dated in the presence of 2 witnesses. What's more, it must be structured and written in such a way to make it legally valid and binding[22] to ensure there is not ambiguity or misinterpretation of what was meant by the individual, thus, ensuring it complies with the law to stop any contest to what is written – they also register the will with appropriate agencies if needs be – child services for example. This can be a long drawn out process that is becoming more outdated due the information society. The commission, therefore, have multiple important proposals, the most relevant to this thesis are the ones that are included under the electronic section of their report. The

[22] https://www.gov.uk/make-will/make-sure-your-will-is-legal

implementation of electronic wills is clearly an important factor to the commission, shown through the dedication to introduce electronic wills:

> "Since technology is already widely used to prepare hard copy wills, the intuitive next step is to develop our capacity to execute wills electronically and to make use of fully electronic wills."
>
> - https://s3-eu-west-2.amazonaws.com/lawcom-prod-storage-11jsxou24uy7q/uploads/2017/07/Making-a-will-consultation.pdf (page 106)

They also recognise that in today's information society, the digital implementation of a will is the only logical development going forward in this sector. The report suggests that the ability to create a will digitally, in turn allows citizens to do so at home and in their own convenience which will most likely result in more people taking a short amount of time out of their day to do so. If this is new commission is passed, it will help tackle the problem of low percentages of UK citizens that have a will, especially within the younger generation. The Kings Court Trust report did not only highlight the insufficient number of people that currently have a will in place but found that in younger adults – specifically those in their late teens and early twenties – account for a significantly small percentage of those with a will. The age group that has the least number of citizens with a will, the electronic implementation will no doubt encourage the younger generation to create their last and will and testament. These findings only further the argument for the relevance of Lifeium's vision and subsequently the importance of this thesis.

When combining the results of all 3 sections of this literature review, it is clear that this proof of concept can help prove cognitive competence and will facilitate Lifeium's mobile application idea. The MMSE is a suitable psychological test to use, digital implementations of paper based competence tests can be successful and legislation changes in relation to will making, shows that an application such as Lifeium's is not only possible but can be very successful. It can contribute to the exponentially growing digital health sector and aid the governments hopes for a significant increase in the number of UK citizens that have a last will and testament in place.

3.Methodology

3.1 Requirements

I am building a proof of concept to measure cognitive competence for the purposes of my thesis, therefore, the following requirements are not transferable to the mobile application that Lifeium are looking to build. My proof of concept will be a potential guide for the implementation of one of many components that will be needed for their venture. I am by no means trying to build a digital equivalent of the MMSE for my dissertation. Rather, I am looking to build a proof of concept in which the MMSE is transformed into a digital format whereby it has been expertly evaluated. The aim of which will be to implement a digital version of the MMSE that is a proof of concept to test for competence that is ready for future work to test for equivalence. After reading empirical literature on both the MMSE and other digital implementations of cognitive measures, as well as, in depth discussions with my dissertation supervisor the requirements are as follows, some of what have been adapted to

suit the environment users will be in and to suit a digital version. The Original MMSE can be found in Appendix 3.

1. Provide a digital implementation of the MMSE that can be equivalence tested in the future.
2. Implement each question from the MMSE where possible:
    a. What year is it? – equivalent of MMSE question.
    b. What month is it? – equivalent of MMSE question.
    c. What day is it? – equivalent of MMSE question.
    d. What Country are you in? – equivalent of MMSE question.
    e. What City are you in? – adapted from what town are you in?
    f. What Street are you on? - adapted from what district are you in?
    g. What is your building/house number? - adapted from what hospital are you in?
    h. What is your postcode? – adapted from what floor are you on?
    a. Show user 3 named objects and prompt them to type in their names – adapted from examiner names 3 objects then asks the patient to name all three immediately after.
    i. Subtract 7 from 100 and repeat 5 times – equivalent of MMSE question.
    j. Alternative to requirement question i. – spell the word world backwards – equivalent of MMSE question.
    k. Ask the names of the 3 objects shown earlier –equivalent of MMSE question.
    b. Name these objects (user shown a pencil and a watch on screen) – equivalent of MMSE.
    l. Say “No ifs ands or buts” – adapted from repeat no ifs, ands, or buts.
3. Ensure each user is prompted that the resulting score of the examination is by no means indicative of any cognitive impairment, merely a suggestion that these significant decisions should be made with a legal guide at hand and a meeting with a lawyer is advised.
4. Do what is possible to ensure that the relevant cognitive function is being measure and my user interface does not change this e.g. orientation, registration, attention and calculation, recall and language.
5. The proof of concept should be scalable.
6. Ensure any text boxes that require user input have relevant restraints.
    a. A text box should not allow an unlimited amount of characters.
    b. Appropriate messages should be shown to the user to make them aware that not answering a question will result in a zero score for that question.

I have categorized the requirements into 2 groups: functional requirements and non-functional requirements:

Functional requirements

1. Provide a digital implementation of the MMSE that can be equivalence tested in the future.
2. Implement each question from the MMSE where possible:
    a. What year is it? – equivalent of MMSE question.

b. What month is it? – equivalent of MMSE question.
c. What day is it? – equivalent of MMSE question.
d. What Country are you in? – equivalent of MMSE question.
e. What City are you in? – adapted from what state are you in?
f. What Street are you on? - adapted from what town are you in?
g. What is your building/house number? - adapted from what hospital are you in?
h. What is your postcode? – adapted from what floor are you on?
i. Show user 3 named objects and prompt them to type in their names – adapted from examiner names 3 objects then asks the patient to name all three immediately after.
j. Subtract 7 from 100 and repeat 5 times – equivalent of MMSE question.
k. Alternative to requirement question j – spell the word world backwards – equivalent of MMSE question.
l. Ask the names of the 3 objects shown earlier –equivalent of MMSE question.
m. Name these objects (user shown a pencil and a watch on screen) – equivalent of MMSE.
n. Say "No ifs ands or buts" – adapted from repeat no ifs, ands, or buts.

3. Ensure each user is prompted that the resulting score of the examination is by no means indicative of any cognitive impairment, merely a suggestion that these significant decisions should be made with a legal guide at hand and a meeting with a lawyer is advised.
4. Do what is possible to ensure that the relevant cognitive function is being measure and my user interface does not change this e.g. orientation, registration, attention and calculation, recall and language.

Non-functional requirements

1. The proof of concept should be scalable.
2. Ensure any text boxes that requirement user input have relevant restraints.
    a. A text box should not allow an unlimited amount of characters.
    b. Appropriate messages should be shown to the user to make them aware that not answering a question will result in a zero score for that question.

3.2 ethical implications of implementing the MMSE into a mobile platform

The main ethical issue posed by building a proof of concept to prove user competence using the MMSE that is designed, tested and expert user evaluated is that of a below competence score in the examination. It is important to acknowledge the impact that a user failing to successfully meet the no cognitive impairment score will have. A user inferring that they have been clinically diagnosed with a cognitive dysfunction violates both ethical principles in psychology and software development. For these purposes, it is vital it is made abundantly clear before any user completes this digital implementation of the MMSE that although it is a valid, reliable and established test for cognitive impairment there are numerous external factors that can interfere with the results. A failure to meet a passing score is in no way reflective of the ability of their cognitive functions and this is by no means a diagnostic tool when used in the context that I am implementing it in. Merely a proof of concept that is built to the extent of being ready to test its ability to be used for a diagnostic tool if digital

equivalence can be proved in the future. If a score is below the no cognitive impairment bracket it merely means that we are suggesting for the user, it would be more appropriate to have a one to one conversation with a lawyer as a more suitable way of making and/or changing their last will and testament. To avoid violating these crucial ethical principles, the design of my application includes a disclaimer at both the front page before a user begins the examination and the end page of the application where a user receives their score. The front-page caution reads:

"USERS PLEASE READ BEFORE YOU BEGIN
Please note that the results of this MMSE are in no way indicative of your competence levels or cognitive functions. Any score that falls below no cognitive impairment merely means that it would be recommended that you make or amend your will in the presence of a lawyer".

While the back-page caution reads:

"Please note that this version of the MMSE is only a general guideline and does in no way accurately reflect your cognitive ability".

This ensures that all users understand that this is not a clinically diagnostic tool as of yet, just a general indicator of competence and has not been built to accurately reflect cognitive ability. At every appropriate time. The outcome of the examination itself is either recommendation to make a will with a lawyer present or not.

3.3 Design

I have developed the following use case diagram to mirror the functionality that users of the application will need in order to get the most from it. This has helped visual the needs of the user and keep them in the forefront of my mind at all times when designing the application. Doing so has ensured that the architecture of my system is comprehensive and all the requirements are transformed into functionality, ensuring none are overlooked. See figure 1.

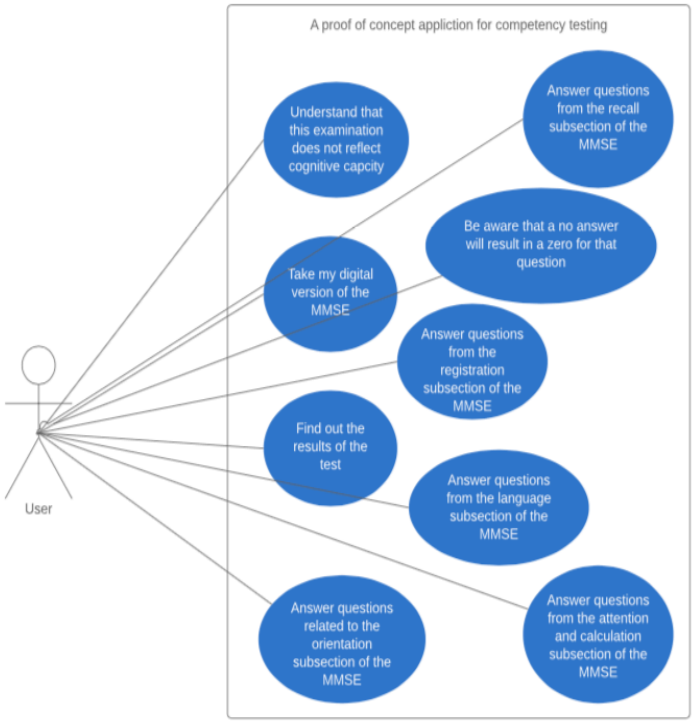


Figure1. Use case diagram

3.3.1 Front-end Design

Before building my proof of concept, I made a low fidelity prototype using Adobe XD. This platform allowed me to begin the design process by easily and quickly making mock ups of some pages giving me a basis to build upon. See figure 2 below. The full prototype can be found in Appendix 1.

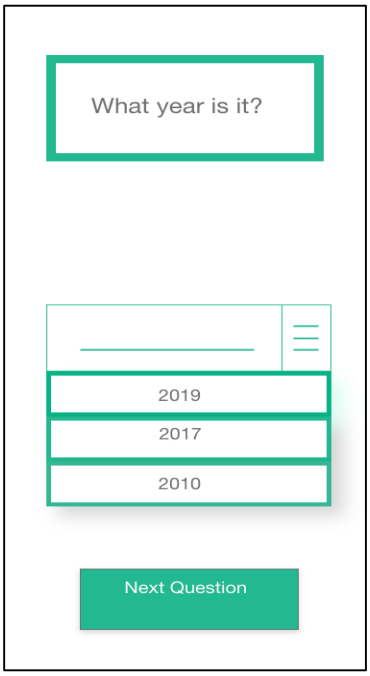


Figure2. First page of prototype

By doing so, I could visualise my digital MMSE before coding took place which helped ensure the GUI incorporated the 10 user design heuristics. These are needed to assure that the functionality I implement is not only accurate and reflects the requirements appropriately but that it is also user friendly and is designed around their needs and technical knowledge. The 10 usability principles are as follows[23]:

1. **Clarity of system – users should always be aware of what is happening at all times via responses from the system.** This was done by creating toasts that communicate any reason why the system may not behave in a way that they would assume. For example, I have implemented pop up messages prompting a user to enter an answer before moving on that appear if a user has left an answer empty.
2. **Consistency between the system and the non-technological word – the wording used and shown by the system to the user should be consistent with that of the real word. All instructions and error messages should not use technology orientated wording so users can easily understand.** This was done by writing all my error messages carefully to be sure all users regardless of technological background can easily understand what is happening.
3. **Flexibility for user – the application should be easily navigable for users, reducing the likelihood that wrong actions will be carried out by mistake**. My application uses limited buttons to avoid confusion. They will be able to easily proceed to the next question while making use of the back button on their device.
4. **Cohesion of system – users should be able to differentiate all actions and situations without ambiguity.** All pages, button and language is consistent throughout the application.
5. **System fault evasion – common errors must be checked for; meaningful error messages are not enough to satisfy this principle.** Code has been implemented to account for common errors such as leaving answers empty to prevent this happening.
6. **Understanding rather than remembering – all actions needed to be carried out by the user should be transparent.** All questions, answers and buttons in the GUI have been designed such that users are clear on what to answer and how to answer the questions implemented in my digital version of the MMSE.
7. **User control and effectiveness – the application should cater to users of all technological knowledge level.** This principle also states that expert users should be able to tailor the application to their expertise. Due to the nature of this proof of concept this was not possible as the MMSE is not build for flexibility rather it is a measure, however, keeping this principle in mind at all times during design I tried to make the interface as simple as possible to improve efficiency.
8. **Layout – the design of the app should have no redundant information or extras. It should be a minimal and easy to understand interface.** I have kept to this principle by ensuring that there is no more information than necessary in each page of the

[23] Nielsen Norman Group. (2019). *10 Heuristics for User Interface Design: Article by Jakob Nielsen*. [online] Available at: https://www.nngroup.com/articles/ten-usability-heuristics/ [Accessed 8 Aug. 2019].

application. It has been kept to the question, answer and either the submission and/or next question button.

9. **Enable all users to identify errors and resume use thereafter – all error messages to be in easy to understand language. No technical language or code should be used to describe the error.** Similarly, to principle 7, due the nature of the application there are few errors that could possibly occur. All error messages, however, are written in plain English with no technological language or references.
10. **Appropriate help pages and FAQ's where applicable – these should be easily found and accessible.** Although, help pages and FAQ's are not applicable to my proof of concept, user information indicating that this MMSE is not for diagnostic purposes and is not indicative of a user's cognitive functions are found both at the start and the end of examination. Easily readable and accessible.

