The University of York
Department of Computer Science

Submitted for the Degree of Computer Systems and Software Engineering MEng

A Serious Game For Aiding the Screening of Dyslexia in Children and Young Adults

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24510 words as counted by `detex | wc -w`.
This includes all content and appendices.

May 2014

Abstract

In the UK, alone there are approximately two million undiagnosed individuals with dyslexia. The standard screening tests for detecting dyslexia in adolescents typically involve a number of written, spoken, and visual tests to be carried out by a specialist dyslexic teacher or psychologist. This test lasts around half an hour and can cost the individual in excess of £300. This paper presents a more accessible and engaging method of screening individuals for dyslexia, through the use of a serious game. The game was created for the Apple iPad device running iOS7 and tested on 42 participants, 7 diagnosed with dyslexia, and 35 controls which were seen to be in no way dyslexic. Testing showed that two gameplay performance metrics identify significant differences between the two groups, and that the game can identify diagnosed dyslexic subjects from those without dyslexia with an accuracy of 95.2%, whilst providing an engaging experience for all users. Though no definitive conclusions can be reached about the games predictive power, due to this study' small size, promising results were achieved and it is felt that the game could in the future be used as a replacement to the standard screening tests. It is hoped that this will allow more young adults to be properly diagnosed and receive the specialist help they require.

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CHAPTER 1

Introduction

Targeting adolescents, this project examines whether the conventional screening test for dyslexia could be replaced with a serious game. The game aims to use the gameplay performance metrics of a player to predict wether they are likely to have dyslexia. The game also aims to screen individuals without explicitly highlighting the literacy and phonological deficits often associated with dyslexia, with the hope of producing an engaging experience for those with and without dyslexia. If the game is successful, it should vastly reduce the cost, personnel, and time taken to identify dyslexia through not requiring a specialist dyslexia teacher, or psychologist, to conduct a screening test[3, 4]. Hopefully the accessibility of the game, to teachers, parents, and students themselves, will result in more young people being tested and receiving the specialist help they require.

1 Statement of Ethics

During the course of this project a study evaluating the created game was completed, this study involved human participants. At no point were participants in any danger or required to perform a task against their wishes. Participants were told in advance the purpose of the experiment and that they were under no obligation to take part. Informed consent forms were signed and read by all participants before commencing their experiment. All data identifying participants has been kept confidential and is anonymised for the purpose of analysis. Upon the completion and acceptance of this project data identifying participants will be destroyed.

Because this project is targeted at children and young adults, participants under the age of eighteen were recruited through their high school. In this case, consent forms were completed by parents or guardians. Participants were still informed that they were under no obligation to participate in the study. The participating schools are also not identifiable in this report, ensuring participants anonymity is retained.

It is also considered that the work conducted in this project could in the future be used as a dyslexia screening test, having an affect on a large number of peoples lives, it is possible some people may confuse this with diagnosis. Every effort has therefore been made to ensure readers are aware that the software created in this project is not designed for diagnosis, but to determine if significant differences can be found between the gameplay performance metrics achieved by those with dyslexia and by those without, using the models and techniques presented. It is also stressed that much more data and research is required in order to produce definitive results.

2 Project Report Structure

The remainder of this project report is divided into five further chapters, each of which draws on material presented in those previous to it. Each of these chapters concludes with the summary of the content presented.

The first is a review of current literature, explaining what is currently understood about dyslexia and how it is currently screened for. The literature review goes on to consider games and how they are currently used in the context of health, education, and dyslexia. Following this is the game design chapter, which considers the process of game design and how that can be applied to this project. This includes examining themes, goals, and game platform, in order to build a detailed design of the game built as part of this project.

The game implementation chapter details the realisation of the game design. This includes the software methodology used, the requirements extracted from the design, and the software architecture. The next chapter details a study conducted using the game implementation, experimenting with the game to gain insight into user opinion and into its ability to be used as a screening test.

The last chapter of this project report is conclusions. This chapter summarises what has been presented in this project and reflects on the decisions made. It also identifies possible extensions to the game, and user study, which could be completed in the future in order to achieve better results.

CHAPTER 2

Literature Review

This chapter examines current literature, surrounding both dyslexia and games, to determine the breadth of current knowledge in both areas. The purpose of this is to show how this project could change what is state-of-the-art by combining the two fields. Existing attempts at creating games for health and education, including for dyslexia screening and management, are also reviewed.

1 Dyslexia

Dyslexia is a specific learning disability which affects around 8-10% of the UK population [5, 3]. It is often considered a continuum, with no distinct cut off and varying severity. Though there are disagreements as to the definition of the word 'dyslexia' and everything it entails, there are two points all sources agree upon:

- Each individual with dyslexia is different, and is likely to present only a subset of the skills and deficits known to be related to dyslexia
- Individuals with dyslexia will most commonly have difficulty processing and decoding words, regardless of intelligence and cultural opportunity

Because of this, many see dyslexia as a reading disorder affecting spelling and reading acquisition. Common examples of this include confusing similarly shaped letters such as *d*, *b*, and *p*, and jumbling letters within words[6]. However, dyslexia has also been linked to verbal memory and processing speed, affecting an individuals ability to remember verbal information such as lists and sequences, and their ability to read fluently[5, 7]. Research in recent years has also suggested that dyslexia may manifest in areas other than phonological awareness and literacy skills[8, 6].

[8] describes dyslexia as a disorder which changes the way it presents itself as time and environment change, suggesting that with the right help at the right time individuals with dyslexia can reduce its impact on their lives. [9, 8] suggest that dyslexia can have a large impact on an individuals basic numeracy skills, and that despite having knowledge of high level mathematical concepts, those with dyslexia can have difficulty with times tables, mental arithmetic, and confusing mathematical symbols.

[6] states the literal translation of *Dyslexia* as 'difficulty with words', however, considers reading problems to merely be *"the tip of the iceberg"*, identifying other symptoms of the disorder including difficulty with auditory memory and visual sequential memory.

The British Dyslexia Association (BDA) describe dyslexia as a barrier one must overcome in order to fulfil their potential and make a full contribution to society[3], offering help and advice to those with the learning disorder. The BDA explain how indictions of dyslexia include confusing directions, difficulty with sequencing, and a lack of organisation skills[3].

The following sections consider reported symptoms of dyslexia, other than literacy problems, attempting to gain a broad knowledge about how dyslexia can really affect every area of an individuals life. The categories below in no way fully encapsulate the problems associated with dyslexia, however, provide an insight into the most commonly experienced and researched issues.

1.1 Organisational Skills

[10, 5, 11] all explain how dyslexia can affect an individual's organisational and time management skills, concluding that those with dyslexia are often unaware of time and cannot easily determine how things should be organised. For example, those with dyslexia often struggle grouping similar items together.

[12] also identified a trend of organisational deficits within dyslexics, conducting a study on 48 participants (26 dyslexics, 22 controls). The study concluded that those with dyslexia are more likely to make 'cognitive slips' than those without, these slips include forgetting whether doors have been locked, names, appointments and where items have been placed. The study also concludes that those with dyslexia are more likely to lack planning and concentration, all of these factors relate to an individuals organisational skills. The method of this study was to present participants with open questions, meaning an individuals answers merely reflected their opinion, and not fact. Despite this, the study still managed to find some significantly different results between those with dyslexia and those without. These results could tell us one of two things, either there is a significant difference between the likelihood of dyslexics and non-dyslexics making these cognitive slips, or that those with dyslexia generally have a lower opinion of themselves when considering the skills examined by the paper. Regardless, organisational deficits are worth investigating, especially since so many sources believe them to be associated with dyslexia.

1.2 Spatial Orientation

[13, 14, 6] suggest those with dyslexia are likely to have poor spatial orientation, struggling to differentiate between left and right, north, east, south and west. This is likely to make tasks such as interpreting maps and following directions difficult. Most of the research into directional confusion among dyslexics was completed circa forty years ago, and since then it has been widely accepted as a symptom of dyslexia. [15] found that some dyslexics can be distinguished from controls though the 'Block Design' task, used as part of the WISC-R intelligence test to test spatial orientation[16], in which individuals must use blocks to reproduce a presented design. Individuals with dyslexia were seen to produce very good results in comparison to controls when their literacy skills were not affected by their dyslexia. Participants with dyslexia whose literacy skills *were* affected were seen to score significantly worse than controls. These results suggest that this task may be able to distinguish between dyslexic and non-dyslexic individuals.

1.3 Working Memory

A large amount of research has been completed investigating the short term memory of those with dyslexia, particularly when reading. Individuals with dyslexia often struggle to remember list items, sequences, and even the contents of text they have just read. The reasons for this from a scientific perspective are debated, however, from a high level it seems that someone with dyslexia will put a large amount of effort into interpreting and reading the words, concentrating on understanding them as opposed to remembering them[10, 17].

[8] states that:

"Dyslexics typically perform poorly when their memory is assessed using tests such as the digit span task, in which sequences of digits have to be recalled in forwards and backwards order"

This suggests that the auditory memory of an individual with dyslexia can be impaired by the learning disorder, this effect was also seen by [18] when conducting a similar experiment.