It became clear, however, after designing and creating my low fidelity front-end application prototype, that it was not a suitable design to implement for the purposes of my proof of concept. As shown above, this prototype was designed with drop down menus. I did so for the GUI as these are good for the user. Enabling efficiency and ease of use as well helping with a contextual understanding of what is happening at each stage of the examination and at what page. The nature of the MMSE made this proposed design ineffective because it may invalidate what the examination is aiming to measure rendering the outcome of the proof of concept inaccurate due to eternal variables; in this case the very design of the examination. The MMSE as mentioned above in the literature review, is composed of questions that can be divided into 5 subsections: orientation, registration, attention and calculation, recall, language and copying. Giving the users a group of options could potentially change a question that was designed for recall into a question that is measuring recognition. A drop-down menu providing the user with options may also skew results of the examination due to external variables such as lucky guess work to a more significant degree than would be found and measured when users are not given a choice (there are always outliers in such examination results, some of which may be accounted for by guess work). The outcome of both potential external variables has significant ethical and professional implications by which could conceivably result in a user who is not cognitively competent to make and/or change their last will and testament go forward to do so due the design of the application causing the examination to not accurately represent a user's cognitive abilities. This would result in potentially vulnerable individuals being taken advantage of or making poor decisions which are facilitated by our software. For these reasons, therefore, I had to redesign the user interface relative to how users will answer each question as not to invalidate resulting scores. The best option for this, in my opinion, was a simple and self-explanatory need to type the answer into an edit text box. I found that because of the nature of my thesis, there was sometimes a need to sacrifice the usability and ease of the user interface to ensure the validity of the MMSE. It is crucial to meet my central requirement on which this whole thesis is based; build a digital version of the MMSE. Not forgoing some preferred usability functions would result in a failure to meet the overarching core of my dissertation as a consequence.

3.3.2 Back-end design

While considering the design of the back-end of my proof of concept, I felt that it was best fit to follow the design of the app overall. It could be argued that the back-end design of the application could have been more concise with the use of a super class but this quickly

produced unnecessary code during implementation. The same could be said about having a question class, an answer class and a score class, which has not escaped me. Again, this was unsuitable due to the over complication that it causes and although a good back-end design is necessary it should not be at the expense of others being unable to understand your code. The architecture of the design, therefore, was made up of each question having its own class in which the answer is also coded. The front-page caution and end-page score reveal also had their own class. This design made the back-end code much easier to understand and it was consistent with the overarching architecture of the overall application itself. It made the most logical sense to do so and keep the design coherent with the paper-based MMSE. It also meant that any changes and edits to the code were much easier without the need to refactor such changes across multiple different classes which would leave the proof of concept open to many errors which would cause the code to break and the application itself not to compile. The number of classes needed does increase the file size which is important to recognize when considering the issue of scalability. The larger file size has consequences, the numerous lines of code that must communicate with each other will take longer due to the fact they are in separate classes with no super classes, interfaces or hierarchy. This is turn, will cause the application to perform slower when moving from function to function, especially if more content is added in future. In this case, I felt it was appropriate to make the decision to possibly compromise an aspect of scalability for a comprehensive design, especially because there are limited users and my proof of concept does not have a back-end database which will help reduce other scalability problems in future. This was a worthwhile concession in my opinion and enabled the back-end of my proof of concept to make the most common sense by following the design of the application as a whole.

3.4 Methodologies for supporting the software development life cycle

There are 2 software life cycles. The Software Development Life Cycle (SDLC): the project as a whole, requirements, design, construction, testing and evaluation and the Software Product Life Cycle (SPLC): deployment, maintenance and support thereafter. The software life cycle is a crucial component of any software development project. This is key to managing the software long-term not just during development but also after deployment – a good software maintenance facilitates a good software life cycle and will ensure the requirements for my thesis will be continued to be met[24]. Not only this, but it will help with efficiency and cost in the future[25].

3.4.1 SDLC Methodologies

Youtrack, a project management development tool proved incredibly useful throughout the SDLC of my thesis. I used Youtrack to help with my agile scrum like development process. An agile development process is by far the best at it allows developers to adapt to issues and changes throughout the process to best deal with issues that arise. It facilitates the development not only for the developers themselves but for the client as well – saving time and money. This makes agile development a superior process compared to the outdated rigid old styles of development that has led to the failure of numerous projects. Scrum – an agile development method - is made up a project backlog – a list of requirements and functionality that needs to be completed, the sprint backlog – delegated work that comes from the project

[24] Bourque, P. and Fairley, R. (2014). *SWEBOK*. 3rd ed. IEEE Computer Society.
[25] Bourque, P. and Fairley, R. (2014). *SWEBOK*. 3rd ed. IEEE Computer Society.

backlog and daily scrums – meetings where the team will discuss progress and problems that need to be overcome[26]. Traditionally, scrum is used by software development teams but I modified the main principles to suit my thesis and development process. Youtrack was used to do this. I entered the requirements into Youtrack to create a modified version of the project backlog and colour coded these accordingly: red for a severe level of urgency, orange for a moderate level of urgency and green for a mild level of urgency. From this, I was able to create a scrum backlog by completing the red tasks first and changing the urgency levels of different functionality over the course of the development depending on any issues I ran into. For example, location technology needed for the second half of the orientation questions to be implemented was originally labelled orange, however, it was changed to red as I ran into issues when writing code for this making it a time sensitive issue over the course of a few weeks. By doing this, I could see at glance what I have done, what needs to be done and get an approximate overview of how much time it would take to complete my digital version of the MMSE. This allowed me to plan, adapt and overcome any issues saving me time and making my process more dynamic.

3.4.2 SPLC Methodologies

Although, this is a dissertation project it is still important to plan and prepare for the potential future of my proof of concept and how I will support this. It is a natural element of the software development process that should not be ignored and I felt it important due to Lifeium's potential to use my application to help raise funding for their app. I therefore, saw Lifeium as a potential client and it is only natural for them to be treated as such. Android Studio facilitated the SPLC by having Git integrated software. Git was a vital element in my development process and it meant I always had 2 copies of my code, so if there was a problem with my device I had another stored copy as a back-up (this is needed in any project and is good practice). It also meant that as I committed any changes I was able to pin point what change had broken my code as it provides a descriptive break down of what changes were made and on what date. This for example, helped me solve my problem of null object reference – I had a built a new page which was committed with a detail description, after which my application kept crashing. Using Git helped me find that it was this page causing the issue so after a close inspection of my java code behind this question page it became clear I hadn't reference the correct the text box – something that would have taken a long time to figure out without Git because I was making multiple pages a day. My IDE - Android Studio - meant that I was able to conveniently upload my project to Git and commit any changes that have been made over the development period, along with comprehensive and detailed notes regarding the changes that were made and why. I will be able to give Lifeium access to this private project through Git so they can download and modify my proof of concept at their own convenience. It will allow a new developer to see my process and understand what I have done and to what point I have reached. It also provides version control which is imperative for any application going forward, with any successful app it is common for multiple users to have different versions of the applications software. If Lifeium's mobile application was to become popular Git will help to control for this problem, so using Git to support the SPLC was the best choice for my MSc thesis. Regression testing was also used throughout my project to

[26] Scrum.org. (2019). *What is Scrum?*. [online] Available at: https://www.scrum.org/resources/what-is-scrum [Accessed 12 Aug. 2019].

not only help with development but to support the SPLC. This will be discussed in more depth in the analysis section.

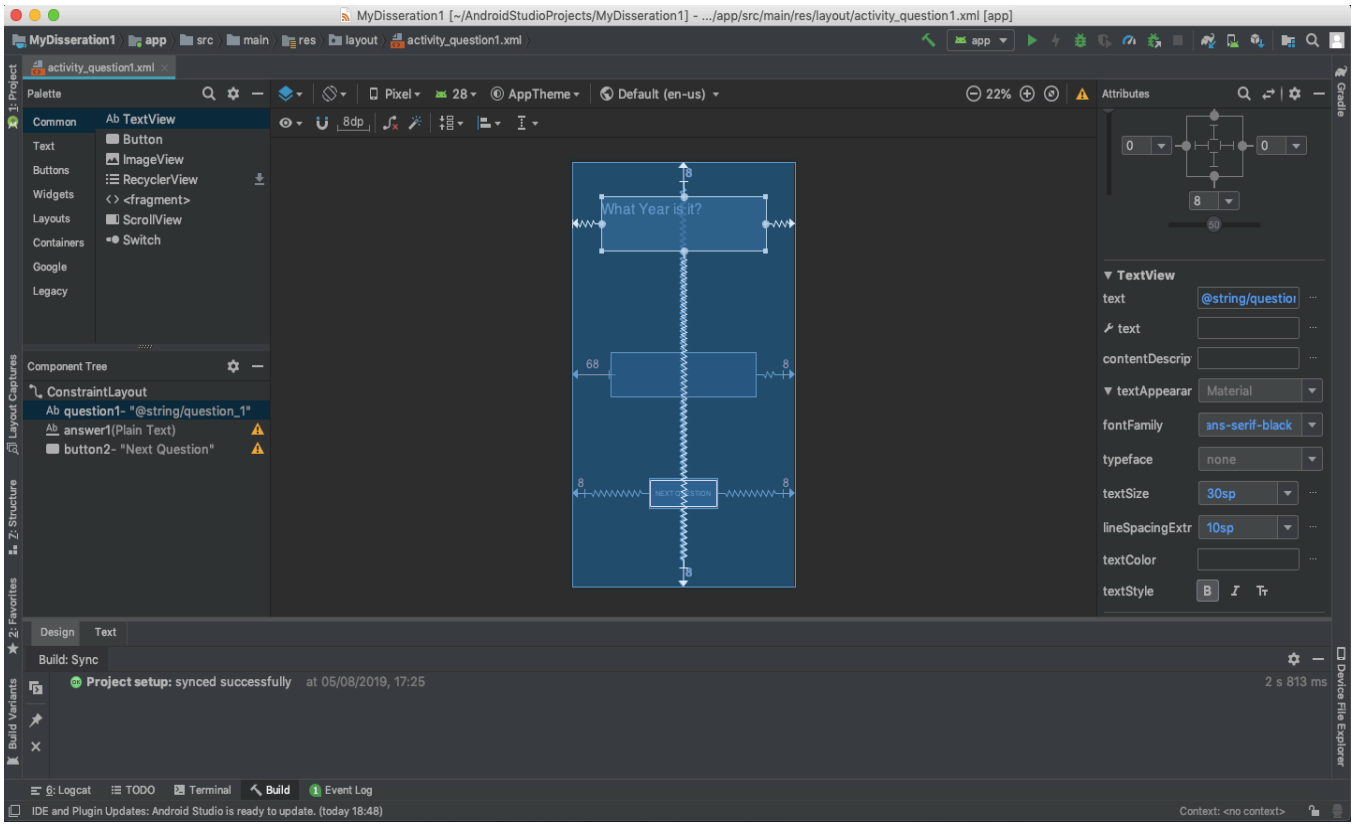
4.Construction

4.1 Construction tools

When developing software, it is important that the right tools are used. Without these, the build process can be over complicated and confusing – this will result in poor code consistency, poor integration, subpar user interface, availability problems and other developers being unable to understand what you have implemented. A good and established IDE is, in my opinion one of the most important tools when developing a piece of software. For this reason, I chose Android Studio as my IDE. This IDE provided me with seamless integration between my back-end and front-end code which helps with scalability issues preventing slow functionality for current users and if/when my proof of concept is built upon. Not only this, it has a comprehensive debugger that helped me fix problems with my code during the construction process – specifically my counter but not limited to – by stepping through the method to see at what point my function was not executing what I thought it was. Android studio also offers refactoring functionality across the whole application saving time, effort and easily missed but avoidable errors. As well as this, it has Git integration software that enabled me to link my dissertation project this Git so it was easy to create the Git project and commit any changes I had made saving time. All the functionality discussed in this subsection has no doubt facilitated my construction process for the entirely of my thesis work which in turn, further shows the significance of construction tools when developing software. A good IDE is central to the development process.

4.2 Front-end construction

The front-end language used to build my competence examination was xml. This language is a comprehensive and easy to use mark-up language that I am familiar with. This meant I had the relevant experience needed to build a GUI that is usable and accessible for the mass majority of the public. The IDE I used to build my digital version of the MMSE was Android Studio that predominantly uses xml; this language lent itself well to the environment, using little memory and allowing the application the adaptability needed for scalability issues in the future. Android studio was the best fit for me to build my whole application because it is more available and well known than IOS: Apple have their own unique programming language – swift - meaning less developers are familiar with it and many extras cost money when using Apple compared to Android. Xml was used to create text views, edit texts and buttons to join the back-end code to the front end. Input types were also set using xml to code the input types required in text boxes and link buttons to the relative programmed code in the back-end. These were constructed, edited, sized and customized in what is called an activity - each activity makes a different page of the app. These can be built in 2 different ways. Android Studio allows the front-end to be built using an interactive design page, where you select what type of layout is needed and from there selecting text boxes, edit texts, buttons and more. Resizing is done by using the mouse to physically size and enter dimensions, drag to position them and customize by changing font and colour through the interface. A page of my application is shown below within the interactive design page as an example – figure 3.



Firgure3. Design interface picture

It also allows a user to build the activity page through actual xml code as well as the design interface as shown above. Xml is a mark-up language so it is easy to understand and program but it is also powerful enough to make some very comprehensive design views if used correctly and if a developer knows the language relatively well. Text views, edit texts and buttons are all created using the same syntax. These constraints are opened using the < icon and all information concerning each is written in the main body, eventually being closed using the /> icon. The first question page of my application is shown as an example of the xml code used to create each page of the graphical user interface:

```
<?xml version="1.0" encoding="utf-8"?>
<android.support.constraint.ConstraintLayout
xmlns:android="http://schemas.android.com/apk/res/android"
    xmlns:app="http://schemas.android.com/apk/res-auto"
    xmlns:tools="http://schemas.android.com/tools"
    android:layout_width="match_parent"
    android:layout_height="match_parent"
    tools:context=".Question1Activity">

    <TextView
        android:id="@+id/question1"
        android:layout_width="304dp"
        android:layout_height="94dp"
        android:layout_marginTop="8dp"
        android:layout_marginBottom="8dp"
        android:lineSpacingExtra="10sp"
        android:text="@string/question_1"
```

```
            android:textSize="30sp"
            android:textStyle="bold"
            app:fontFamily="sans-serif-black"
            app:layout_constraintBottom_toBottomOf="parent"
            app:layout_constraintEnd_toEndOf="parent"
            app:layout_constraintStart_toStartOf="parent"
            app:layout_constraintTop_toTopOf="parent"
            app:layout_constraintVertical_bias="0.082" />

        <EditText
            android:id="@+id/answer1"
            android:layout_width="268dp"
            android:layout_height="76dp"
            android:layout_marginStart="68dp"
            android:layout_marginLeft="68dp"
            android:layout_marginTop="8dp"
            android:layout_marginEnd="8dp"
            android:layout_marginRight="8dp"
            android:layout_marginBottom="8dp"
            android:ems="10"
            android:hint="@string/answer_1"
            android:inputType="textPersonName"
            app:layout_constraintBottom_toBottomOf="parent"
            app:layout_constraintEnd_toEndOf="parent"
            app:layout_constraintHorizontal_bias="0.044"
            app:layout_constraintStart_toStartOf="parent"
            app:layout_constraintTop_toTopOf="parent"
            app:layout_constraintVertical_bias="0.499" />

        <Button
            android:id="@+id/button2"
            android:layout_width="126dp"
            android:layout_height="52dp"
            android:layout_marginStart="8dp"
            android:layout_marginLeft="8dp"
            android:layout_marginTop="8dp"
            android:layout_marginEnd="8dp"
            android:layout_marginRight="8dp"
            android:layout_marginBottom="8dp"
            android:onClick="nextQuestion"
            android:text="Next Question"
            android:textColor="#FFFFFF"
            android:background="#009688"
            app:layout_constraintBottom_toBottomOf="parent"
            app:layout_constraintEnd_toEndOf="parent"
            app:layout_constraintHorizontal_bias="0.498"
            app:layout_constraintStart_toStartOf="parent"
            app:layout_constraintTop_toTopOf="parent"
            app:layout_constraintVertical_bias="0.809" />
    </android.support.constraint.ConstraintLayout>
```

As is shown by this code, xml is a descriptive and easily understandable language.

4.3 Back-end construction

I have built the back-end of my proof of concept using java. Not only is java one of the most commonly known and predominantly used languages, it has numerous libraries available to it which facilitated the construction process of the back-end. Not to mention it is the programming language I am most familiar with. By choosing java, it also allows Lifeium – if

they so desire – to give my proof of concept to another developer in future and have them build upon it. Java will ease this transition because most developers know the language well and will easily understand the code written and what it is designed to do, while allowing them to build over it and make it more scalable for multiple users. For example, a back-end database using SQLite is fairly easy and has the ability to cope with larger volumes of data. There are many accessible libraries in java that have helped transform the MMSE into a digital format. The first library used was Calendar which was used alongside Locale. The Calendar API proved very useful in transforming the first section of the MMSE – orientation – into a digital format. By implementing this library, I was able to easily get the current date and time. It was relatively simple once this was done to engineer these data fields to return the year, month and weekday[27] by implementing the Locale class that finds these data sets specific to the Country. From here, it was a case of using a getter to return the data field needed using the Locale, for example - the month as was done in question 2:

```
        public String getMonth(){
    String month = Calendar.getInstance().getDisplayName(Calendar.MONTH,
Calendar.LONG, Locale.getDefault());
    return month;

}
```

I then coded the front-end to check for equality between the user answer and the back-end getter method. This was done for questions 1 – 3 of the MMSE, enabling me to successfully implement these questions digitally. Questions 4 and 5 were not implemented in this proof of concept the reason for this will be explained in detail in both the evaluation section and the future development section. The second class implemented was for the remaining questions in the orientation subsection. There questions related to where a subject was located: country, town, district, hospital and ward which were adapted to suit the needs of this application. Android studio has a Geocoder Class that enables developers to implement a Geocoder for the purposes of converting the longitude and latitude coordinates into a street address and vice versa[28]. I was able to implement the Geocoder Class into my code and use it for the function of translating coordinates into a street address. By doing this, I used the Geocoder to return the street address of the users coordinates by setting a list of strings equal to the street address as follows:

```
        myAd = myGeoCoder.getFromLocation(latitude, longitude, 1);
```

After initialising the Geocoder as shown above, it was able to return a set of data fields such as the country, the country code, the postcode, the street, the building number etc. An example used to return the country is shown below, this was taken from my question 6 code:

[27] Docs.oracle.com. (2019). *Calendar (Java Platform SE 7)*. [online] Available at: https://docs.oracle.com/javase/7/docs/api/java/util/Calendar.html [Accessed 10 Aug. 2019].

[28] Android Developers. (2019). *Geocoder | Android Developers*. [online] Available at: https://developer.android.com/reference/android/location/Geocoder.html#getFromLocation(double,%20double,%20int) [Accessed 10 Aug. 2019].

```
        public String getCountry() {
          String country = myAd.get(0).getAdminArea();
          return country;

      }
```

The same was done for remaining questions within this subsection again, coding the front-end xml to check for equality between the user answer and the back-end getter. Questions 11, 12, 12 alternative, 13 and 14 of the subsections: attention and calculation, recall and language did not need external classes to implement them. All it needed was back-end java code that programmed what the answer should, an example taken from question 12:

```
               public int subtractFirst7(){
                    myNumber1 = 100 - 7;
                    return myNumber1;
           }
```

and front-end code that checked that the users answer was equal to the back-end programmed answer, an example taken from the question 12 front-end activity class:

```
        public void firstAnswerCorrect(View view) {

    EditText first7 = (EditText) findViewById(R.id.first7);
    int first = Integer.parseInt(first7.getText().toString());
    first7.setFilters(new InputFilter[]{
            new InputFilter.LengthFilter(30) {
            }
    });
    if (!(first7.getText().toString()).equals("")) {
        if (first == mySubtraction.subtractFirst7()) {
            SharedPreferences myPrefs = getSharedPreferences("myPrefs",
Context.MODE_PRIVATE);
            SharedPreferences.Editor editor = myPrefs.edit();

            int counter = myPrefs.getInt("counter", 0);

            counter++;

            editor.putInt("counter", counter);
            editor.commit();

        }
```

although this example was taken from question 12, question 12 through to 14 had similar code – the same premise was used and adjusted to suit the MMSE question. Question 15 was executed by using speech to text technology as the MMSE requires a patient to say a sentence at this point in the language subsection. This was done using java code and starting a speech to text intent to execute the activity and then transforming the speech into a list of strings:

```
public void startToSpeak(View view) {
    Intent intent = new Intent(RecognizerIntent.ACTION_RECOGNIZE_SPEECH);
    intent.putExtra(RecognizerIntent.EXTRA_LANGUAGE_MODEL,
RecognizerIntent.LANGUAGE_MODEL_FREE_FORM);
    intent.putExtra(RecognizerIntent.EXTRA_LANGUAGE, Locale.getDefault());
```

```
    if(intent.resolveActivity(getPackageManager()) == null) {

        Toast.makeText(Question15Activity.this, "Correct",
Toast.LENGTH_LONG).show();
    }
    else {
        startActivityForResult(intent, 20);
    }

}

@Override
protected void onActivityResult(int requestCode, int resultCode, Intent
data) {
    super.onActivityResult(requestCode, resultCode, data);
    switch (requestCode) {
        case 20:
            if (resultCode == RESULT_OK && null != data) {
                ArrayList<String> result =
data.getStringArrayListExtra(RecognizerIntent.EXTRA_RESULTS);
                mySpeechToText.setText(result.get(0));
            }
            break;
    }
}
```

The final aspect that needed to be implemented to complete my digital version of the MMSE was a counter to keep track of the users score. This proved difficult as first due to each page having its own activity class in Android Studio. Trying to build a counter that worked outside of each class yet tracked the answers within each class took some time to solve but eventually was realised with the SharedPreferences Class available form android studio, this allows data to be retained in a constant state across multiple activities[29]. SharedPreferences was a very useful interface in solving this problem. Code was written into the if statements that checked the equality of the user answer and the correct answer – if the user was correct 1 was added to the counter (an asterisk has been added to the left hand side of the relevant lines of code):

```
public void nextQuestion (View view) {
    EditText answer1 = (EditText) findViewById(R.id.answer1);
    answer1.setInputType(InputType.TYPE_TEXT_FLAG_AUTO_COMPLETE);
    answer1.setInputType(InputType.TYPE_TEXT_FLAG_AUTO_CORRECT);
    int answer = Integer.parseInt(answer1.getText().toString());
       if (answer == myQuestion1.isAnswer1Correct()){
        * SharedPreferences prefs = getSharedPreferences("prefs",
*Context.MODE_PRIVATE);
       * SharedPreferences.Editor editor = prefs.edit();

       * int counter = prefs.getInt("counter", 0);

      *  counter++;

       * editor.putInt("counter", counter);
```

[29] Android Developers. (2019). *SharedPreferences | Android Developers*. [online] Available at: https://developer.android.com/reference/android/content/SharedPreferences [Accessed 10 Aug. 2019].

```
        * editor.commit();

    }
```

The last 2 lines with an asterisk introduce and editor, the reason being any modifications to a SharedPreference must be inspected by this editor object to maintain the values constant state before being stored in the preferences[30]. The ShapredPreference data was the totalled and displayed in the OverallScore class needed to show the user their score (similarly an asterisk was placed to the left of the relevant lines of code):

```
@Override
protected void onCreate(Bundle savedInstanceState) {
    super.onCreate(savedInstanceState);
    setContentView(R.layout.activity_overall_score);
    TextView myFinalScore = findViewById(R.id.myFinalScore);
    TextView myDisclaimer = findViewById(R.id.myDisclaimer);
    myDisclaimer.setText("Please note that this version of the MMSE is
only a general guideline and does in no way accurately reflect your
cognitive ability");

   * SharedPreferences prefs = getSharedPreferences("prefs",
Context.MODE_PRIVATE);

   *  int counter = prefs.getInt("counter", 0);

   * myFinalScore.setText("YOU SCORED: " + counter + "/ 22");



}
```

Finally, I had to implement a method that cleared the score because any value in the SharedPreference remains contestant as it sorted until it cleared (asterisk at the left of code applicable):

```
public void OnClickResent(View view) {
    TextView myFinalScore = findViewById(R.id.myFinalScore);
    SharedPreferences prefs = getSharedPreferences("prefs",
Context.MODE_PRIVATE);
    * int counter = prefs.getInt("counter", 0);
    * prefs.edit().clear().commit();
    Intent intent = new Intent(this, MainActivity.class);
    startActivity(intent);
}
```

The use of java made the back-end construction of this application efficient, comprehensive and adjustable in future. It proved throughout the build process that it was the most suitable choice for this proof of concept.

[30] Android Developers. (2019). *SharedPreferences | Android Developers*. [online] Available at: https://developer.android.com/reference/android/content/SharedPreferences [Accessed 10 Aug. 2019].

5.Analysis

5.1 Testing

I have tested both my front-end xml code and back-end java code in depth to ensure that there are as little bugs as possible. It was important that I used a multitude of different testing techniques because no individual method of testing would have been sufficient enough to ensure that my proof of concept was properly integrated and that my code worked the way in which I intended.

5.1.1 Unit Testing

All the back-end java code of my application has been vigorously unit tested. This ensured that I could test my back-end code in isolation from other components of my system[31]. Unit testing allowed me to evaluate each line of code from each class independently. It was important to do so because I had to check that not only did my application work but each aspect of code regardless of integration is doing what it should be. Unit tests confirmed that the code was working appropriately. I did so by predominantly using the following test functions to ensure that all back-end methods were behaving in the way in which I intended:

```
assertEquals();
assertNotNull();
```

5.1.2 Functionality Testing/ Test Driven Development – form of test driven development in this way

Test Driven Development (TDD) is an agile development tool, I used my own interpretation of TDD throughout the development process. Traditionally, TDD is done using unit tests. A unit test for a select piece of functionality is written before the actual method is written. Once the unit test is complete, the bare minimum amount of code is written specifically to pass the previously written unit test. I modified the conventional method of TDD and instead of using unit tests, I tested the functionality by printing results to my screen using toasts – a line of code within Android Studio that prints messages onto the user's screen. The reason for doing so was because although unit tests are an integral part of the testing procedure, my proof of concept contained more code in the front-end that linked both components together to create a cohesive application. The back-end code was mostly returning a value from a java library or a few lines of code to program the answer, making unit tests for TDD potentially ineffective. It was the linking of the front-end to the back-end ensuring that these are properly integrated that was most important in the development of this proof of concept. The whole reasoning behind TDD is to establish that while developing a piece of software, the client requirements are always in the forefront of the developer's mind. Unit tests would not satisfy this for my project so it was best to test each piece of functionality by writing an if statement that would toast (print) correct onto my screen if the users answer matched the java answer or incorrect if it did not. I then wrote the code that would link this together and satisfy the if statement, from here the method was executed and the toast printed on screen to alert me

[31] Bourque, P. and Fairley, R. (2014). *SWEBOK*. 3rd ed. IEEE Computer Society.

as to whether the code was doing what it was meant to. An example taken from my application:

```
        if (answer.equals(myDate.isAnswer1Correct())) {
             SharedPreferences prefs = getSharedPreferences("prefs",
Context.MODE_PRIVATE);
             SharedPreferences.Editor editor = prefs.edit();

             int counter = prefs.getInt("counter", 0);

             counter++;

             editor.putInt("counter", counter);
             editor.commit();

             Toast.makeText(Question4Activity.this, "Correct",
Toast.LENGTH_LONG).show();

    } else {
        Toast.makeText(Question4Activity.this, "Incorrect",
Toast.LENGTH_LONG).show();

    }
}
```

My take on TDD meant that I could implement the requirements properly because they were the very basis of the functionality tests that were written – I had to make sure that I was writing the correct tests before writing the code – consequently ensuring the requirements were met while eliminating any redundant code by only writing code that was needed to satisfy said test. TDD has proven to be a useful tool throughout my thesis work as it allowed me to always keep the requirements and design in mind when programming, this helped me spot and solve problems with code that did not work the way in which it was meant to[32], problems with my design and when I was straying from the requirements at hand. This ensured that the application was appropriately integrated as well as helping with fulfilling a non-functional requirement. It did so because it helped to eliminate redundant code, in turn keeping the file size down and making it more scalable for different devices and functionality in future.