Confrontation naming is also used to test the short term memory of those with dyslexia, which involves showing the participant a picture of an object and asking them for its name. [8] found that

"typically dyslexic children show more naming difficulties than controls, although the extent of their difficulties is not clear"

and goes on to suggest that, in order for this to be an effective test, objects must be familiar to all participants, a reasonable requirement.

1.4 Visual Memory

[19] suggests that individuals with dyslexia are likely to have poor visual perception, including visual memory. Visual memory is described by [19] as:

"The ability to remember for immediate recall all of the characteristics of a given form, and to be able to find this form from an array of similar forms"

It is suggested that weaknesses in visual perception are what cause commonly seen problems such as letter reversal and confusing letters within words, because an individual with dyslexia struggles to remember the shapes of the words. In theory this could also be applied to numbers, for example 6 and 9 could easily be reversed in the same way as *b* and *d*.

1.5 Visual Sequential Memory

[15] found that across 39 dyslexic participants, with varying literacy and mathematical ability, all participants performed similarly when their visual sequential memory was examined. Participants were split into four groups:

- Controls without dyslexia
- Those with dyslexia and low literacy ability
- Those with dyslexia and low mathematical ability
- Those with dyslexia and low literacy and mathematical ability.

The study tested the visual sequential memory of participants by presenting them with sequences of symbols or pictures for a period of 5 seconds and then asking them to recall that sequence. Results of this study suggested that this test is a good way be identify individuals with dyslexic from controls, with significantly better scores being obtained by controls, when the objects presented are symbols.

1.6 Visual-Spatial Discrimination

[1] conducted a study which suggests that those with dyslexia may perform better than average, in terms of speed, when identifying impossible figures; a task designed to assess an

individuals visual-spatial discrimination abilities. The study suggests that, though no more accurately, the dyslexic group tended to distinguish between impossible and possible objects significantly faster. [1] also tested participants on their ability to match complex images, the images used in this test are shown in Figure 2.1. They found that the control group in general outperformed the dyslexic group, however, state that as the test was only using one shape their results may not be accurate. They also point out that the difference between the control and dyslexic groups was found in males only, with females in both groups performing equivalently. Despite the somewhat inconclusive results and small size of this study, the concepts may be worth testing.

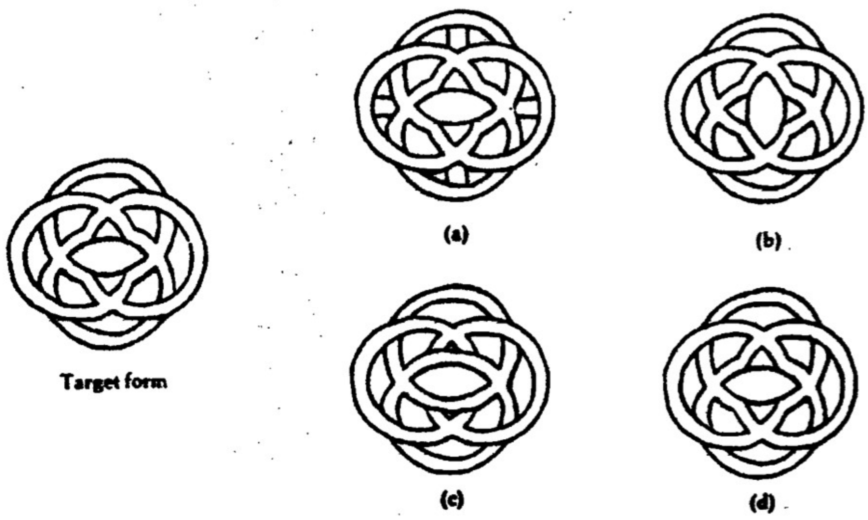


Figure 2.1: The Celtic Matching Task from [1]

2 Dyslexia Screening

A large amount of research has been conducted into the benefits of diagnosing dyslexia early including [20, 21], but there are always individuals who slip through the cracks. Currently it is estimated that there are over two million people in the UK alone with undiagnosed dyslexia [22]. Older children with dyslexia are more likely to act out behaviourally, due to lack of support, and low self-esteem [23]. Adults with undiagnosed dyslexia are more likely to find it more difficult to get a job, and in some cases, due to lack of specialist support when growing up, can be completely illiterate [3].

[24] identifies some of the key advantages to the late diagnosis of previously undiagnosed individuals, these include the emotional benefits that come with knowing the reasons why they may have struggled at school, and no longer feeling ‘hopeless’ or ‘slow’. Diagnosis is likely to limit the highlighted problems in older children and adults with dyslexia, such as behavioural difficulties, by allowing them to attain specialist help and support they would previously have been unable to access. However, before being diagnosed most individuals are required to go through a screening test which determines whether they are likely to be at risk of dyslexia and require full diagnosis. This screening test costs around £300 and is not currently administered to everybody [3]. For these reasons the target age group for the software created in this project is young adults and teens between the ages of eleven and

twenty-five, at this age having left primary school, support for dyslexia begins to diminish, and individuals are less likely to be diagnosed[6].

2.1 Screening Tests

There are currently two standard screening tests for dyslexia in the UK which cover the target age range of this project, the *Dyslexia Adult Screening Test* (DAST) and the *Dyslexia Screening Test* (DST) [3, 4].

The DAST is designed for adults over sixteen and the DST for children between eleven and sixteen. Both are described by [4] as screening tests, not assessments, aimed at identifying whether an individual is at risk of dyslexia, and not at dyslexia diagnosis.

The tests include a number of tasks that the participant must complete, including a digit span task as described earlier in section 1.3, and rapid automatised naming (RAN). [8] describes RAN as a test which involves naming highly familiar objects under pressured conditions, these objects may include letters, digits, symbols or colours. [8] found that:

"Dyslexic readers take longer to complete such tasks than control children of the same age"

Both the DAST and DST test also include bead threading, this test notes how many beads the participant can thread within a 30 second time period, designed to examine hand eye co-ordination[25].

The screening tests take a round 30 minutes to complete and also includes a number of tasks related to literacy such as testing vocabulary, letter naming, spelling, reading, and writing[26]. Though not a long time individually, if administered on a large scale—for example to an entire school—the process would require weeks of a specialist psychologists time. In addition to this, the test requires participants with dyslexia to actively complete tasks that they are likely to have trouble with, such as spelling, which may cause them to become stressed and disengaged.

2.2 A New Screening Test?

The DST test was first developed in 1996, closely followed by the DAST test in 1997, both over fifteen years ago [27, 28]. The creators detail in their accompanying papers very similar goals to those of this project. They created the screening test to reduce the cost and increase the accessibility of dyslexia diagnosis, allowing those who appear to have a high risk of dyslexia to be rapidly distinguished from those who do not. This meant that only individuals who were identified as high risk needed to continue with full assessment, a costly and lengthy process.

Fifteen years on and the world has changed, technology is now at the forefront of everything we do, a screening test which requires pen and paper and access to a specialist who owns the required equipment seems outdated.

With the technology currently available more and more tasks which used to require specialised expertise are becoming available to everyone, accessible in schools, homes and even on the go. For example, fifteen years ago when wanting to deposit or withdraw money you had to visit the bank, now this can be done using a smart-phone from almost anywhere. This makes it much more accessible for those in rural areas or with mobility issues, as well is simpler and quick for the everyday user. With this new technology being so readily available the question has to be asked:

Surely there is a more cost effective and accessible way to screen for dyslexia?

3 Games

In this section the concept of a *game* is reviewed and defined, with current digital games used in the health of eduction sector being examined. This is done to help make informed design decisions when creating the software to be used in this project, building on the mistakes and success of others.

3.1 The Definition of a Game

Games can be physical, digital, or even mental. The definition of the word *game* is therefore highly debated, with every book or paper including their own interpretation of what it means for something to be a game. [29] defines a game as a *"rule based formal system"*, a system in which the outcome is not predetermined, stating that there must be interaction with the user in such a way that the user can influence its outcome, causing them to feel emotionally attached to that outcome. [30] includes nine definitions of the word game, none of which fully agree. The general consensus is that a game involves rules that enforce limitations on the users, it must be goal orientated and involve activities, events, and decision making. The definition given by [31] provides a nice summary of these definitions:

"A Game is a problem-solving activity, approached with a playful attitude"

This definition appears particularly useful as it is short and to the point, whilst encompassing a number of criteria needed in order for something to be viewed as a game. The use of *problem-solving activity* suggests that there must be some form of challenge within the game, an obstacle for the user to overcome. Games, under this definition, must be interactive, allowing the user to participate and control the flow of play. This means there must be rules governing the bounds of what the user can and cannot do. A *playful attitude* suggests that the user should want to play the game, it should be a fun and interesting experience whilst providing the necessary challenge.

Though the definition provided by [31] in no way fully expresses what a game is or can be, it appears the most suitable for how the word *game* should be interpreted in the context of this paper, which focusses on digital games. Particular emphasis is placed upon the need for a game to be a playful experience, the user should want to play the game and be fully immersed within its story. Users should not feel like they are being tested or forced to play against their will.

3.2 Serious Digital Games

Serious games are a subset of games that aim to achieve something more than just user experience and entertainment[32]. They are used in many fields, including politics, health, and education, and have serious goals such as skill acquisition, or identifying users with a particular trait, skill or deficit[33].

[33] identifies the differences between serious games and those designed purely for entertainment, determining that serious games are more likely to value achieving their serious goal above rich user experience and learning above fun. This creates the question:

What if a rich user experience is required in order to solve the serious problem?

For example, when attempting to realistically simulate an environment in order to test a skill, the user must be completely immersed in the game environment in order to perform as they would when confronted with the same situation in reality. In the case of the work conducted in this paper, solving the problem and the user experience are equally important. The serious goal of this work is to accurately map users to one of two groups, those with dyslexia and those without, this accuracy is only achievable if players fully engage with the process, making user experience just as important.

The decision to make user experience equally as important as achieving the serious goal creates another goal: engaging the user. When defining the word game, it was strongly emphasised that the user should enter the game willingly, and not feel like they are being tested or forced to play, however, the user will be being tested and, in some cases, will be forced to play by a parent or teacher, this creates another question:

How can a game be created which hides this from the user?

The answer appears to be to carefully examine the mechanics, aesthetics, story and technology of the game in order to design a game which successfully abstracts its serious nature and goals from the user.

3.3 Serious Games for Health and Education

In recent years games have become ever more common as a method of education[34], allowing players to learn whilst being entertained. [34] describes how people who play games can be seen as learners, with different players learning the concepts and goals of a game at different rates. [34] compares learning through games and learning through school, stating that games encourage players to learn as it is their choice, unlike in a school environment where they are told what they must learn and when. This suggests that people may learn better through games. The game *Supercharged* is given as an example of a serious game designed for learning, specifically teaching players about physics[35]. Results of an experiment involving *Supercharged* found that the game helped children to understand basic physics concepts, however, often children—particularly boys—became disengaged with the game after a short time[35], likely due to its repetitive nature.

Games have also been used as teaching tools for those with disabilities such as autism spectrum disorder. A nice example of the use of games to aid individuals with autism is the *Let's Face It* program, aimed at teaching children face recognition skills[36]. [36] accepts that the games within the *Let's Face It* program are limited, however, they still manage to show promising results and appear particularly excited at the idea of producing a free tool available to everyone at home, school, or elsewhere.

Games to help with dementia have also been investigated, [37] describes games and puzzles that have been created to help tackle the memory, visual attention and coordination problems associated with dementia, including digital mazes and jigsaws.

The above show that recently serious digital games have been used in an attempt to solve existing and prominent issues, both in the health and education sectors.

What about Dyslexia?

3.4 Serious Games for Dyslexia

Previously, Section 1 discussed common skills and deficits associated with dyslexia, with a focus on tasks which involve minimal reading, writing and spelling. This has been done in order to allow a dyslexia screening game to be created which is as appealing and accessible as possible to those who struggle with these vital skills. It is unlikely that individuals with these difficulties will engage with a game which so openly points out their known weaknesses, instead the game content must be designed such that the link with dyslexia is as subtle as possible. In addition to this, because the game will not rely heavily upon the players English language skills, it may easily port to other languages.

Accessibility was a key factor in choosing to experiment with using a game as a dyslexia screening test. Most individuals understand the concept of a game from a very early age, and in todays society games are commonly digital, played on a computer, console or mobile device. Having a game as a dyslexia screening test takes advantage of the users existing knowledge and familiarity with games, making them feel at ease when playing, and making the experience fun and engaging. If the user feels connected to the game, they will be more likely to perform to their best ability making the test more accurate. In addition to this, a digital game has relatively low cost, with no specialist equipment required other than a device with which to play, making it much more accessible than the current screening tests. On top of this, most households in the UK have access to a mobile device or computer already, meaning the extra cost involved is nil[38]. The availability of digital devices means the catchment of the game could be enormous, an entire school could be tested, using existing resources, within a few hours with no additional cost other than electricity. This is a stark contrast to the specialist teachers and equipment currently required.

3.4.1 Existing Serious Digital Games for Dyslexia

[39] uses the serious game paradigm in an attempt to maintain user attention, and encourage full participation in their study, much like the reasoning behind using games within this project. They recognise that participants are more likely to perform the required exercises if the tasks do not appear to be boring, and they do not feel like they are being tested. The paper describes the creation of a set of serious games, targeted at predicting the risk of dyslexia in pre-readers. The target audience of the games demand that the tasks completed by participants are primarily non verbal, though an alphabetic theme runs throughout. Despite the papers title: *"A serious game for predicting the risk of dyslexia in pre-readers"*, it does not describe how a serious game can be used to predict the risk of dyslexia, but the creation of a set of games that a group of dyslexic children enjoyed, and did not find too difficult.

[39] details only three created games, though hints at the existence of more. The first *Paths* is described as a game to *"train the users ability to discriminate among images in the fovea region and surrounding ocular region"*. The paper presents their reasoning behind the game design, and how it allows for them to test an individuals visual search skills, they do not however relate these skills to dyslexia. At no point is any research into how those with dyslexia are likely to perform better or worse than controls on this task referenced.

The second game *Fence Letters* is much of the same, the paper states what they are trying to test, an individuals ability to split their attention, but provides no links between the skill being tested and dyslexia.

The final game presented in [39], *Wizards*, is designed to test an individuals temporal order judgment. With this game the paper, unlike with the others, has linked it to dyslexia. The paper explains the hypothesis that those with dyslexia could have a *"defect in the brain zone that processes rapid auditory stimuli"*, and then explains how they designed a game to test this. The game attempts to utilise the common dyslexic problem of confusing similar looking and sounding letters, such as *b* and *p*, however, uses the upper case letters which are not mirror images or rotations of each other.

It was expected, given the title of the paper, that [39] would present a study explaining how well their games distinguished between participants with dyslexia and controls. However, the participants were only asked questions about the games interface and usability. At no point was any data presented showing how participants scored on each task. Of course, even if the data was presented it would have no context as the study did not include any control subjects without dyslexia, meaning that any data collected could not detail statistical differences between the performance of the two groups. The conclusions of [39] state that they have proved that the games can be used to train skills such as visual-spatial attention and phonological awareness, however the content of the paper in no way supports these claims and it seems that the work is still in progress.

[40] is a paper which describes the creation of *Dyseggxia*, a serious game designed to train the literacy skills of dyslexic individuals and not as a tool for screening or diagnosis. Unlike this project, [40] makes little attempt to hide its serious goals from users, nor does it attempt to limit the users exposure to tasks they are likely to find difficult, making them repeat the same task over and over until they work out the correct answer. Since the game is designed to train literacy skills it is inevitable that they will be at the forefront of the game, however, this does not make for an engaging experience. It is very obvious this game is designed for learning and little else.

Despite the differences between the goals of this project and [40], there are still some lessons that can be learnt. Firstly the paper only goes to support the idea presented in this project about not focussing on literacy deficits. The heavy focus on spelling and literacy in [40] means that the game very quickly becomes boring and tedious, with the user constantly repeating the same five tasks. It also meant that, when converting the game between languages, mistakes were made, with some of the English words used within the tasks being non-words, causing the game to become frustrating and confusing, defeating its purpose.

As with [39], the study conducted within [40] was very small, with the game only being evaluated on 7 participants, which does not seem like a large enough sample for making any definitive conclusions about the developed game. Despite this, the tasks used in the game seem appropriate for their purpose, and would likely benefit from a larger test group and a usability study, to help make it a more engaging experience.

Both [39] and [40] are aimed at significantly younger children than this project, with graphics and themes to suit, meaning little can be taken from the games aesthetics and design for this project.

4 Summary

In summary, this chapter has reviewed the current literature surrounding dyslexia in order to gain an informed understanding of how it can affect an individual, including their memory and organisational skills. The current dyslexia screening tests have also been examined and critiqued, and it has been suggested that a new test, more applicable to the modern world, is needed to help make dyslexia screening more accessible and cost effective. The use of a serious game has been proposed as a way of achieving this, whilst making the process more engaging and less intimidating for those that struggle with reading, spelling, and writing. Existing serious games designed for health, education, and dyslexia, have been reviewed and none have been found to achieve the goal of this project. One paper reviewed appears to be aiming for something similar to this project, however, the research presented is not sufficient to analyse the created game on its ability to screen for dyslexia.

CHAPTER 3

Game Design

There are a number of factors which must be considered when developing a game, these include the mechanics, aesthetics, goals and technology. This section examines the process of game design, as described by current literature, to help make design decisions about the dyslexia screening game to be developed in this project. The structure of this chapter is loosely based on the sections detailed in [31]. References in this chapter may be slightly more informal than in other chapters as this is the nature of the field.

1 Genre and Theme

The genre and theme are very important considerations when designing a game, they must be consistent in order to create an immersive experience for the user, as they influence every design decision and game asset. The theme and genre are especially important when designing a serious game, an immersive and enjoyable experience needs to be created for the user, whilst ensuring that the serious goal can be achieved. In this section, game genres and themes are examined in order to determine the best choices for the game being developed in this project.