5.1.3 Regression Testing

Regression testing was also used to test the code written for my thesis. This, as previously mentioned in the methodology section, supports the SDLC. It was important that as more functionality was added to the application that they system did not change, unless intended to. It is vital that all previously tested methods continue to pass as the system grows[33]. I implemented regression testing as I conducted my TDD: each time a new page was added to my proof of concept I wrote an if statement, wrote the code to pass it, reloaded my application on the emulator and then began going through the MMSE I digitised from the beginning. This process combined both TDD and regression and ensured that the system behaved in the same way after new functionality was added and the new functionality also behaved the way in which it was intended. In the event that my system failed, regression

[32] Bourque, P. and Fairley, R. (2014). *SWEBOK*. 3rd ed. IEEE Computer Society.
[33] Bourque, P. and Fairley, R. (2014). *SWEBOK*. 3rd ed. IEEE Computer Society.

testing, along with Git helped to pin point what new code had broken my proof of concept as every method was tested and checked off before adding new functionality – when the application broke during development it had to be the newest functionality added. This saved time and effort while completing the software aspect of this dissertation project.

5.1.4 Integration Testing

Integration testing proved to be particularly useful throughout my project by enabling me to locate exactly what line of code was causing an error when the method was large with numerous different components. Integration testing involves testing individual components of the system as independent parts before integrating the system. I was able to find and fix bugs that emerged when combing all individual parts of code. For example, when integrating the system, the correct answer counter was not working correctly. The debugger was used to isolate this method and step through each line of code individually to locate the issue that was occurring when integrating all classes. It turned out that I was creating a new counter for every instance of a class rather than building a counter that persisted across the whole system, after realising this the problem was fixed by making the counter a SharedPreference:

```
SharedPreferences prefs = getSharedPreferences("prefs",
Context.MODE_PRIVATE);
SharedPreferences.Editor editor = prefs.edit();

int counter = prefs.getInt("counter", 0);

counter++;

editor.putInt("counter", counter);
editor.commit();
```

Integration also solved the location error. For the majority of questions in the orientation subsection I needed to return a street address – this requires a location manager and to return the locations longitude and latitude coordinates and a Geocoder that transforms these coordinates into a street address. For weeks, the code continually crashed when I invoked this method. When this code was in complete insolation rather than when it was integrated as whole method within the system, I could check the location manager and Geocoder individually and found that the location manager was not retrieving location coordinates so it was this section of code that was causing the error rather than the Geocoder. Integration testing, therefore, facilitated the development process significantly by allowing me to find errors through isolating code, thus, confirming the importance of integration testing when working on a development project.

5.2 Evaluation

To appropriately evaluate the outcome of my dissertation project it is important to consider 2 main questions: Have I met all the project requirements? And have I built what I intended to? It may seem that these questions are interchangeable, however, this is not the case. Meeting all the requirements is one thing but it does not necessarily mean that I have built what was indented. For this reason, following section has been split into 2 parts: expert evaluation whereby I determine if I have built what I have intended to and acceptance testing where I determine if I have adequately met all the project requirements.

5.2.1 Expert evaluation

It is important that any application is appropriately tested before it is said to be complete. For my proof of concept the most suitable method of user testing was in the form of expert evaluations. Due to the nature of this application a simple version of user testing to check that the GUI was acceptable, easy to use and understandable was not suitable because of its complex psychological underpinning. An effort to check that others found the interface useable does not confirm that the digital implementation of the MMSE measures what it does in the paper based version. Although it is always beneficial for all applications to be user tested and interfaces changed based on others opinion this user testing would not have benefited this project in the same way expert evaluations would. For this purpose, I used expert evaluations to analyse my application. I did so by hand picking a number of lecturers throughout the University whose skills collectively would provide me with a thorough set of expert opinions ranging from psychological to technical. This meant that GUI and the way the questions were implemented i.e. not changed the measure that the MMSE aims to score, were rigorously tested by a broad range experts, thus, allowing me to make changes based on their opinions and produce the best proof of concept possible to be used for equivalence testing in the future. I ended up with 4 expert evaluators:

- Expert 1. Expert from the Computer Science Department, has significant knowledge of cognitive functions tests and cognitive impairment.
- Expert 2. Expert from the Computer Science Department, has significant experience with applications and mobile user interfaces.
- Expert 3.Expert from the Psychology Department, has significant experience in regards to the MMSE and has administered it numerous times.
- Expert 4. Expert from the Psychology Department, has significant knowledge of cognitive impairment and has worked in collaboration with numerous software developer and engineers on projects.

Like all expert evaluation outcomes during a development project, I had to prioritise which changes would be made first and which ones could be made in the future due to time constraints and the scope of my proof of concept– this was done by rating the evaluation points based on urgency as was done in the expert evaluations. The same ratings were used:

- 0 Don’t think this is a usability problem
- 1 Cosmetic problem; fix only if extra time is available
- 2 Minor usability problem; give a low priority to fixing the problem
- 3 Major usability problem; give a high priority to fixing the problem
- 4 Usability catastrophe; fix the problem before product is released

There were some points made that were not able to be implemented due to the nature of this proof of concept – some questions are too subjective to be implemented by myself and would need a trained clinician to advised on before further development. For the purpose of analysis, I have grouped the following evaluation points by urgency, completed and to be completed in future into clear tables for ease of reading and analysing. The section that is headed “a brief in description of evaluator concerns” does not contain the full version of the evaluator concern. The transcriptions from the expert evaluations are appended. Please see Appendix 2 for full details. See tables 4 and 5 for in depth analysis of expert evaluations below:

Changes made due to evaluation outcome

Problem description	**A brief description of evaluator concerns**	**My Severity rating**	**Explanation for severity rating**	**Changes to proof of concept in line with evaluation**
Originally Question 5 – What is your country code?	The problem is that people might not know their country code but not because of a cognitive impairment, which could cause results to be skewed. Another question already askes what country you are in, this is duplication.	4.	Problems with this question came up multiple times. Every evaluator had similar issues so this causes concern. It also means that is it likely users will have the same issues so it had to be addressed quickly. The severity of expert comments also made this a priority – it could cause inaccurate results.	The question itself was changed. The question was adapted from the orientation subsection of the MMSE to suit the needs of this proof of concept. An evaluator commented on how this a good idea but perhaps choose questions more likely to test for a deficit. The question was change to "what City are you in?". This takes away any ambiguity surrounding the question.
Registration subsection needs to adapted. Originally this question shows 3 pictures of different objects with their names next to it and askes a user to type in the names of each object.	The way the question was implemented meant that it was not measuring the aspect of cognition the MMSE aims to. The names of the objects are on the screen; they should instead be held in working memory.	4.	The way in which this question was interpreted came up numerous times. The MMSE states that the clinician say 3 object names then get the patient to repeat them until learned. A score of 1 is given for each object name repeated. The severity of the expert evaluations made this problem	Rather than have the picture and name of the object on the same page that the user is asked to enter their names, I separated the original 1 page to 6. Each object was given its own page where a picture and the name are shown. The next page askes the user to input the name of the object on the previous page. This expectedly will ensure the names of the objects are held in working memory.

			one that had to be addressed immediately.	I have coded a user message to appear on screen that says "correct" or incorrect when a user inputs the answer with the aims of helping a user to remember the object names.
Attention and calculation subsection needs to be adapted. Originally this question showed 5 calculations to be done by the user. The first 100-7 then subtracting 7 each time.	The way this question is implemented means that it does not measure calculation. The test is also easier by showing the sums i.e. I had set the questions as 100 – 7, 93 – 7 and so on.	4.	The way this question is laid out will cause inaccurate results. I had all questions on one page, which meant the answer to the question always visible. For example, 100 – 7 = what? the next section of the page askes 93 – 7 = what? This enables a user to figure out 93 is the answer to the first question meaning that this question wasn't measure calculation at all. The whole point of this project was to develop a proof of concept that is ready to be equivalence tested in the future. If my implementation of a question does not measure the cognitive function intended by the MMSE then I have	To avoid a user being able to see the answer to the question on the page of the application, I separated what was originally 1 page into 5 separate pages. Each page showed a calculation and asked the user to input the answer. This ensures that The first calculation had to show the sum to get the base value – e.g. 100 – 7 after which each question was worded the same "Subtract 7 from your previous answer" so the calculation sum was not shown, thus, not making the test easier.

			not reached the goal of this project.	
Order of the orientation questions.	The order in which the orientation questions are asked is important, the MMSE was designed in a way that these questions should go from a scale of very general to very specific. If this scale is changed it could have consequences for the validity	4.	Although only 1 evaluator mentioned it explicitly in their transcript it was also mentioned by another in conversation. The expert evaluation opinions made this an urgent change.	I changed the order of the orientation questions ranging from general e.g. “What country are you in?” to “What is your postcode?”. This is now in line with the original paper based version of the MMSE.

	of the proof of concept I have built.			
Layout of some Question Pages. The question page for the attention and calculation had all subtraction questions on one page with buttons to submit each answer, as well as, a next question button. The same was done for the registration and recall page – all questions on one page with a submit button for each answer and then a next question button.	No enough information on how to respond for these questions – this must be change due to high levels of confusion. This violates many user heuristics. The scoring of the examination could also be negatively affected by the setup. If a user did not click submit before proceeding to the next question, the answer was not scored as correct.	4.	Multiple experts expressed concerns over these pages – it was confusing so could result in inaccurate results due to my interface, not cognitive impairment. It violates many user heuristics. The user interface is also a very important part of the application, without a good interface design a good measure of cognition is not possible – results may reflect poor interface rather than design.	All question pages that were laid out in this manner where changed. Each question had its own page making it much easier to understand how to respond. The scoring is also fixed by this, there is now only 1 button on screen so a failure to press any buttons does not result in inaccurate scoring. The only page that has 2 buttons is now the registration for the objects, an object is shown and on the next page a user is asked to name the object and then press submit. Once done press next question to move on. This was done to help the user remember the object name - a message saying "correct" is shown when the user types in the correct object name and presses submit. It is the next question button that creates the score count in these pages if they have entered the correct answer then the next question button scores

				this once only then moves on.
Not clear what MMSE means. To start the MMSE I had a button that said "Begin MMSE".	Not sure what MMSE means, this violates user multiple heuristics.	3.	Expert evaluation concern meant that it should be changed urgently.	I changed the button wording to the non-abbreviated name. It now reads "Begin the Mini Mental State Examination". This a much more descriptive way to begin the exam.
More instructions and details needed throughout the application. More instructions based on what's happening next. More detail on what to answer when user faced with ambiguous questions.	When carrying out an MMSE in person, more context surrounding the question is given. An introduction is given for example "remember the objects from earlier…..". The proof of concept is lacking this which can confuse users. The way certain questions were laid out and little instruction given leaves a user unsure on what they are meant to do and can lead to inaccurate results.	3.	If the way in which questions are asked causes user confusion that can cause a poor result score that does not reflect cognitive impairment. It is important that there is no confusion surrounding the questions because this causes problems across 2 different aspects of the application: usability issues and accuracy of results. The spacing and format of how to enter the postcode is unclear.	I added more detail and instruction throughout the application. For example, previously question 2 asked "What month is it?" I have changed this to "What month is it? Please enter the name of the month not the number". The change means that users will not enter 08 instead of August which could have been a common mistake. This ensures more reliability of results. I have changed the "What is your postcode" question to "What is your postcode? Please use the following format: A9A 9AA" this stops any user error when inputting the postcode as the question is clear about how to answer. I have also introduced instructions for example, before the

				recall questions I have a purely front end page for the users' benefit explaining that the objects from earlier are going to be questioned and how this will be done. By doing so I added context surrounding the questions. This will again, help to ensure reliable results by minimising any user confusion.
Make the alternative question option more visible – the MMSE has an option to answer a different question instead of the serial 7s.	Some users may have issues with mathematics perhaps it makes them nervous which can cause inaccurate result or suffer from dyscalculia which again results in unreliable scores.	3.	It is important users are aware of the alternative question especially when considering the experts' comments on this. Although there was an alternative question option an expert did not notice it.	To combat this page, I created another activity page before the questions. It displays clearly that the user has a choice of question and should click the button corresponding to their choice. The buttons are clearly labelled and the descriptive text reads: "YOU HAVE THE OPTION TO COMPLETE A SET OF MATHS QUESTIONS OR A LANGUAGE QUESTION" + "PLEASE SELECT THE RELEVANT QUESTION BUTTON BELOW".

Orientation of the application.	The change in orientation can be off putting for users but this would be amplified if an elderly user suffering from cognitive dysfunction. It would cause a problem with cognitive load in this demographic of users which would cause results to be inaccurate.	3.	The application was set up so that the orientation of the screen changed when the phone was moved from a portrait position to a horizontal one. The expert evaluator concerns led to this to be a priority.	Code was added to each activity class to fix the orientation to portrait at all times, even when the mobile device was turned horizontally: this.setRequested-Orientation – (AcitivityInfo. – *SCREEN_ORIENTATION* - *SENSOR_PORTRAIT*); (This is represented in one single line of code in the application but had to be broken down for the purposes of this table format).
Distraction.	A user may be half way through the examination when their phone rings causing them to stop the examination half way through, resulting in a poor score but not due to any cognitive error.	2.	The MMSE is usually administered in a room with only a patient and a clinician so there are little to no distractions. The context of this changes when being used on a personal mobile phone in relation to distractions.	I added an activity page to the proof of concept that instructs a user to turn their phone to flight mode before beginning the MMSE to avoid distraction: " PLEASE PUT YOUR PHONE INTO FLIGHT MODE. IT IS IMPORTANT YOU ARE NOT DISTRACTED AT ANY POINT DURING THE EXAMINATION".
General input type validation.	When a number is required as input it is not always clear. The application crashes when it is expecting a number input	2.	Confusing interface again can cause unrepresentative results. It is important that the interface is understandable as this facilitates reliability.	I prevented the application from crashing when a number input was expected but not given. I did this by using an if statement that essentially tells the application only to retrieve and compare the answer if input is

	but doesn't one.		The app can crash when it expects a number and input but doesn't receive this. I cannot allow my application to fail.	given by using the following line of code: if (!(answer1.getText()- .toString()) - .equals("")) { (This is represented in one single line of code in the application but had to be broken down for the purposes of this table format). I also restricted the input that a user could give to make it clear what input is expected. When a number input was required I made sure that only numbers were shown on the keyboard. This was done by changing the input type in the xml format from: android:inputType= - "textPersonName" to: android:inputType= - "number" (This is represented in one single line of code in the application but had to be broken down for the purposes of this table format).

The picture of the watch I used. One of the questions in the language subsection involves showing the patient a watch and asking them what it is.	In the paper based version the clinician is to show the patient a wrist watch and ask them what it is. The picture I have used doesn't show a watch on a wrist, just a watch. This could cause some users to be confused as they normally see a watch on a wrist.	1.	The picture of the watch should be changed because it wasn't clear, however, it was not as urgent as others.	I changed the picture I had to a picture of a larger watch on a wrist.

Table1.Changes made following expert evaluations

<u>Changes not made due to prioritising</u>

Problem description	**A brief description of evaluator concerns**	**My Severity rating**	**Explanation for severity rating**	**Potential fixes to these problems in future.**
The name of my application.	The name of the application isn't suitable for users, it's not descriptive and it violates good design principle.	4.	The name of my application was "myDissertation1 " which is not appropriate for any users. It should be changed urgently.	This was left for the next development process because my application will not be deployed. It was more important to fix problems that could cause an inaccurate result due to psychological nature of the MMSE. This problem does not change the behaviour of the system but it should be done urgently in future development.

				The name of the application could be changed from “myDissertation1” to a more descriptive title potentially: "An Application for Indicating Cognitive Competence as Measured by the Mini Mental State Exam”.
Users may continually take the MMSE until they have learned it.	This would invalidate results as the answer to all questions are from memory – this would mean all questions in the digital version are failing to measuring what the paper based version aims to.	4.	This would invalidate the whole application so should be dealt with immediately in future development.	This was not changed as it is out with the scope of this thesis project. I am building a proof of concept to be ready for equivalence testing. This is a problem that would need to be addressed in the equivalence testing phase. It could be potentially solved, however, by limiting the amount of times a user can take the MMSE over a period of time or by changing the order of questions each time the user takes the examination.
Serial 7’s is not scored based on previous answer given only the correct answer.	This question should be scored based on the previous answer e.g. if the first answer is not correct then the next can still be given a score of 1 if the answer is 7 subtracted from	3.	It is important that the digital version is kept as close to the original version as possible to support validity and accuracy of results. This should be changed urgently	I did not make this change due to prioritising. I had already made significant changes in regards to this question based on all evaluations. It was important that I spend an equal amount of time changing various aspects of the system

	their previous wrong answer.		in future development.	to produce the best application possible. I felt spending too much time on one page would have been counterproductive. In future, I would recommend implementing this by accessing the users previous answer – this could be done by potentially using the SharedPreferences functionality android studio offers as it holds information in memory until its clear or by initialising an instance of the previous activity class. Once this has been done, then an if statement that declares if the answer given for this input is 7 less than the previous input then it as a correct answer.
Issues with the question "What is your house number?".	This question is about current orientation so it's not tapping into this because YOUR house number is specific to them not where they are.	3.	The aim of this project it to build a proof of concept that is ready for equivalence testing, it is important that the digital question measure what the paper based version does.	This was not changed to prioritising. The scope of my location add-on for android is limited and only returns a certain amount of information. I would recommend using a better location library like google maps. This can locate what floor of a building you are on. The expert

			This should be changed urgently in future development.	suggested this would be a better question to ask so the google maps location library may the best option.
The registration question should be read out rather than shown on screen.	This question could potential cause inaccurate results due to the different implementation.	3.	I realise that I need to ensure that my digital interpretation of this should measure the same cognitive functions so this must be changed urgently in future development.	I did not make this change due to prioritising. I had already made significant changes in regards to this question based on all evaluations. It was important that I spend an equal amount of time changing various aspects of the system to produce the best application possible. I felt spending too much time on one page would have been counterproductive. Speech generation and recognition libraries could be implemented in future to enable this question to mimic the paper based version more closely and hopefully result in more reliable scores.
Implement all orientation questions.	I have not implemented all the orientation questions. “What date is it?” and “What season is it?” have not been implemented.	2.	I have implemented all other orientation questions. I feel these 2 questions would be difficult to implement. The date is shown on a phone so asking a user to enter it	I did not change this as I am no qualified to make decisions based on the validly of the measure. I suggest that an in-depth analysis and discussion is had by those who are qualified to do so to decide where the cut

			doesn't test orientation, thus, compromising the validity of the measure. The season is very subjective and I am not qualified to decided how far off someone is from the season in question to either categorise it as right or wrong.	off point for what qualifies as a correct answer to the season question is and if the question of date is accurately measuring orientation.
No spelling errors or abbreviations are considered.	This could cause unreliable results – the score could be based on poor spelling rather than poor cognition.	2.	This should be addressed relatively quickly in future development to ensure the most accurate results.	I did not change this as I am not qualified to decide how much the spelling may differ from the correct spelling of a word to count as correct. This must be done by a group of professionals. Once this has been decided a string search could be coded and to help account for spelling errors and abbreviations.
The registration question.	This question usually allows a user to repeat the objects back up to 6 times to remember them. I have tried to mimic this by allowing a user to enter the object and then press a submit button	2.	it is important that the digital version I have built of MMSE is not any easier than the original version but I feel question is sufficient for this proof of concept as it is.	I did not make this change due to prioritising. I had already made significant changes in regards to this question based on all evaluations. It was important that I spend an equal amount of time changing various aspects of the system to produce the best

	that tells the user if this is correct. It is suggested that the button be disabled after 6 attempts to mimic the paper based MMSE more closely.			application possible. I felt spending too much time on one page would have been counterproductive. In future program a counter that is linked to the button – once the button is clicked 6 times the counter hits 0 and the button is disabled.
The scoring total.	The paper based version of the examination is scored out of 30. This version is scored out of 22.	1.	It is important that the scoring of the measure is accurate, however, I have used the same scoring system as the paper based MMSE. The total score is lower because I have not implemented all the questions due to the nature of this proof of concept – this is discussed more in the future functionality subsection of the report found under conclusions.	I did not change this as I am not qualified to make decisions based on the total score. I have followed the scoring scheme from the MMSE. If the scores need to be amended due to lack of questions it should be a trained professional that does so. If the rest of the questions are implemented in the future, then this problem will be solved as it will be scored out of 30.
The picture of the watch used in the language question.	The image is of a large watch on a wrist. This could result in an answer of arm rather that watch resulting in unreliable results.	1.	It is important that the digital version of the MMSE is as transparent as possible, any confusion surrounding what the image is	I did not change this due to prioritising of tasks. I had already changed it from a watch with no wrist to a watch with a wrist based on another evaluation. I had to make sure I

			of violates this principle. I feel this question is understandable enough to be used for equivalence testing and then adapted if needs be based on results from this.	amendments to aspects of the system that had not been changed yet. By doing this it ensured I had the best version of my application possible. I am not qualified to make a final decision on which evaluation should be implemented. This should be discussed in future by professionals to decide if the picture should contain a wrist or not.
The question "What city are you?" requires a user to type "city" after their answer e.g. "Glasgow City"	This could cause user error; this is an extra complication to a cognitive impairment test.	1.	This is rated 1 as I have already programmed a quick fix for this but it is in this table of results as a more permanent solution is needed.	I have programmed the answer to accept an answer without city after it by using the .contains() method. This is not a permanent fix though ad it does not use the android location library value that is returned. In future, a better location library should be used such as google maps as this has more scope than the Android Studio location manager and geocoder.
Appropriate error messages are not displayed when the application crashes.	This violates usability heuristics and should be changed to give more descriptive error messages so the user knows	1.	It is important that a user is aware of what is happening and why when the application crashes, however, this is	I did not make this change due to prioritising. This is a rare problem so it was more important to make other changes that impacted the

	what is happening.		rare and most bugs have now been fixed so although it must be addressed it is not urgent.	application more significantly.
Answer boxes do not contain a descriptive default text.	These violate the user interface; it should be more descriptive that this.	0.	This does not impact the usability of my application. It should be changed but it is superficial so it is not urgent.	I did not make this change due to prioritising. This is a superficial problem so it was more important to make other changes that impacted the application more significantly. More descriptive strings can be added in future to be used as the default text.
Screen navigation.	Most of the navigating of the application between pages relies of the devices back button.	0.	This impacts usability but only to a small extent. This should be addressed in future development but not urgently.	I did not make this change due to prioritising. It was more pressing to make changes based on evaluations that had a significant impact of the usability of the application. Back buttons should be added to each page in future development so the application doesn't rely so heavily on the device.
Compatibility across platforms.	Application seems ok when used on a phone but when used on a tablet there are issues with design.	0.	This does not impact the usability of my application because my proof of concept is meant for phones. It should be changed but it is superficial so it is not urgent.	I did not make this change due to prioritising. This is a superficial problem so it was more important to make other changes that impacted the application more significantly.

				This is beyond the scope of my thesis because it was based on being a mobile application, however, when building my application, analysing the design and evaluation results and considering future development it has become clear that using this application of a tablet would be beneficial. Certain questions that have not been implemented due to the mobile nature of this project could be successfully when used with a larger screen. This should be investigated and changed in future development.

Table2. Changes suitable for future development

This type of user testing was very beneficial as it enabled me to ensure that my digital version of the MMSE was as accurate to the paper based version as possible and that my GUI was user friendly and easily understandable while still looked nice. Issues were raised that I hadn't considered which meant my expert evaluation were invaluable for this dissertation project by pointing out problems that would otherwise have gone unnoticed, helping me to guarantee that my proof of concept mobile application was the best standard of work that it could be. Not only this, but these expert evaluations supported the completion of the main requirement that my whole dissertation was centred around: *1. Provide a digital implementation of the MMSE that can be equivalence tested in the future* and allowed me to conclude that I have built what I ended to. Expert advice allowed me to adapt my application to ensure I was measuring the correct cognitive function while not skewing results due to cognitive load or other such issues and ensured that I had successfully implemented a digital version of the originally paper based MMSE that is ready to be tested for equivalence in future.

5.2.2 Acceptance Testing

This from of testing, along with all previously mentioned techniques, helped ensure that all requirements had been met. In any software development project, it is vital to make sure that the clients requirements were met and my thesis is no different, below is table 3 that shows each requirement and a corresponding test that verifies it has been completed. This will demonstrate that my functional requirements for this project have been met.

Acceptance test table

Requirement number	Requirement	Test number	Test
1.	Provide a digital implementation of the MMSE that can be equivalence tested in the future.	1.	All tests below ensure that my proof of concept is ready to be equivalent tested in future.
2.	Implement each question from the MMSE where possible:	2.	The tests below (section 2) of this table are evidence that I have implemented each question where possible.
2.a	What year is it? – equivalent of MMSE question.	2.a	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.b	What month is it? – equivalent of MMSE question.	2.b	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.c	What day is it? – equivalent of MMSE question.	2.c	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed.

			A unit test was also written to prove this question was implemented.
2.d	What Country are you in? – equivalent of MMSE question.	2.d	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.e	What City are you in? – adapted from what town are you in?	2.e	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.f	What Street are you on? - adapted from what district are you in?	2.f	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.g	What is your building/house number? - adapted from hospital are you in?	2.g	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.h	What is your postcode? – adapted from what floor are you on?	2.h	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.i	Show user 3 named objects and prompt them	2.i	Functionality testing whereby, an if statement was used to print a meaningful

	to type in their names – adapted from examiner names 3 then ask patient all three after you have said them.		message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.j	Subtract 7 from 100 and repeat 5 times – equivalent of MMSE question.	2.j	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.k	Alternative to requirement question j – spell the word world backwards – equivalent of MMSE question.	2.k	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.l	Ask the names of the 3 objects shown earlier – equivalent of MMSE question.	2.l	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.m	Name these objects (user shown a pencil and a watch on screen) – equivalent of MMSE.	2.m	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed. A unit test was also written to prove this question was implemented.
2.n	Say “No ifs ands or buts” – adapted from repeat no ifs, ands, or buts.	2.n	Functionality testing whereby, an if statement was used to print a meaningful message on screen to check this question was completed and passed.

			A unit test was also written to prove this question was implemented.
3.	Ensure user is prompted that the resulting score of the examination is by no means indicative of any cognitive impairment, merely a suggestion that these significant decisions should be made with a legal guide at hand and a meeting with a lawyer is advised.	3.	A set text method was linked to a corresponding text box in the first page of the app to make each user aware that their score from this version of the MMSE is not indicative of cognitive impairment: `TextView textView = findViewById(R.id.textView); TextView importantNotice = findViewById(R.id.importantNotice); textView.setText("USERS PLEASE READ BEFORE YOU BEGIN:"); importantNotice.setText("Please note that the results of this MMSE are in no way indicative of your competence levels or cognitive functions." + "Any score that falls below no cognitive impairment merely means that it would be recommended that you make or amend your will in the presence of a lawyer. ");`  A set text method was linked to a corresponding text box in the last page of the app for the same purpose: `TextView myDisclaimer = findViewById(R.id.myDisclaimer); myDisclaimer.setText("Please note that this version of the MMSE is only a general guideline and does in no way accurately reflect your cognitive ability");`
4.	Do what is possible to ensure that the relevant cognitive function is being measured and my user interface does not change this e.g. orientation, registration, attention and calculation, recall and language.	4.	Expert evaluations were carried out for the purposes of testing this requirement. Expert opinions were taken on board and changes were made accordingly. See appendix for the transcripts of these evaluations.

5.	The proof of concept should be scalable.	5.	I avoided using a database for this proof of concept due to this requirement. When an application uses a database it can cause severe issues regarding scalability: as more users are added the system becomes slower. A database could have been used for this application to store users previous score in order to measure their cognition over a period of time. Although this functionality could be useful it was not a requirement, thus, it was important to decide between scalability issues vs functionality. For this purpose, no database was used to ensure that the proof of concept was scalable. By using java as my programming language, it ensures that the application will be scalable in future. For example, there are a number of back-end databases that are easily integrated with java – SQLite.
6.	Ensure any text boxes that requirement user input have relevant restraints.	6.	The following tests mentioned below are evidence of this requirement being completed.

6.a	A text box should not allow an unlimited amount of characters.	6.a	Code has been implemented and linked to all text boxes that allows no more than 30 characters. This was done by the following lines:
			`answer1.setFilters(new InputFilter[]{`
			`new`
			`InputFilter.LengthFilter(30) {`
			`}`
			`});`
			
			This was then tested using functionality testing. No more than 30 characters are able to be inputted into text boxes.

6.b	Appropriate messages should be shown to the user to make them aware that not answering a question will	6.b	Code has been implemented in all pages so that a toast (user message) appears when a user clicks the next question button without inputting an answer into a text box. This was by the following lines:
			`if(answer.isEmpty()){`
			
			`Toast.makeText(Question2Activity.this,`

	result in a zero score for that question.		"Leaving the answer blank will result in a score of zero for this question", Toast.*LENGTH_LONG*).show(); } Functionality testing was used to ensure this was the case. This message appears on screen when a user leaves an answer blanks and clicks to the next question button.