1.1 Genre

Digital game genres are used to categorise different styles of game, much like with books and films. There are a number of existing genres, including: action, adventure, casual, simulation and sports; all of which are popular. There are no formal definitions as to the behaviour a game of a particular genre must exhibit, because of this it is very hard to concretely place a game into a particular genre.

If the above list was to be taken as the list of all possible genres then the game to be created in this project is likely to be a casual, action, or adventure game. This is enforced by the need to incorporate tasks designed to test for dyslexia into the game design. Examining the traits of popular games listed under these genres is likely to help when deciding between them.

The games listed under the action genre on the *Steam* platform, are mostly first person shooter (FPS) games such as *Half-Life 2* and *Call of Duty*, where the user plays as if they are a character within the game, and often uses weapons to progress[41]. When examining the *Google Play Store*, FPS games are again prominent in this genre [42]. Despite its popularity, an FPS game is unlikely to be suitable for this project as the violent gameplay which appears popular with older users may not be suitable for younger users.

When researching adventure games on the *Steam* platform they appear to be very much about the narrative and game story, creating elaborate and intricate game worlds to enhance this narrative. A similar trend is seen in the *iOS App Store* with games such as *Broken Sword 5 - the Serpents Curse* and *The Room* topping the charts [43]. These adventure games are likely to be very immersive, and would accommodate for tasks involving dyslexia to be incorporated. Unfortunately timing and personnel constraints are likely to prevent the game being developed in this project from being able to fully capture the adventure genre, as professional graphic designers and game writers are unavailable.

This leaves the casual genre, which appears to be the most diverse of the three genres. Popular games under this genre include puzzles, 2D platform games, strategy games, and tower defence games. Of these sub-genres, two are appealing in the context of this project: puzzles and platform games; these genres seem suitable for incorporating tasks designed to screen for dyslexia into them, with the time and resources available. When considering the serious goal of this project, to screen for dyslexia, the game should be as immersive and enjoyable as possible in order to encourage full participation. With this in mind the game developed in this project was chosen to be a *2D platform* game.

2D platform games are an incredibly popular genre of digital games, examples include *Sonic the Hedgehog*, *Super Mario Bros.* and *Little Big Planet*. Movement within these games is simple and well defined, users can move in the x-axis, can often jump, and can normally interact with objects.

The simple nature and popularity of this genre will hopefully mean that there will be no bias towards users with a strong gaming background, with little for new users to learn. A key factor to ensuring this is the game mechanics and controls, which must be carefully designed to be an intuitive as possible and eliminate bias.

1.2 Theme

With the genre chosen to be a 2D platform game, the theme of the game must be chosen. [31] describes the game theme as *"the idea that ties your whole game together"*, without a strong theme a game is unlikely to fully engage users and may cause them to become unnecessarily confused.

For this project, the game theme must appeal to both males and females, as well as teens and adults, between the ages of eleven and twenty-five. This is a large target audience making choosing an enjoyable theme for all users difficult. The theme must not be too specific so as not to exclude some user groups, allowing all users to immerse themselves in the world. It must also not include adult themes and content which may frighten or confuse younger users. [31] describes two steps that must be taken when creating a game theme:

1. Figure out the theme
2. Do everything possible to reinforce it

There seems not to be a tried and tested method of deciding upon the game theme, instead the game designers creativity is tested. With this in mind the chosen theme for the game in this project is:

The fantasy of being a lost robot

The user plays the game as a lost and lonely robot, attempting to escape an underground sewer. The robot must navigate across platforms through the sewer, utilising objects and completing puzzles as they go.

Having achieved step one, step two involves designing every other aspect of the game to support this theme, including the game mechanics, aesthetics and technology.

2 Aesthetics

It is important to consider that user engagement and immersion are likely to lead to more accurate results, with users being more likely to play to the best of their ability and less likely to become distracted by the outside world. The user interface (UI) may effect the engagement and immersion of the user through colours, font and characters. Each of these areas must be researched to determine the best choice for the game and the target audience, encouraging full participation and therefore more accurate results.

2.1 Colours

The colour system of a digital game is an important decision when considering both immersion and accessibility. [2] and [44] explains how users give meaning to colours, relating them to emotions and real world items. For example, red is often seen as the colour of blood and fire, but is seen by some communities and age groups as the colour of happiness. These papers show the importance of choosing the right colour for the right world item or character, in order to connect with the user and encourage immersion. They also show the disparity between age groups, and how they associate colours to emotions, it is therefore important when deciding on the colour system of a game to consider the target audience.

Colour	Meaning
Red	Warmth, fire, blood
Black	Death, hiding, authority, criminality
Brown	Earth, comfort, worn out
Gold	Value, honour
Orange	Strength, warmth, endurance
Grey	Neutrality
White	Purity, innocence, coldness
Green	Nature, balance, youth
Yellow	Hope, joy, sun
Purple	Royalty
Blue	Sadness, calm, wisdom

Table 3.1: Colours and possible user interpretations, based on [2]

Table 3.1 shows possible colours to be included in the game and how members of the target age group are likely to interpret them. When choosing the colours for game objects Table 3.1 should be consulted, in order to maximise the probability of invoking the desired emotional and physical response from the user. However, it is important to remember that Table 3.1 only details the hue of the colour, changing the saturation and brightness may alter the meaning and the emotions invoked.

As well as considering the meaning users may attach to colours, we must also consider those who cannot easily distinguish between certain colours. Approximately 5% of males and 1% of females suffer from some form of colourblindness [45]. Colour blindness comes in many forms, the most common of which is protanopia, or red-green colour blindness as it is commonly known, followed by dueteranopia, green-red colour blindness [46]. Other, less common, forms of colour blindness include tritanopia, blindness in the blue end of the spectrum, and monochrome, also known as total colourblindness. When ensuring a game is accessible to all, the colour system should be tested to ensure important colours can be distinguished by

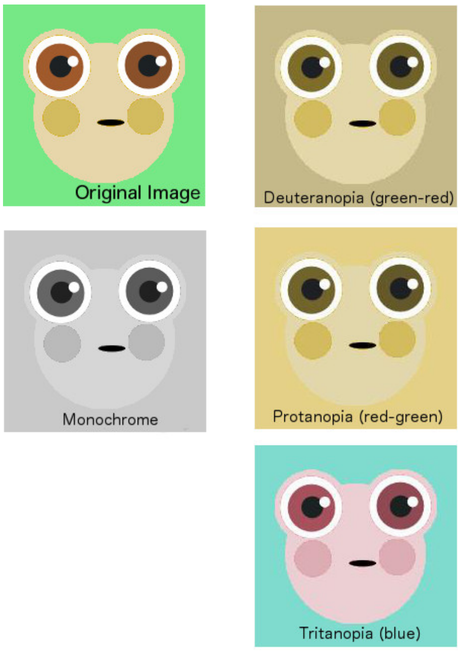


Figure 3.1: Distinguishing between foreground and background colours

every possible user. Figure 3.1 shows an example of how choosing the wrong colours can cause objects to be indistinguishable to users suffering from colour blindness, examples were generated with [47]. The example shows a particular issue for those with protanopia, with the world character and background being near inseparable.

Colour is not the only visual cue that helps users identify the differences in objects, other factors such as shadowing, inter-reflections, and motion parallax also play a big role [48]. However, without the help of colour users may be at a disadvantage, this could impact the users game experience and immersion, as well as affect the game result. It also is important to consider that shadowing and inter reflections are advanced computer vision concepts which many games, particularly 2D games, to not often implement.

Because the game will be set underground the colour scheme will include dark greys and blacks in the background as shown in Figure 3.2, with red and blue undertones creating a rustic and futuristic environment. Foreground colours, shown in Figure 3.3, will contrast with the background, using lighter greys and whites with hints of gold, red, and blue to create metallic objects, again emphasising the industrial nature of the theme whilst adding warmth.

Figure 3.2: The Background colour scheme of the game

Figure 3.3: The Foreground colour scheme of the game

2.2 Font

Font is a very important consideration for this particular game, the purpose of the game is to distinguish between those with dyslexia and those without. The wrong choice of font could result in some individuals with dyslexia being unable to understand instructions, hints, or aspects of game play. This in turn could affect the game outcome and possibly result in an incorrect classification, preventing the individual from accessing the help they require. [3] and [49] suggest some general guidelines about font:

- The typeface should be san serif, the size should be 12 point or higher
- Text should be dark coloured when placed over a light background
- Many dyslexics report that bright white backgrounds make text difficult to read and should be avoided

On top of these general guidelines, the actual typeface is also important. Most modern fonts have been developed to be aesthetically pleasing, with the letters appearing similar, this causes a problem for some individuals with dyslexia who can often mirror or rotate letters. In recent years a number of fonts of been developed, targeted at those with dyslexia, with the aim of decreasing the confusion between alphabet letters. Examples of these fonts include *Open Dyslexic* and *Dyslexie*.

The quick brown fox jumps over the lazy dog

Figure 3.4: An example of text in the typeface *Open Dyslexic*

Dyslexie [50] is a font designed to reduce the number of reading errors made by dyslexics, whilst still being aesthetically pleasing to all users. The letters are designed to be bottom heavy, preventing users from mirroring letters on the horizontal axis. The shapes of the letters are such that each letter is individual, for example *b* is not the mirror image of *d*, as with traditional fonts, making it harder to flip letters on the vertical axis. The spaces between letters and words is larger than with traditional fonts, meaning they are easier to distinguish.

Open Dyslexic [51], shown in Figure 3.4 is another example of a font aimed at assisting dyslexic individuals with reading, again it is bottom heavy, with each letter being individual to prevent the mirroring or flipping of letters. This font, unlike *Dyslexie*, is freely available to use in proprietary and commercial software, making it a good choice for the game. It has also received over two thousand commendations by dyslexic users through social networking sites[51].

2.3 Characters

[52] explains a series of good learning principles for serious educational games, ensuring an immersive user experience whilst achieving the serious objective. Though these principles are aimed at serious games with a view to teach as oppose to test, the goals and need to engage the user remain the same. [52] identifies the role of characters in games and how the user must feel committed and connected to their character, this is done by either providing the user with powerful off-the-shelf characters, or allowing them to create and design their own. Commitment to the character allows the user to more easily commit to the game,

allowing for the serious goals to be achieved without alienating the user and making them feel like they are being assessed.

Since the target audience for the game being developed in this project is quite large, characters need to be relatable to all users regardless of background or gaming familiarity. [31] explains how research shows that as game objects become more human users begin to empathise with them more, becoming more invested in their success. When game designers attempt to make human characters but don't completely convince users, the characters can be seen as "repulsive" and "creepy" which may be desirable for some characters but not often for the character the user is portraying.

The theme of the game being created in this project specifies that the user will control a character in the form of a robot. This character needs to be designed to be human enough for users to relate and empathise with it, but not so human that it becomes repulsive. Based on this requirement, and using the colour palette identified in Section 2.1, *TOM* was created and is shown in Figure 3.5.

TOM's name comes from his manufacturing code *897TOM* displayed on his chest and head, giving the robot a visible human name was done so as to help the user personify him. *TOM* was designed to be lifelike enough so that users can relate to and personify him, however, not so lifelike that the limited artistic talents of the game designer would be off putting to the user. *TOM* is shaped like a human, however, is clearly made of metal components with the bolts connecting his body parts allowing his arms and legs to move. His visual display is designed to appear like eyes, large and coloured very brightly, to draw the user in and incite emotion.

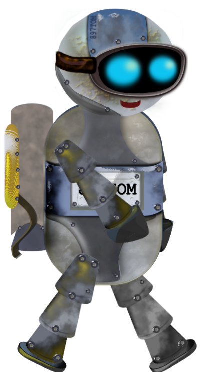


Figure 3.5: The game character *TOM*

3 Technology

[31] describes technology as being the most unpredictable element of game design, with game hardware constantly changing and advancing. The timescale of this project is short and thus evolving hardware is unlikely to be an issue, especially since new devices such as the *Xbox One* and *iPad Air* have just been released. Deciding on the game hardware is important as it may limit the game mechanics by dictating the actions that the user can perform.

There are currently three distinct categories of gaming hardware:

Consoles Dedicated gaming machines, examples include the *Xbox One* and *Wii*. Consoles either have built in controls or compatible game controllers. Games are external, often on compact disks or cartridges.

Computers Computer users can play online games, installed games such as *Solitaire* and even have dedicated gaming software such as *Steam*, allowing them to buy, download and play games.

Mobile Device's Users of mobile devices, including phones and tablets are able to install and play games—commonly referred to as *Apps*—from markets normally provided by the device manufacturer.

For this project creating a console game is unfeasible due to insufficient time and resources, meaning the game will either be targeted at mobile devices or computers. Creating a game targeted at computers is also likely to be unfeasible, if the game was designed as a web application a constant network connection and domain would be required, multiple browsers would have to be supported, and in order to be used in schools the web page hosting the game would have to be allowed past firewalls. If the game was developed as a standalone computer application it would have to be developed in a cross platform language, capable of running on a range of hardware. This is possible, however, this does not allow for much flexibility, or for a simple and secure way to package the game for users. Creating the game as a mobile application would allow the game to be played without a network connection or hosting and across a range of hardware, whilst providing a simple way for users to obtain the game through app markets.

3.1 Mobile Operating Systems

In the world of mobile devices two operating systems currently dominate the rest: *iOS* and *Android*.

Android runs on a variety of mobile devices by a variety of manufacturers, there are also a number of different versions, because of this the *Android* market is very fragmented, making designing a single application which works well on all devices a difficult task. Android application are written in the *Java* programming language, and there are numerous frameworks available for creating games including the *LibGDX* framework, which provides a 2D physics world and graphics renderer.

iOS is designed to run only on *Apple* devices and would limit the audience of the game, however because of this, fragmentation is not an issue. When prototyping the game, the *iOS* platform would allow for quick development cycles and feature addition, particularly with the new built in *SpriteKit* framework, designed for the creation of 2D games.

For the first version of the game, being developed in this project, the chosen operating system is *iOS*, specifically versions 7 onwards. This operating system was chosen as it seems to be the most versatile and allows for quick development cycles, which is important as integrating the dyslexia screening tasks within the game will be in iterative process. Initially the game will be optimised for *iPad* hardware, however, will easily extend to *iPhone* and *iPod Touch*.

On top of this the game could later be extended to support *Android* devices, as the *SpriteKit* framework, used to create 2D games in *iOS*, has similar counterparts for *Android* such as *LibGDX*.

4 Mechanics

The mechanics of a game are the procedures and rules which describe the goals[31], defining the extent the user can influence the game outcome. Mechanics are the core of the game, independent of technology, story, or appearance. In a digital game mechanics may include the game space, game objects, and the rules and actions that govern game play.

4.1 Actions

Every game must have actions, else the user would never progress. An action could be something the user chooses to do, or something that occurs as a result of another action. The user controls the flow of these actions, but the game designer controls the side effects[31].

User actions define what happens when the user performs a specific operation, such as a mouse click or a touchscreen swipe. These actions should be consistent, for example, if an upwards swipe performs a jump it should always perform a jump.

The game being created in this project is being designed for touchscreen devices which support a limited number of user actions, known as gestures. These gestures include tapping, swiping, dragging, shaking, and pinching[53].

Characters in 2D platform games can often move freely in the x-axis, jump, and fall. The user controls need to be as simple as possible, so as not to frustrate users with little gaming experience or create bias towards more experienced game users. The controls also need to be as intuitive as possible as, due to the nature of the game, it is preferable to have to include as little written instruction as possible.

With this in mind the touch gesture was used to allow the user to control the game character in the x-axis. The screen is to be split by the game character, such that touches to the left of the character cause *TOM* to turn to the left, and touches to the right cause *TOM* to turn to the right. Touching and holding causes the character to move in the direction of that gesture. This seemed like a very natural action that users would easily recognise. In addition, this method of moving the character means that if the user expects the swipe motion to be used instead of touch, the character will behave in a similar way.

Allowing the character to fall is a simple by-product of the x-axis movement, if the character moves off the edge of a platform they will fall until they hit the platform below.

Deciding on the gesture to use for the jump action is more complex, a swipe or tap gesture would both be suitable. Some *iOS* platform games also use a button tap to trigger a character jump, this however seemed restrictive and less natural than the gestures. The decision was made to initially use a double tap gesture to jump, as the transition between holding the screen and double tapping seemed the most natural. When experimenting with the game the perceived ease of use of the controls will be recorded to ensure this decision was correct, and that the use of the double tap gesture does not seem obscure.

4.2 Objects

Within most games exist interactive objects, each object will have attributes. These attributes can include where the object can go and how the user can acquire it. Because of this, each object must have a state, holding the current values of its attributes [31]. Since this project designs only a single user game, the user is likely to be informed of most changes occurring within the game world. The only exception to this would be if a *physics engine* is used, in which case objects will be able to interact with each other without the users knowledge.

There are three key assets within a platform game[54]:

Avatar A single user game normally has one avatar, though the user may be able to choose between a variety of possible avatars. The avatar represents the user, moving and behaving as the user defines, within the limits of the game world.

Platforms Platforms are objects which the user walks, runs, or jumps along in order to advance in the game. Platforms can be seen as a static object.

Other Objects Amongst other things objects could be collectable, throwable, or stackable, they could also be jumpable, pushable, or breakable. These objects should be interactive, and somehow useful within the game.

4.2.1 Avatar

The game avatar has already been defined in section 2.3, however, its attributes have not. A character will need a position, defining where it currently is in the game world. It will also need to hold the direction it is currently facing, left or right. To prevent glitches when jumping or falling the character should hold a state defining whether it is currently standing on a platform, jumping, or falling. If collectable items are included within the game then the character will also need an inventory, detailing the items it holds. In addition, the character will need a texture, the graphic representing it on screen.