Table3. Acceptance tests to confirm completion of requirements

By having a numbered set of requirements and a corresponding number of tests that relate to a particular requirement has allowed me to demonstrate that they have all been met and a comprehensive system now exists. This not only allows me to verify that each task has been completed but if Lifeium are interested in using this proof of concept further down the line this comprehensive table shows them what functionality has been implemented and tested to verify its completion. This is useful to hand down to other developers if they so desire and will facilitate their further development of this mobile application because they can see clearly what has been done, what functionality hasn't been added and bridges the gap for integration testing that should be done if the system is developed further.

6. Future directions and conclusion

6.1 Future functionality development and equivalence testing

The aim of this proof of concept was to build a digital version of the originally paper based cognition test, the MMSE that can be used later to evaluative the equivalence in scores each version reports to determine if it could be used in practice. This has been done and proven by the evidence discussed in the evaluation sections. I have implemented the questions that were applicable to this proof of concept application. These include questions from MMSE subsections; orientation, registration, attention and calculation, recall and language:

Orientation:

- Question 1. What year is it?
- Question 2. What month is it?
- Question 3. What day is it?
- Question 4. What country are you in?
- Question 5. What city are you in?
- Question 6. What street are you on?
- Question 7. What is your country code?
- Question 8. What is your building/house number?

Registration

- Question 9. Show user 3 named objects and prompt them to type in their names.

Attention and calculation:

- Question 10. Subtract 7 from 100 and then repeat these 5 times.
- Question 11. Alternative to question 10 – spell the word world backwards.

Recall
- Question 12. Ask the names of the 3 objects shown earlier.

Language
- Question 13. Name these objects: a user is shown a pencil and watch on screen.
- Question 14. Say “no ifs and or buts”.

Only 2 questions from the language subsection were implemented and no questions from the copying section were implement due to the restrains that derive from a mobile phone and the time restraints of the dissertation – these were pre-agreed with my dissertation supervisor. The questions that were not digitised are as follows:

Orientation
- Question 2. What season is it?
- Question 3. What date is it?

Language
- Question 15. Follow a 3 stage command “take a piece of paper in your right hand, fold it in half and put it on the floor.
- Question 16. Ask patient to read and obey a written command stating "Close your eyes".
- Question 17. Ask the patient to write a sentence. Score if it is sensible and has a subject and a verb.

Copying
- Question 18. Ask the patient to copy a pair of intersecting pentagons.

For the purposes of this thesis project, question 2 was not implemented because season is so subjective. I am not qualified to decided where the cut off for each season is or how far off a user must be before the question is scored as incorrect. A trained clinician and group of experts will need to decide this. Similarly, with question 3, the date is shown on a user’s phone, thus, it will not measure orientation so I felt it best to exclude this question from the proof of concept because it will not measure what the paper based versions aims to. A well experienced clinician should make the decision whether to include this. These 2 questions were omitted due to the lack of knowledge needed to properly mimic these in my digital implementation which could have caused unreliable results, something I had to avoid. In future, a trained clinician should decide where these questions stand in regards to a digital duplication. Question 15 was not implemented because sophisticated video technology would have to have been used and due to the scope of the project it would not be feasible to do so. Body recognition is now being widely used due to the information society we live in today and should be taken advantage of when further developing this proof of concept. This can be done by using OpenCv (Open Source Computer Vision Library) a library that makes use

of machine learning and computer perception[34].OpenCv can recognise, track and analyse faces, actions and objects[35] and is compatible with java[36] making this the most suitable option for digitising Question 15 in future. Similarly, Question 16 would benefit from OpenCv for the same reasons, the user would still read a written command with OpenCv classifying if the user did in fact close their eyes. Both these questions are unambiguous so classifying a correct answer should not be difficult to do especially when using this library. Question 17, again was not achieved due to time constraints and the ambiguity that surrounds the questions - "score if it is sensible" this statement is highly subjectable and would be difficult to score via technology as it lacks a certain degree of common sense knowledge (context surrounding situation that enables a person to deduce what is appropriate and what's not in a situation). This question will require a parser to interpret if the sentence contains a subject and a verb, a highly validated and reliable parser I would recommend is the Stanford parser. It is well established and is compatible with java[37] which makes this the best option for digitising the question. To solve the issue of ambiguity that surround what is or is not a sensible question, it would be beneficial to have an in-depth conversation with a clinical who specialises in administering the MMSE and similar cognition examinations to determine where to draw the line and attempt to program this. The final question that is still to be implemented is question 18. This question was not able to be implemented due the hopes of a mobile application for this project. Question 18 is the only subsection that was not digitised, therefore, it is arguably the most important question that should be implemented in future. It involves the copying of a picture of a pair of intersecting pentagons and due to the size of a mobile phone screen, it is not a suitable question to digitise because a small screen will make it more difficult to accurately copy to an acceptable degree. The sensitive nature of a poor score on the MMSE can negatively impact a user leading them to worry that their cognitive functions are impaired, by digitising a question that could potentially result in unreliable results and cause users significant psychological stress is extremely unethical. If this proof of concept is built upon in future, it is important that it is made for a device with a larger screen like an IPad or tablet so it is easier to accomplish an accurate copy of the picture given the larger amount of space. Pattern recognition software will also be necessary to establish if the pair of pentagons have been suitably copied, after some research it became clear the best option would be the Canvas class, it is a java library and therefore will be easily integrated with the current proof of concept. Canvas allows a user to draw and can track this[38] making it a feasible option when considering how to digitise this question. Again, it is important to have an in-depth conversation with an experienced clinician to determine what would classify as passable answer and where the cut-off point between this and a failing picture would be to ensure that the question delivers reliable results.

---

[34] Opencv.org. (2019). *About*. [online] Available at: https://opencv.org/about/ [Accessed 14 Aug. 2019].

[35] Opencv.org. (2019). *About*. [online] Available at: https://opencv.org/about/ [Accessed 14 Aug. 2019].

[36] Opencv.org. (2019). *About*. [online] Available at: https://opencv.org/about/ [Accessed 14 Aug. 2019].

[37] Nlp.stanford.edu. (2019). *The Stanford Natural Language Processing Group*. [online] Available at: https://nlp.stanford.edu/software/lex-parser.shtml [Accessed 14 Aug. 2019].

[38] Courses.cs.washington.edu. (2019). *Class java.awt.Canvas*. [online] Available at: https://courses.cs.washington.edu/courses/cse341/98au/java/jdk1.2beta4/docs/api/java/awt/Canvas.html [Accessed 14 Aug. 2019].

Once this functionality is implemented the application should then be tested for equivalence. To do so a clinical case study should be conducted by trained clinicians using a varied participant pool. Each participant should be administered the original paper based version of the MMSE and then the digital version, potentially over a period of weeks to account for external variables that could be relevant to a specific day or time. Once this has been done the results should be analysed and compared. If no significant difference is found between the results across both platforms, the digital version could then be deemed a significant measure of cognitive impairment and could be used as a reliable diagnostic tool.

6.2 Copyright issues to be considered in future

It is important to recognise that the MMSE is a copyrighted examination and this will have implications regarding future development. Until recently the MMSE was widely accessible for all to use freely, however, in 2000 the original authors (Folstein, Folstein and McHugh, 1975) gave the copyright to a company[39]. This has caused a significant amount of issues since, with authors of 2 separate cognitive measures both of whose development was facilitated by the MMSE having to be revoked from publish due to copyright infringement issues[40]. Due to these issues, any future development processes should ensure that there are no copyright infringement complications surrounding their work by purchasing the necessary forms[41]. By doing so, this will avoid any work of great value having to be retracted.

6.3 Future scope for this proof of concept

The need for a proof of concept application that measures cognitive competence came from Lifeium's aim of building a mobile application that allows a user to create a last will and testament, however, it is important to consider the wider extent of use that this proof of concept has. In today's information society where digital health is beginning to play a key role - the opportunities to make use of such an application are countless. The need for tools and assessments for those suffering from one of the many dementias are considerable and the scope to aid many from such an application is boundless. One of my expert evaluators acknowledges the potential for such a concept and has given permission to be quoted:

> "This type of innovation is something of considerable scientific importance well beyond the scope of this individual study. The prototype developed has been well thought through. I'd be really excited to see the next steps of this research particularly given the 60 million individuals with dementia across the world and many of whom face significant challenges regarding diagnosis and forward planning".

Future development should consider the impact an application built upon this concept could have in regards to the health and wellbeing of numerous people throughout the world. Such an application could save the health sector time and money, as well as, being able to provide

[39] Kristina Fiore (2019). *Copyright Issues Hinder MMSE Use*. [online] Medpagetoday.com. Available at: https://www.medpagetoday.com/neurology/dementia/52040 [Accessed 17 Aug. 2019].
[40] Kristina Fiore (2019). *Copyright Issues Hinder MMSE Use*. [online] Medpagetoday.com. Available at: https://www.medpagetoday.com/neurology/dementia/52040 [Accessed 17 Aug. 2019].
[41] Kristina Fiore (2019). *Copyright Issues Hinder MMSE Use*. [online] Medpagetoday.com. Available at: https://www.medpagetoday.com/neurology/dementia/52040 [Accessed 17 Aug. 2019].

those suffering from cognitive dysfunctions the adequate help and management that is needed for their quality of life. It would be naive not to recognise the extensive impact that such an application could have on an aging society.

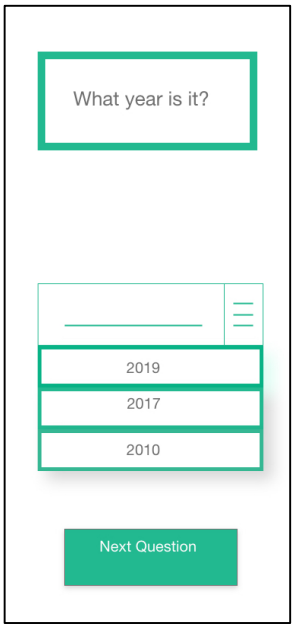
6.4 conclusion

The aim of my project was to build a proof of concept application that measures an individual's level of cognitive competence by creating a digital version of the MMSE that is ready to be equivalence tested in the future. I have done so by carefully designing the application, building it, and testing it. The outcomes from in-depth expert evaluations have allowed me to produce the best proof of concept possible by ensuring the user interface was understandable and user friendly but did not change what the original paper based MMSE aimed to measure. These results also allowed me to adapt the way in which questions were asked and instructions were given to insure the validly of the cognitive functions measured. I have developed a proof of concept that is ready to be used in future to carry out an evaluation piece based on this application to determine the validly and equivalence of this digital version of the MMSE compared to the paper based version, as well as, if it could be used in practice - either as part of an application that enables users to make their last will and testament on an electronic device or an application that can be used for diagnostic and management purposes in relation to cognitive impairment. Although there are other applications on the market that measure cognitive impairment, to my knowledge none implement the MMSE, which makes this project interesting when considering the overall scope such an application could have due the validity of the MMSE and the exponential growth of the digital health sector.