If a physics engine was to be used then the character will also require a physics body, allowing it to react to interactions with other objects.

4.2.2 Platforms

The platforms are static objects, the user can interact with them but they cannot move. Fitting with the industrial theme, examples within the game could be girders, pipes or stones. Because these objects are static they require only two attributes: a position, and a texture.

If a physics engine was used then static objects would also need a physics body, as otherwise the character will be unable to interact with them. The *SpriteKit* framework allows for both static and dynamic physics bodies meaning this would not be an issue when implementing the game for *iOS*.

4.2.3 Other Objects

For this game there are likely to be four types of objects, excluding the character and platforms.

Scenery Stateless objects that the user cannot interact with existing in the background.

Dynamic Physics objects that the user can push around, they can interact with both the user and other dynamic objects, examples include boxes and barrels.

Collectable Statics objects which the user can collect, removing them from the game world and adding them to an inventory to be used later.

Special Objects which perform special functions, such as start in game tasks

Scenery objects merely require a position and a texture, and exist in the background of the world, to enrich the experience and reinforce the theme. Examples for this game could include bricks, steam, and graffiti.

Dynamic objects are defined like platforms, however, the physics body would be dynamic. This means that the character can push them around and forces such as gravity and friction will act upon them.

Collectable and special objects are defined in the same way as the scenery objects. This is because information concerning whether they should perform their special function, or be collected is not their concern. Their position alone can be used to determine whether an event should happen.

With the above in mind the sprite sheets shown in Appendix D have been created and show all the objects to be used in the platform game.

4.3 Space

The game space is the place in which the game takes place, in digital games this is normally referred to as the *game world*. [30, 31, 29] all mention *the magic circle*, defined by [30] to be the border separating the scope of the game from its game world, where the game world is itself a fictional projection of the real world.

Some games such as *Fifa 2013* and *GTA V* aim to make the game world as true to the real world as possible. Others such as *Spyro the Dragon* and *Minecraft* offer the user a real world environment but are not concerned with overall realism, including dragons and mystical potions within the world.

Some digital games do not include a game world, instead opting to use a *game environment*, what the user can see is all there is. Examples of this include *Candy Crush* and *Bejewelled Blitz*. These games have merely an anchor to the real world, including familiar shapes and objects, past this they are completely abstract. There is often not a correct outcome or an unfolding story, the user could be playing to score points, or to beat themselves and their friends on social networking sites. This system makes these games highly engaging, drawing on the human desire to be the best and to win. Since the game space is highly limited, often without an emergent story, decisions concerning mechanics, aesthetics, and technology are likely to become even more important.

The game presented in this project will be a *2D Platform* game. It is unlikely that the game will allow users to share their scores or compete, as the game is required to collect sensitive and personal data. This suggests that the game will need a well defined and consistent world in order to engage and immerse users. The game space itself is likely to be discrete, with well defined edges, this not only fits in with the platform genre but should help ensure inexperienced gamers can identify the goals and rules of the world. A simple way to represent the edges of the space would be to use walls, since in the real world a wall defines a boundary between two areas. The aim is, at each level of the platform game, to make the user feel like they are in one of many underground rooms within the sewer. Figure 3.6 shows how the game space will be presented to the users of the game, with clear boundaries being defined, however the user is free to imagine the world beyond the walls.

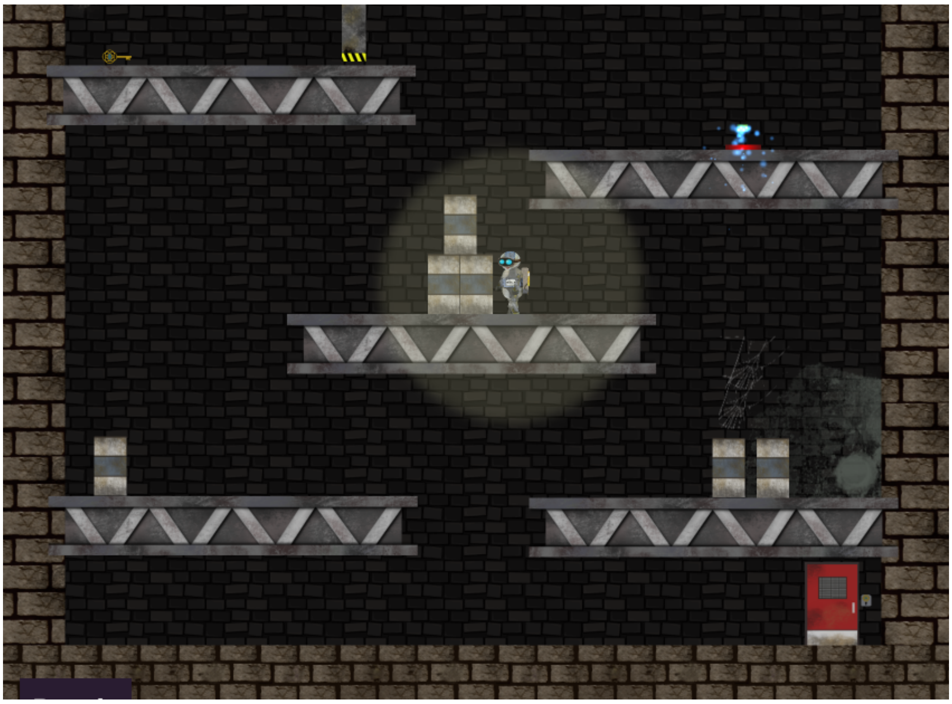


Figure 3.6: The game space boundaries seen by the users

4.4 Goals

In the context of a serious game, goals could refer to the goals of the user or the serious goals of the game. In this section the goals of the user are discussed.

Goals define the purpose of the game, the user should want to achieve the goals defined by the game designer meaning they must be well defined. Goals should be made clear to the user as early as possible, as they influence the decisions the user makes, giving meaning to their choices [31, 30]. Without a goal, a game has no endpoint, no way of the user winning or losing[30].

Games can have both short-term and long-term goals. For example, in *Half Life 2* the long-term goal of the game is to defeat the *Combine* enemy, however, in pursuit of this goal many other short-term goals must be accomplished, such as destroying enemy ships and completing puzzles in order to advance. A good strategy when designing goals seems to be to define a single long term goal, the *aim* of the game, but require the user to complete a series of short-term goals along the way. Without achieving these short-term goals, the long-term aim cannot be achieved.

The long-term aim of the game designed in this project is simple and requires little instruction, to travel though the sewer and escape. However, this task is made difficult by dyslexia screening tasks integrated into the platform game along the way, the user must successfully complete these short-term goals in order to advance through the sewer.

Some games also use scoring points as a goal, the initial version of the game will not include a scoring system since it will have no context as the game is not designed for users to compare performance. Instead, the user will be able to find and collect special items within the game, this is something that users could discuss, but does not relate to the serious nature of the game. It is very important that rewards within the game are not correlated with the user's performance in the tasks designed to screen for dyslexia, so as not to alienate groups which are likely to perform worse on particular tasks. A user with dyslexia should be able to get exactly the same score, bonuses, or rewards as a non-dyslexic user.

4.5 Rules

Rules are the most basic game mechanic, they are used to limit the actions that the user can perform[29, 31, 30]. The rules control what in the game world the user can explore, what objects the user can interact with, and how the goals of the game can be achieved.

Game rules are there to place limitations on user actions[30], a nice example of this is the game of chess. Each piece can perform specific moves, if a user was to try and make a move outside of the defined moves it would be against the rules of the game and the turn would be invalid. This concept extends to digital games, with one key difference: within the game world, the user has no choice but to obey the rules.

[30] argues that rules should be fixed and should not change as the game progresses, however, this is contestable. [30] uses the game of chess as an example, to which it makes sense for the rules to be fixed, however, in the digital world a game can grow as the user does. For example, as the user advances through levels new objects can be added, which do not conform to the previous rules. It therefore seems better to argue that alterations to rules make sense, if the rules change they should grow. It would not make sense for the user to establish rules about an object and for them to then change, however, it would make sense for a new object to be added and the rules about that object be different from the others.

[30] states that rules are repeatable and should not change between game instances. If one user was to do exactly the same action at exactly the same point in the game as another, then they should receive the same reward or penalty.

[31, 55] identify rules by type. This method, designed around board games, does not fit in with the creation of rules for a single user digital game. There are no behavioural rules between users, or written rules, the game should instead be intuitive and require little instruction.

Many of the rules for the game being created in this project are implicit within the other game mechanics, such as what actions the user can perform and when. The advantage of a digital game is that, providing the implementation is sound, the rules cannot be broken by the user. Furthermore, the system functional requirements can be used to explicitly state the game rules.

5 Integrating Screening Tasks

The game created in this project is required to screen for dyslexia, meaning that screening tasks must be integrated into its story, whilst respecting the *2D platform* game genre. The most appropriate way to do this was to include them as short-term goals.

Screening tasks would be triggered throughout gameplay and must be completed in order to continue. This method of integrating the screening tasks will hopefully enhance the game play by providing short-term goals for the user. The user interacting with the special items within the platform game will cause a screening task to be triggered.

The research conducted in Chapter 2 is consulted when designing dyslexia screening tasks in order to increase the chance of being able to use them to distinguish between users with and without dyslexia.

5.1 Possible Screening Tasks

Confrontation naming and RAN, as detailed in Chapter 2 could be tested by presenting the user with a word and a series of images, before asking them to select the image which corresponds the the word. However, this does not make for an engaging task and would rely heavily on the users knowledge of the English language. The study conducted by [8] was also skewed when users were presented with words they were not familiar with. Instead the general concept could be combined with the identified organisational and grouping problems to create an 'Odd one out' task. The user would be presented with a set of images where the majority of them belong to a particular group that all of the target audience should be familiar with, one of the images would be an anomaly, the users task would be to identify that anomaly. How many anomalies the user correctly identified would be used to measure performance on this task.

The users time management and awareness skills could be tested by asking them to guess how much time has passed since a game event, or when a countdown should complete. The difference between the actual time passed and the guessed time could be used as a metric to measure performance in this task. This task would be easy to implement, however, may be difficult to fit into the story whilst making it engaging for the user.

The organisational skills of the user could be tested by creating a task in which the user must separate items of one type from another as quickly as possible. For this task the time taken to separate the items, and the number of errors made, could be collected as performance metrics.

The users spatial orientation could be tested using a maze task. The user would be given cues as to the direction they should travel in order to escape. This would be a difficult task to implement, however, is likely to be easier to integrate into the game theme. For example, the character good be lost in the underground sewers and must navigate through to escape. The time taken and number of errors made could be recorded as metrics for this task. Spatial orientation could also be tested by digitising the 'block design' task, getting the user to rotate blocks on screen to match a target design. This could easily be integrated into the game story using circuitry, where the user must correctly copy a circuit blueprint. The time taken to correctly copy the circuit would be used as a metric for this task.

Working memory could be tested by presenting the user with a light or sound sequence and having them remember and repeat the seen or heard sequence. Again the number of errors made and the time taken to complete the task could be recorded as metrics.

Visual spatial discrimination could be tested by creating a task in which the user must match complex door and lock images in order to advance. The number of errors made and the time taken could be recorded as metrics for this task. This task would be both simple to implement and simple to integrate into the game story, at the end of a particular game level to user could need to unlock an exit with a key.

Visual sequential memory could be tested by presenting the user with a series of symbols and then asking them to select the correct sequence from a list of possible matches. In order for this to test memory the target sequence and possible matches must not be on screen at the time. The time taken and number of errors made could be recorded as metrics, in addition it may also be benefical to record the number of times the user switches between viewing the target sequence and possible matches.

Visual memory could be tested by presenting the user with a number and asking them to select that number from a list of similar numbers. As when testing visual sequential memory, the target number and the possible matches must not be shown at the same time. The time taken to complete the task and the number of errors made would be recorded as metrics.

5.2 Initial Screening Tasks

Not all of the possible screening tasks listed above can be implemented within the timeframe of this project, instead, a subset of the tasks will be used in the initial implementation. If time permits, and it is felt additional tasks are required, others can be added at a later date.

The chosen tasks to be included in the initial game implementation are shown in Table 3.2 along with the performance metrics to be collected from them. All tasks will be repeated a number of times in order to to reduce uncertainty, with the exception of task 1 which will have a number of rounds, each with increasing difficulty.

Task ID	Tested Skill	Outline	Repeats	Metrics
1	Working Memory	User is presented with a visual sequence of length 3 and must remember and repeat that sequence. The length of the sequence is increased by 1 with each round until the sequence is of length 6	1	Time, Errors
2	Spatial Orientation	User is presented with an image and must reproduce the same image by rotating block components	2	Time
3	Visual-spatial Discrimination	User must match complex door and lock images in order to advance	5	Time, Errors
4	Visual Sequential Memory	User is presented with a sequence of images and must select the correct sequence from a set of possibilities.	5	Time, Errors, Switches
5	Visual Memory	User is presented with a number and asked to select that number from a list of similar numbers.	5	Time, Errors

Table 3.2: Dyslexia screening tasks to be included within the game

6 Summary

In summary, this chapter has discussed the key factors in game design including mechanics, technology, and aesthetics, utilising guidelines from current literature to formulate a design for the dyslexia screening test digital game being created in this project. The game will be developed initially for the Apple iPad touchscreen device, will be a *2D platform* game, and will have a futuristic robot adventure theme. In addition to conventional digital game design, a set of screening tasks have been designed and will be integrated into the game levels.

CHAPTER 4

Implementation

This chapter describes the process of turning the game design, discussed in Chapter 3 , into a game implementation. This process includes examining software engineering methodologies, creating a development plan, extracting use cases and requirements, determining the key quality attributes, and finally the development itself.

In this chapter *the game* refers to the game being developed in this project, *the game application* refers to the mobile application containing the game including menu systems.

1 Approach to Software Engineering

When undertaking any software engineering project it is important that there is a well defined plan and methodology in place, in order to enable end goals to be met in a timely fashion. There are many documented methodologies including linear methods, such as the *V-Model* and *Waterfall*, and iterative methods such as *Test Driven Development (TDD)*, *Scrum* and *Extreme Programming (XP).*

A linear method is unlikely to be suitable for this project, as the game may need to be dramatically altered. For example, experimenting may reveal that more screening tasks are required or that users do not understand the controls, meaning project requirements would need to be extended or modified. A linear method, such as *Waterfall*, does not allow for this, giving time only at the beginning of the process for requirement and specification formulation[56]. [56] discusses how the linear development cycle can cause wasted time and money when a system is often changing, causing projects to be "late, over budget and riddled with bugs", due to errors when integrating components that the original specification did not allow for.

Instead, a more appropriate strategy in this case is to follow an iterative or agile development methodology. [57] describes a variety of agile methodologies, some of which do not fit with a single person project such as *Crystal, Scrum* and *XP*, to which team management and customer communication are critical elements in the cycle. For a single person project *TDD* could be used, a methodology which focuses less on personnel and more on *how* the system is being developed.

TDD is a subelement of *XP*, however, it is often used in its own right [58]. *TDD* involves creating user stories and scenarios describing the required functionality of the system, and then using automated tests to drive the development of code. A test for a particular function is written before the function itself, meaning the test can be run throughout development [58], generally the function is seen to be correct when the automated test passes, meaning the process of implementing each function is iterative.

This method encourages low coupling, as units are testable before creation, making it easier to modify the system when its functionality must be changed. It is also likely to increase the reliability of the system, at every stage all system functionality is integration and regression tested meaning the source of errors can easily be determined. There are however downsides to this approach, a constantly developing system means there is never a full software architecture, and if done incorrectly the developed system may not allow for high cohesion within the system, as is often the case when coupling is low. If there is a problem with the system structure, there is also little documentation to fall back on, with no explicit requirements or architecture.

Adopting *TDD* for this project would help produce a reliable and stable game, with a codebase capable of expanding as the required functionality changes. However, it may also be useful to explicitly state the requirements beforehand ensuring that, should the adoption of *TDD* fail, there is documentation to fall back on. This is not actually a large amount of extra work, since requirements can easily be derived from the use cases and user stories which drive *TDD*.

2 Developing for iPad

This section provides a short introduction to the tools and frameworks required to develop an iPad game, allowing the process of development to be explained in greater detail.

Games and applications for all *Apple* devices are written in the Objective-C programming language. Objective-C is, as the name suggests, an object orientated superset of the C language[59]. The *XCode* integrated development environment is designed specifically for creating Objective-C programs and is provided freely by *Apple*, it includes a number of frameworks and tools required to create a mobile application. One of these frameworks is *SpriteKit*, which was introduced in 2013. *Spritekit* is a graphics rendering infrastructure which helps to create games that require sprites and animation, abstracting away the complexities of *OpenGL*. It also provides a physics library which can be used to create game worlds which behave realistically[60].

3 Development Plan

Since software development in this project is constrained by time, a development plan was used to help identify internal deadlines and the tasks to be performed in each iteration of development. A *Gantt* chart can be used to show the tasks to be completed during the development, and the dependencies between these tasks.

Figure 4.1 shows a *Gantt* chart of the planned lifecycle of the game application development, initial tasks include choosing the software engineering methodology and project planning. Project planning could not be started until a methodology had been chosen, as the methodology dictates the steps involved in developing the application. The next steps are to create the use cases and formulate requirements, requirements are formed from the use cases, thus are dependant on their existence.

The plan includes three development cycles, each of which specify a testing, coding, and graphics development task. Since the game application is being developed using *TDD* testing and coding are done synchronously, however, extra time is dedicated to testing at the end of the second and third cycles, both as contingency and allowing for further integration testing. It is also expected that the graphics for the game application will be updated throughout the development, iteratively being refined.