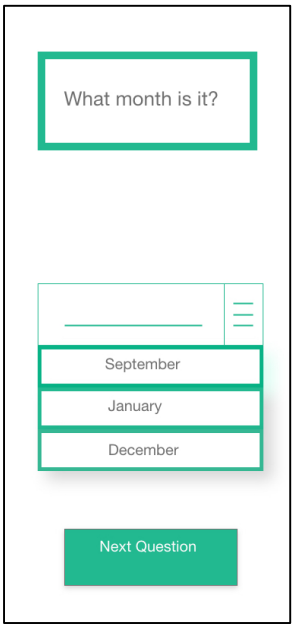
Appendix 1

Full low fidelity prototype

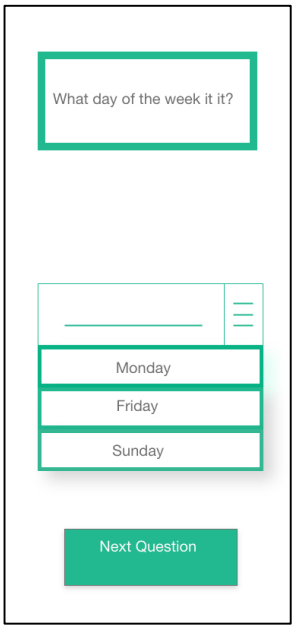
Question1



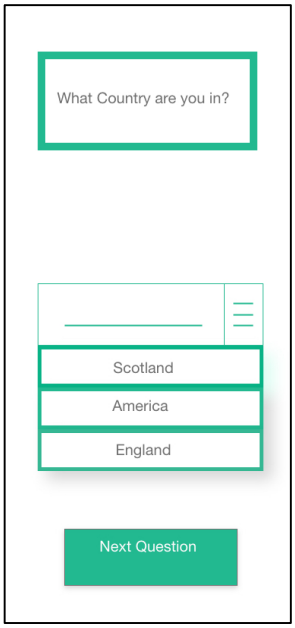
Question2



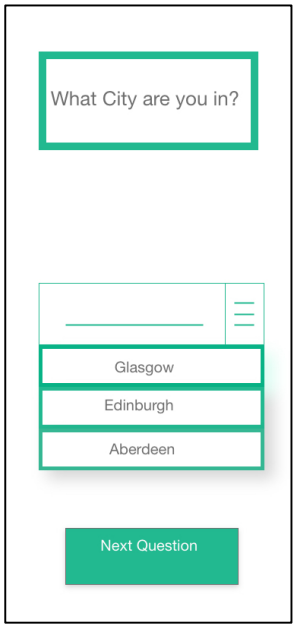
Question3



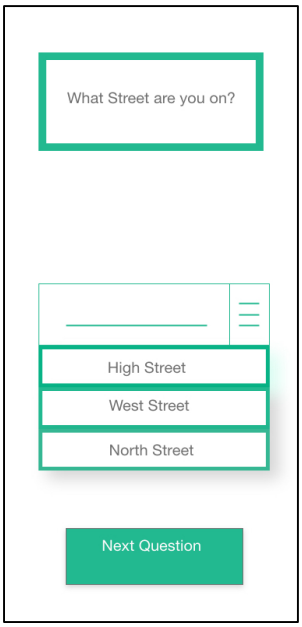
Question4



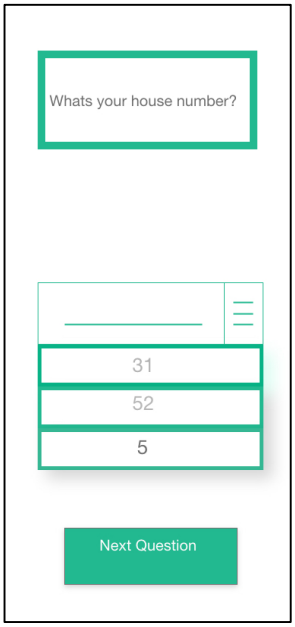
Question5



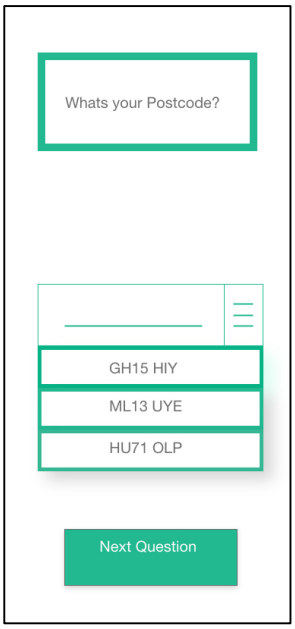
Question6



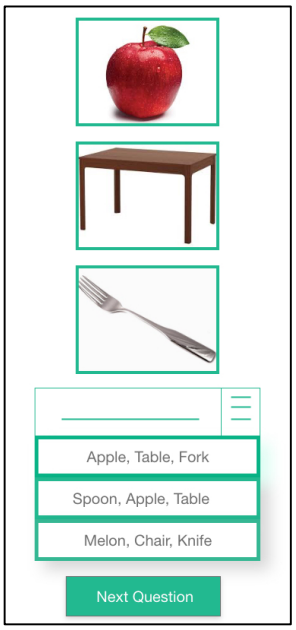
Question7



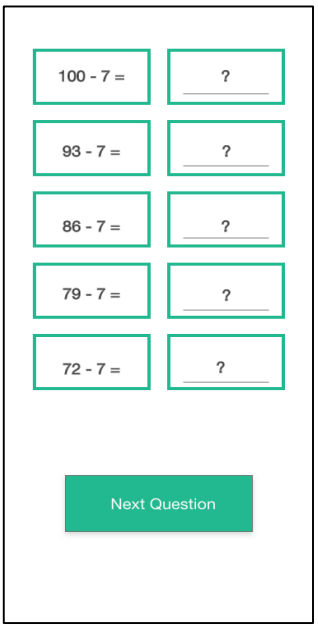
Question8



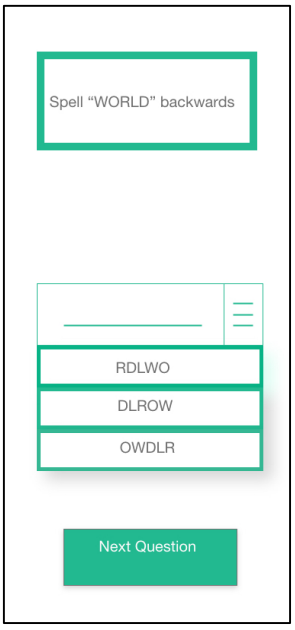
Question9



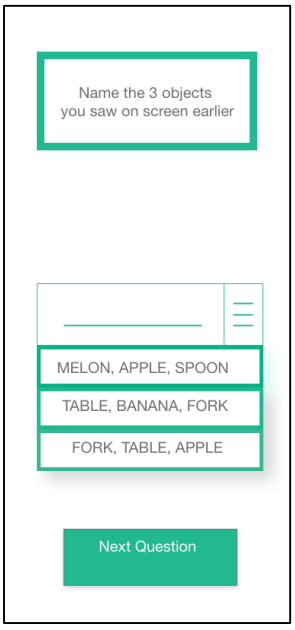
Question10



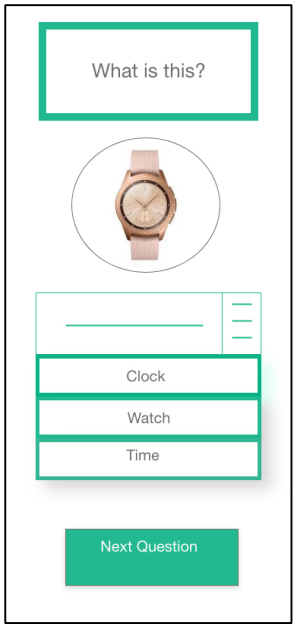
Question11



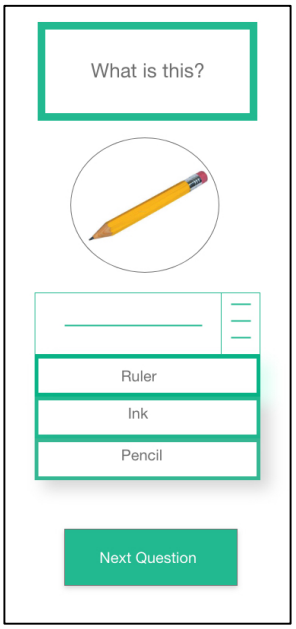
Question12



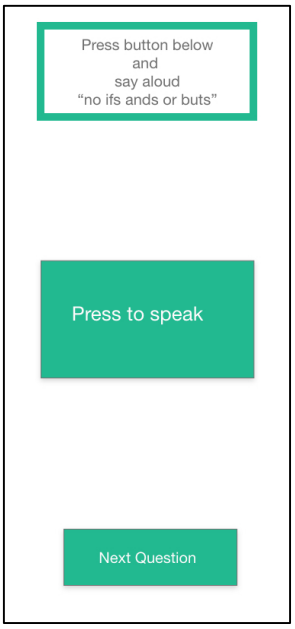
Question13



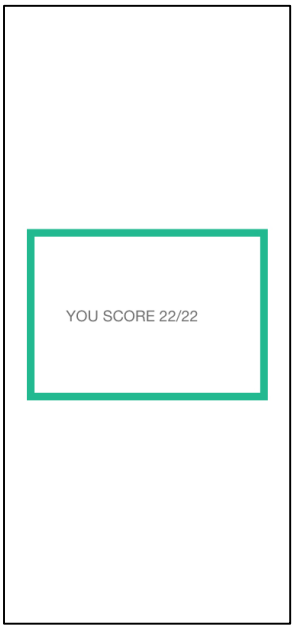
Question14



Question15



Score Page



Appendix 2

Expert Evaluation Transcripts

Heuristic Evaluation of "My dissertation", developed by Sarah McQuoney

Evaluator(s):
Kostas Liaskos

Platforms utilized to run the app:

1. Android A3 mobile device, Android vesion: 6.0.1
2. Android A4 tablet (10.1 inch), Android vesion: 5.0.2

Heuristics used:
Nielsen's [1] updated heuristics:

H1. Visibility of system status
H2. Match between system and the real world
H3. User control and freedom
H4. Consistency and standards
H5. Error prevention
H6. Recognition rather than recall
H7. Flexibility and efficiency of use
H8. Aesthetic and minimalist design
H9. Help users recognize, diagnose, and recover from errors
H10. Help and documentation

Severity ratings:

0 Don't think this is a usability problem
1 Cosmetic problem; fix only if extra time is available
2 Minor usability problem; give a low priority to fixing the problem
3 Major usability problem; give a high priority to fixing the problem
4 Usability catastrophe; fix the problem before product is released

Violations

1. **App name:** "MyDisseration1" (*sic*).
Heuristic(s) violated: H4, H8
Severity: 4
Proposed solution: Consider correcting the spelling. Even better, consider choosing a more descriptive name for the app.

2. **First screen (text):** not clear what MMSE means.
Heuristic(s) violated: H1, H3, H5, H6, H7, H10
Severity: 3
Proposed solution: Consider adding the full text instead of just the acronym. MMSE can be in parentheses. No need to change MMSE in the button name, i.e. "BEGIN MMSE" is fine.

EXPERT EVALUATION FORM

GB question not needed

Problem ID: 1	Description of issue: duplication of GB questions

Detailed description of issue:

two questions are asking the same thing + derivable from paper based MMSE

Violate principles cause by issue:

Authentic replication of MMSE

Severity rating of issue: not severe at all

Proposed solutions to solve issue:

Make sure questions either strictly adhere to original where you must use substitutions be able to explain hypothesis / theory of function. It could be that >1 question = same measure contributes

Post task how many digits do you need?

Problem ID: 2	Description of issue: time + distractions

Detailed description of issue:

~~cognitive~~ assessments require focus (even in fully cognitively intact individuals)

Violate principles caused by issue:

Match between system

Severity rating of issue: 2

Proposed solutions to solve issue:

~~instruction~~ instructions on could state
→ flight mode
→ quiet place
→ free from distraction

EXPERT EVALUATION FORM

Problem ID:	Description of issue:

Detailed description of issue:

watch - maybe use a wrist?

Violate principles cause by issue:

Severity rating of issue:

Proposed solutions to solve issue:

Problem ID:	Description of issue:

Detailed description of issue:

Violate principles caused by issue:

Severity rating of issue:

Proposed solutions to solve issue:

EXPERT EVALUATION FORM

Problem ID:	Description of issue:
3	cheating the system

Detailed description of issue:
you cant stop people "learning" the MMSE if the wanted (e.g. repeating until they pass it)

Violate principles cause by issue:
Match between system

Severity rating of issue: 1

Proposed solutions to solve issue:
lock down → limit the time period on each attempt
the number of times you can do it (eg 1/week) or less?
→ or vary in distracter

Problem ID:	Description of issue:
4	Postcode

Detailed description of issue:
spacing, user error issue

Violate principles caused by issue:
error prevention

Severity rating of issue: 5

Proposed solutions to solve issue:
be clear about number of digits/letters/layout expected or hard code a workaround

EXPERT EVALUATION FORM

Problem ID:	Description of issue:

Detailed description of issue:
✓ More instructions needed on how to respond to individual Qs – e.g. - submit each object individually or all at once? "submit" button doesn't work? e.g. "remember the 3 objects from before? Please name as many as you can remember"

Violate principles cause by issue:

Severity rating of issue:

Proposed solutions to solve issue:

Problem ID:	Description of issue:

Detailed description of issue:
✓ Calculation task has to be mental – answers can't appear on screen. 1 page at a time? Although note, next answer ½ should be based on previous answer given, even if it was wrong

Violate principles caused by issue: Format calculation.

Severity rating of issue:

Proposed solutions to solve issue:

efficiency of use

watch +

EXPERT EVALUATION FORM

Problem ID:	Description of issue:
1	city addition to place

Detailed description of issue:

adding city is an extra complication within a cognitive assessment

Violate principles cause by issue:

Severity rating of issue: 4

Proposed solutions to solve issue:

take the word city out - two advantages - opens out applicability to other towns, villages + is simpler

Problem ID:	Description of issue:
4	order of questions

Detailed description of issue:

better to have an order (country / town → house) than the present order

Violate principles caused by issue:

cognitive load - distraction task

Severity rating of issue: 2

Proposed solutions to solve issue:

follow order in terms of ~~above~~ above

EXPERT EVALUATION FORM

Problem ID:	Description of issue:

Detailed description of issue:

apple / table → you are asking them to type when the info is on screen

Violate principles cause by issue:

Severity rating of issue:

Proposed solutions to solve issue:

more in line with ensuring they have words in working memory by having input on next page without visual prompts

Problem ID:	Description of issue:

Detailed description of issue: serial 7, ~~suggest you do~~ you are making test bit easier than in mase by showing the sums

Violate principles caused by issue:

Severity rating of issue:

Proposed solutions to solve issue:

suggest the instructions are set to make it clear that over next set of boxes they should continue the subtraction.

EXPERT EVALUATION FORM

Problem ID:	Description of issue:
Detailed description of issue: More detail on format of answer req'd. e.g. type name of month or number (or either?) - on this note - could typing errors cause answer to be marked wrong (when in fact the individual knew the correct answer?)	
Violate principles cause by issue:	
Severity rating of issue:	
Proposed solutions to solve issue:	

Problem ID:	Description of issue:
Detailed description of issue: original published version has 5 Qs on orientation to time (and place as well) - date and season missing? *More general issue of relationship with originally published version. i.e. don't know what coding codes means. Questions should be simple / straightforward. - All Qs must be valid for the specific time + place of admin (human reqd to assess answers?)	
Violate principles caused by issue:	
Severity rating of issue:	
Proposed solutions to solve issue:	

EXPERT EVALUATION FORM

Problem ID: 2	Description of issue: No abbreviation or spelling error or non capitalised
Detailed description of issue: acceptability of terms - eg Fri Friday/ Friday Or / Aug August	
Violate principles cause by issue (why is this?): coding error caused by real world participant + reference library	
Severity rating of issue: (1 - 5) 2	
Proposed solutions to solve issue: wider scope of reference library to be more inclusive	

Problem ID: 3	Description of issue: tipping phone (orientation switches view)
Detailed description of issue: screen moves when phone moves	
Violate principles caused by issue: could be offputting to users	
Severity rating of issue: 4	
Proposed solutions to solve issue: switch it off	

EXPERT EVALUATION FORM

Problem ID:	Description of issue:
Detailed description of issue: The watch image should not have an arm as you may get 'arm' or 'wrist' as response.	
Violate principles cause by issue:	
Severity rating of issue:	
Proposed solutions to solve issue:	

Problem ID:	Description of issue:
Detailed description of issue: Apple/table etc → suggest you incorporate a counter so it moves on to next section after 6 tries.	
Violate principles caused by issue:	
Severity rating of issue:	
Proposed solutions to solve issue:	

EXPERT EVALUATION FORM

Problem ID:	Description of issue:
Detailed description of issue: It is extremely sensible to swap out orientation Questions to suit the options the programming allows but, I would caution that not knowing counting code may simply be a lack of knowledge rather than a deficit.	
Violate principles cause by issue:	
Severity rating of issue:	
Proposed solutions to solve issue: consider different Q that perhaps directly tests a deficit in	

Problem ID:	Description of issue:
Detailed description of issue: Issue of your house → if this Q is about current orientation then this is not tapping into this, would need to ask what current floor your are on, or something else about the current orientation to place.	
Violate principles caused by issue:	
Severity rating of issue:	
Proposed solutions to solve issue:	

EXPERT EVALUATION FORM

Problem ID:	Description of issue:
Detailed description of issue: for registration – should be read out 1 at a time – all 3 said before P asked to repeat.	
Violate principles cause by issue:	
Severity rating of issue:	
Proposed solutions to solve issue:	

Problem ID:	Description of issue:
Detailed description of issue: ✓ In the original – P may refuse to calculate (e.g. many artists / dyscalculia) – so need alternative to be possible i.e. spell world backwards.	
Violate principles caused by issue:	
Severity rating of issue:	
Proposed solutions to solve issue:	

EXPERT EVALUATION FORM

Problem ID:	Description of issue:
Detailed description of issue: ✓ Scoring procedure can be affected by set-up – 1 screen per item? i.e. not more than 1 submit button per screen.	
Violate principles cause by issue:	
Severity rating of issue:	
Proposed solutions to solve issue:	

Problem ID:	Description of issue:
Detailed description of issue: I notice the total is 22 – the original is out of 30 ✓ See also MoCA. So validation work would be needed re: indicators relative to total? What score indicates potential impairment?	
Violate principles caused by issue:	
Severity rating of issue:	
Proposed solutions to solve issue:	

Appendix 3

The Mini Mental State Examination (Folstein, Folstein and McHugh, 1975)

"MINI-MENTAL STATE"

Maximum Score	Score	
		ORIENTATION
5	( )	What is the (year) (season) (date) (day) (month)?
5	( )	Where are we: (state) (county) (town) (hospital) (floor).
		REGISTRATION
3	( )	Name 3 objects: 1 second to say each. Then ask the patient all 3 after you have said them. Give 1 point for each correct answer. Then repeat them until he learns all 3. Count trials and record.
		Trials

ATTENTION AND CALCULATION

5 ( ) Serial 7's. 1 point for each correct. Stop after 5 answers. Alternatively spell "world" backwards.

RECALL

3 ( ) Ask for the 3 objects repeated above. Give 1 point for each correct.

LANGUAGE

9 ( ) Name a pencil, and watch (2 points)
Repeat the following "No ifs, ands or buts." (1 point)
Follow a 3-stage command:
"Take a paper in your right hand, fold it in half, and put it on the floor" (3 points)
Read and obey the following:
CLOSE YOUR EYES (1 point)
Write a sentence (1 point)
Copy design (1 point)

_____ Total score

ASSESS level of consciousness along a continuum———————————————
Alert Drowsy Stupor Coma

INSTRUCTIONS FOR ADMINISTRATION OF MINI-MENTAL STATE EXAMINATION

ORIENTATION

(1) Ask for the date. Then ask specifically for parts omitted, e.g., "Can you also tell me what season it is?" One point for each correct.
(2) Ask in turn "Can you tell me the name of this hospital?" (town, county, etc.). One point for each correct.

REGISTRATION

Ask the patient if you may test his memory. Then say the names of 3 unrelated objects, clearly and slowly, about one second for each. After you have said all 3, ask him to repeat them. This first repetition determines his score (0–3) but keep saying them until he can repeat all 3, up to 6 trials. If he does not eventually learn all 3, recall cannot be meaningfully tested.

ATTENTION AND CALCULATION

Ask the patient to begin with 100 and count backwards by 7. Stop after 5 subtractions (93, 86, 79, 72, 65). Score the total number of correct answers.
If the patient cannot or will not perform this task, ask him to spell the word "world" backwards. The score is the number of letters in correct order. E.g. dlrow = 5, dlorw = 3.

RECALL

Ask the patient if he can recall the 3 words you previously asked him to remember. Score 0–3.

LANGUAGE

Naming: Show the patient a wrist watch and ask him what it is. Repeat for pencil. Score 0–2.

Repetition: Ask the patient to repeat the sentence after you. Allow only one trial. Score 0 or 1.

3-Stage command: Give the patient a piece of plain blank paper and repeat the command. Score 1 point for each part correctly executed.

Reading: On a blank piece of paper print the sentence "Close your eyes", in letters large enough for the patient to see clearly. Ask him to read it and do what it says. Score 1 point only if he actually closes his eyes.

Writing: Give the patient a blank piece of paper and ask him to write a sentence for you. Do not dictate a sentence, it is to be written spontaneously. It must contain a subject and verb and be sensible. Correct grammar and punctuation are not necessary.

Copying: On a clean piece of paper, draw intersecting pentagons, each side about 1 in., and ask him to copy it exactly as it is. All 10 angles must be present and 2 must intersect to score 1 point. Tremor and rotation are ignored.

Estimate the patient's level of sensorium along a continuum, from alert on the left to coma on the right.

Appendix 4

The participant information sheet

Participant Information Sheet for Digital Version of The Mini Mental State Examination

Name of department: Department of Computer and Information Sciences

Title of the study: Digital Version of The Mini Mental State Examination

Introduction
My name is Sarah McQuoney. I am currently a MSc student at Strathclyde University studying Software Development, you can contact me on the following email address (sarah.mcquoney.2018@uni.strath.ac.uk). I am currently conducting expert evaluations of my mobile application that aims to create a digital version of the paper based psychology measure of competence: The Mini Mental State Examination. The collected data will be used to produce my analysis and evaluation sections of my dissertation project.

What is the purpose of this research?
This investigation aims to turn the paper based Mini Mental State Examination (MMSE) that measures the cognitive competence of an individual into an accurate digital version.

Do you have to take part?
You do not have to take part in this research. If, however, you decide to take part, then you will be invited to complete my digital version of the MMSE and complete an expert evaluation form that asks your expert opinion on what aspects of my application should be modified and why.
Participation will be completely anonymous, and on a voluntary basis. You have full right to withdraw your participant at any point during this session; however, once the session has been completed you may not withdraw your data as no data sets contain any participant information and it will not be possible to identify which data set is yours.

What will you do in the project?
You will be asked to complete my digital version of the MMSE that is comprised of 14 questions and then complete the expert evaluation form provided.

Why have you been invited to take part?
You have been invited to take part as you have met the requirements of an expert in this field of research. You have significant knowledge of the psychology behind the MMSE or have relevant experience with digital health research. These qualify you to give an expert opinion on what is good about my user interface and what should be modified to increase the accuracy of my application, for example, a drop-down list vs user input. The difference between such a way the user interface is designed could invalidate a factor of cognition that the MMSE is trying to measure. I am in no way trying to test the digital equivalency of application, instead I am trying to get the application to a stage where it would be ready to test the digital accuracy in future. For my research, I am trying to ensure the user interface and input of the questions and answers are satisfactory in terms of layout and input types so that it would be ready test the validity in future work.

What are the potential risks to you in taking part?
The only potential risk of taking part in this study is failing the MMSE examination that may indication you are lacking in cognitive competence. At this point, it is important to remind you that this examination is by no means a diagnosis of reduced cognition. It is merely an indicator and cannot be accurate under these experimental conditions. If you require further assistance relevant to cognition issues after taking part in this test I advise seeking out the help of your GP.

What information is being collected in the project?

The participant consent form

Consent Form for Digital Version of The Mini Mental State Examination

Name of department: Department of Computer and Information Sciences
Title of the study: Digital Version of The Mini Mental State Examination

- I confirm that I have read and understood the Participant Information Sheet for the above project and the researcher has answered any queries to my satisfaction.

- I confirm that I have read and understood the Privacy Notice for Participants in Research Projects and understand how my personal information will be used and what will happen to it (i.e. how it will be stored and for how long).

- I understand that my participation is voluntary and that I am free to withdraw from the project at any time, up to the point of completion, without having to give a reason and without any consequences.

- I understand that I can request the withdrawal from the study of some personal information and that whenever possible researchers will comply with my request. This includes the following personal data:
    - my personal information from transcripts
- I understand that anonymised data (i.e. data that do not identify me personally) cannot be withdrawn once they have been included in the study.
- I understand that any information recorded in the research will remain confidential and no information that identifies me will be made publicly available.

- I consent to being a participant in the project.

(PRINT NAME)	
Signature of Participant:	Date:

Bibliography

- AdvancedMD. (2019). *The Rise of Digital Healthcare - AdvancedMD*. [online] Available at: https://www.advancedmd.com/learn/rise-digital-healthcare/ [Accessed 2 Aug. 2019].
- Android Developers. (2019). *Geocoder | Android Developers*. [online] Available at: https://developer.android.com/reference/android/location/Geocoder.html#getFromLocation(double,%20double,%20int) [Accessed 10 Aug. 2019].
- Android Developers. (2019). *SharedPreferences | Android Developers*. [online] Available at: https://developer.android.com/reference/android/content/SharedPreferences [Accessed 10 Aug. 2019].
- Basw.co.uk. (2019). [online] Available at: https://www.basw.co.uk/system/files/resources/basw_55937-1_0.pdf? [Accessed 2
- Bourque, P. and Fairley, R. (2014). *SWEBOK*. 3rd ed. IEEE Computer Society.
- Cacho, J., Benito-León, J., García-García, R., Fernández-Calvo, B., Vicente-Villardón, J. and Mitchell, A. (2010). Does the Combination of the MMSE and Clock Drawing Test (Mini-Clock) Improve the Detection of Mild Alzheimer's Disease and Mild Cognitive Impairment?. *Journal of Alzheimer's Disease*, 22(3), pp.889-896.
- Courses.cs.washington.edu. (2019). *Class java.awt.Canvas*. [online] Available at: https://courses.cs.washington.edu/courses/cse341/98au/java/jdk1.2beta4/docs/api/java/awt/Canvas.html [Accessed 14 Aug. 2019].
- Digitaljournal.com. (2019). *Dthera Sciences to Provide Corporate Update at the Digital Medicine and Medtech Showcase - Press Release - Digital Journal*. [online] Available at: http://www.digitaljournal.com/pr/4064364 [Accessed 2 Aug. 2019].
- Docs.oracle.com. (2019). *Calendar (Java Platform SE 7)*. [online] Available at: https://docs.oracle.com/javase/7/docs/api/java/util/Calendar.html [Accessed 10 Aug. 2019].
- Folstein, M., Folstein, S. and McHugh, P. (1975). “Mini-mental state”. *Journal of Psychiatric Research*, 12(3), pp.189-198.
- Forbes.com. (2019). *Digital Healthcare Growth Drivers In 2019*. [online] Available at: https://www.forbes.com/sites/greglicholai/2019/01/07/digital-healthcare-growth-drivers-in-2019/#2f8367011dba [Accessed 2 Aug. 2019].
- https://app.hubspot.com/documents/2632673/view/49938227?accessId=8b71ba
- https://s3-eu-west-2.amazonaws.com/lawcom-prod-storage-11jsxou24uy7q/uploads/2017/07/Making-a-will-consultation.pdf
- https://www.cambridgecognition.com/products/digital-healthcare-technology/cantab-mobile/
- https://www.cogstate.com/cognigram-detects-cognitive-impairment-schizophrenia-patients/
- https://www.gov.uk/make-will/make-sure-your-will-is-legal
- iYogi. (2019). *10 Best Medical Apps for Seniors*. [online] Available at: http://www.iyogi.com/editors-pick/10-best-medical-apps-for-seniors.html [Accessed 2 Aug. 2019].

- Junkkila, J., Oja, S., Laine, M. and Karrasch, M. (2012). Applicability of the CANTAB-PAL Computerized Memory Test in Identifying Amnestic Mild Cognitive Impairment and Alzheimer's Disease. *Dementia and Geriatric Cognitive Disorders*, 34(2), pp.83-89.
- Kristina Fiore (2019). *Copyright Issues Hinder MMSE Use*. [online] Medpagetoday.com. Available at: https://www.medpagetoday.com/neurology/dementia/52040 [Accessed 17 Aug. 2019].
- Kurlowicz, L. and Wallace, M. (1999). The Mini-Mental State Examination (MMSE). *Journal of Gerontological Nursing*, 25(5), pp.8-9.
- Lawcom.gov.uk. (2019). *Wills | Law Commission*. [online] Available at: http://www.lawcom.gov.uk/project/wills/ [Accessed 2 Aug. 2019].
- McEachern, W., Kirk, A., Morgan, D., Crossley, M. and Henry, C. (2008). Reliability of the MMSE Administered In-Person and by Telehealth. *Canadian Journal of Neurological Sciences / Journal Canadien des Sciences Neurologiques*, 35(5), pp.643-646.
- Mead, A. and Drasgow, F. (1993). Equivalence of computerized and paper-and-pencil cognitive ability tests: A meta-analysis. *Psychological Bulletin*, 114(3), pp.449-458.
- Nccdglobal.org. (2019). [online] Available at: http://nccdglobal.org/sites/default/files/content/clox.pdf [Accessed 6 Aug. 2019].
- Nielsen Norman Group. (2019). *10 Heuristics for User Interface Design: Article by Jakob Nielsen*. [online] Available at: https://www.nngroup.com/articles/ten-usability-heuristics/ [Accessed 8 Aug. 2019].
- Nlp.stanford.edu. (2019). *The Stanford Natural Language Processing Group*. [online] Available at: https://nlp.stanford.edu/software/lex-parser.shtml [Accessed 14 Aug. 2019].
- Opencv.org. (2019). *About*. [online] Available at: https://opencv.org/about/ [Accessed 14 Aug. 2019].
- Pinto, E. and Peters, R. (2009). Literature Review of the Clock Drawing Test as a Tool for Cognitive Screening. *Dementia and Geriatric Cognitive Disorders*, 27(3), pp.201-213.
- Royall, D., Cordes, J. and Polk, M. (1998). CLOX: an executive clock drawing task. *Journal of Neurology, Neurosurgery & Psychiatry*, 64(5), pp.588-594.
- Sarsby, S. (2019). *Guest Article: The rise of digital therapeutics and what this means for healthcare professionals - AT Today*. [online] AT Today. Available at: http://attoday.co.uk/guest-article-the-rise-of-digital-therapeutics-and-what-this-means-for-healthcare-professionals/ [Accessed 2 Aug. 2019].
- Schramm, U., Berger, G., Müller, R., Kratzsch, T., Peters, J. and Frölich, L. (2002). Psychometric properties of Clock Drawing Test and MMSE or Short Performance Test (SKT) in dementia screening in a memory clinic population. *International Journal of Geriatric Psychiatry*, 17(3), pp.254-260.
- Scrum.org. (2019). *What is Scrum?*. [online] Available at: https://www.scrum.org/resources/what-is-scrum [Accessed 12 Aug. 2019].
- Shulman, K. (2000). Clock-drawing: is it the ideal cognitive screening test?. *International Journal of Geriatric Psychiatry*, 15(6), pp.548-561.

- ttps://www.who.int/sustainable-development/health-sector/strategiestelehealth/en/
- Yildiz, D., Seferoğlu, M., Güneş. A., Büyükkoyuncu, N., Yildiz, A., Kiliç, K. … Sigirli, D. (2018) Assessment of cognitive dysfunction in hemodialysis patients by the mini mental test and the clock drawing test. *Turkish Journal of Nephrology, 27(3),* 262-266.