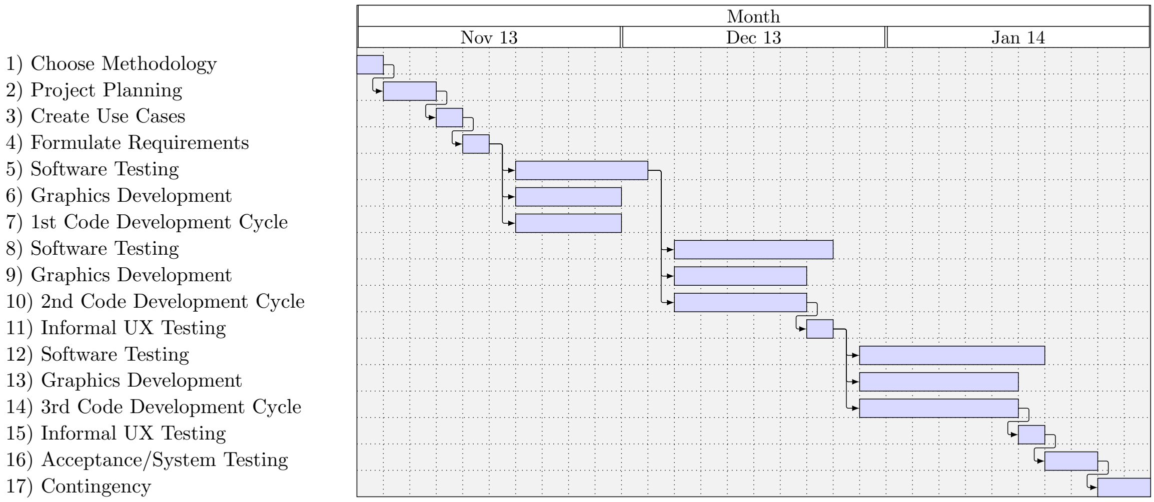


Figure 4.1: Gantt Chart detailing the tasks and dependencies in the development

The second and third development cycles also include informal *User Experience (UX)* testing phases, this allows the game application to be informally tested on potential users and initial feedback collected, identifying possible problems such as offensive content or difficult controls.

At the end of the development acceptance testing is completed ensuring the system meets all requirements, including any new or modified requirements found during *UX* testing. There is also a block of time dedicated to contingency, allowing tasks to slightly run over the allotted time without disrupting the entire project plan.

4 Use Cases

Before creating the game implementation a series of use cases were formulated. Since there is no customer, and therefore no formal specification of what the game is required to do, these use cases can be used to drive the formulation of requirements and help determine what functionality the game must provide. The development of the game is likely to be an iterative process, with changes being made throughout the project as a result of experimentation, however, initial use cases and requirements provide a useful starting point. Use cases describe the behaviour of the system under various conditions when stimulated by a stakeholder[61]. They guide system development by helping stakeholders, including the developer, better understand the purpose of the system and how is will be used. The use cases below are formed using components described by [61], specifically:

Name	The goal of this use case
Primary Actor	A description of the main actor involved in this use case
Context	The conditions in which the goal of this use case can be achieved
Trigger	The action or event initiating this use case
Scope	The systems being considered by this use case
Precondition	The expected state of actors when this use case is triggered
Main Success Scenario	Steps from the trigger to goal achievement
Exception Scenario	Steps from the trigger, leading to the goal not being achieved

The steps between the trigger and a successful or exception scenario can be seen as the user stories, defining in accessible language what functionality the system should provide in different contexts. Other components such as secondary actors and post conditions could be considered, however, did not seem relevant to this game. Use cases are separated into two categories: those during game play and those when using the menu system of the application.

4.1 Game Application Use Cases (GA-UC)

These use cases are based on the desired interaction between the user of the game application and the menu system, outside of the game itself.

GA-UC1

Name A new user makes an account
Primary Actor A prospective game player
Context The user wishes to play the game developed in this project
Trigger The user selects the game application on their device
Scope The game application
Precondition The user has a device running the game application
Main Success Scenario

1. The user launches the game application
2. The user selects the *New Player* button
3. The user is taken to a new screen
4. The user fills in their details
5. The user selects *Continue*
6. The account is created and a new game is started

Exception Scenarios

- The game application does not launch
- The user does not fill in all the required details and cannot continue

GA-UC2

Name An existing user starts a game
Primary Actor A user of the game application
Context An existing user wishes to start a new game
Trigger The user selects the game application on their device
Scope The game application
Precondition The user has a device running the game application
Main Success Scenario

1. The user launches the game application
2. The user selects the *Existing Player* button
3. The user is presented with a list of existing players
4. A new game is started

Exception Scenarios

- The game application does not launch
- The existing player is not found in the list

GA-UC3

Name A user views a players game result
Primary Actor A user of the game application
Context The user wishes to view a game result for a particular player

Trigger The user selects *Player History* on the game application
Scope The game application
Precondition The user has a device running the game application and has opened the application
Main Success Scenario

1. The user selects the player they are looking for
2. A user selects the particular game they wish to view based on a timestamp
3. The user views the players game result

Exception Scenarios

- The game application does not launch
- The user is not found

GA-UC4

Name A user is informed about the purpose and development of the game
Primary Actor A user of the game application
Context The user wishes to learn more about the games creation and developer
Trigger The user selects *About* on the game application
Scope The game application
Precondition The user has a device running the game application
Main Success Scenario

1. The user is shown a screen detailing information about the game, the developer and any game credits.

Exception Scenarios

- The information is not there

4.2 In-Game Use Cases (IG-UC)

These use cases are based on the desired interaction between the user of the application and the game itself.

IG-UC1

Name A user moves the character in the x-axis
Primary Actor A new game user
Context The user has started a new game and wishes to interact with it, by moving the character.
Trigger The user decides to move the character
Scope The game
Precondition The user has a device running the game application and has set up their account.
Main Success Scenario

1. The user touches and holds the screen and sees that the character moves towards their finger

Exception Scenarios

- The user does not think to touch and hold the screen and cannot continue
- The user ends the game

IG-UC2

Name A user makes the game character jump
Primary Actor A new game user
Context The user has started a new game and wishes to interact with it, by making the character jump.
Trigger The user decides to make the character jump
Scope The game
Precondition The user has a device running the game application and has set up their account.
Main Success Scenario

1. The user double taps the screen and sees that the character jumps

Exception Scenarios

- The user does not think to double tap the screen and cannot continue
- The user ends the game

IG-UC3

Name A user completes a screening task
Primary Actor A game user
Context The user is playing the game and needs to complete a screening task in order to progress
Trigger The user reaches a point in the game where a screening task is triggered
Scope A screening task within the game
Precondition The user has a device running the game application, has set up their account, and has started a game
Main Success Scenario

1. The user understands the goal of the screening task
2. The user determines the controls to use within the screening task
3. The user successfully completes the screening task

Exception Scenarios

- The user does not understand the goal of the screening task
- The user does not understand the mechanics of the screening task
- The user ends the game

5 Requirements

Having determined the game design and a set of possible use cases of the game application, an initial set of requirements can be extracted. For this project, requirements are split into two categories. The functional requirements detail the required behaviour of the system and help to refine its scope, in essence *what* the system shall do. The non-functional requirements help determine the desired qualities of the system, such as performance or scalability, and *how* they are achieved, as well as establish constraints which apply to the entire system and the environment it is operating in. In some cases, initial requirements are refined to provide more specific details. All Requirements are given IDs, so that when validating the application it is easy to determine which requirements have been met.

5.1 Functional Requirements

FR1 The game application shall allow new users to create an account

- **FR1.1** The game application shall allow new users to enter their first name
- **FR1.2** The game application shall allow new users to enter their surname
- **FR1.3** The game application shall allow new users to select an avatar
- **FR1.4** The game application shall store user account details
- **FR1.5** The game application shall associate a unique identifier with each user account

FR2 The game application shall allow users to view their game history
- **FR2.1** The game application shall store game records
- **FR2.2** The game application shall associate game records with users
- **FR2.3** The game application shall allow the user to search game records for those belonging to a particular game user
- **FR2.4** The game application shall allow the user to select a particular game record
- **FR2.5** The game application shall allow the user to view a game record summary
- **FR2.6** Game records shall be timestamped

FR3 The user shall be able to view information about the game
- **FR3.1** The user shall be able to view accreditations within the game application
- **FR3.2** The user shall be able to view details about the game developer
- **FR3.3** The user shall be able to access information about dyslexia

FR4 The user shall be able to move the game character in the x-axis
- **FR4.1** Touching and holding the screen shall move the game character in the x-axis
  - **FR4.1.1** Touching and holding the screen to the left of the game character shall cause the game character to move left
  - **FR4.1.2** Touching and holding the screen to the right of the game character shall cause the game character to move right.

FR5 The user shall be able to make the game character jump
- **FR5.1** The user double tapping the screen shall cause the game character to jump

FR6 The game shall include dynamic objects for the user to interact with
- **FR6.1** Game levels shall store information about dynamic objects

FR7 The game shall allow for fixed objects, which the character may interact with
- **FR7.1** Game levels shall store information about static objects

FR8 The game shall include the dyslexia screening tasks detailed in Table 3.2
- **FR8.1** The dyslexia screening tasks shall be integrated into the platform game
- **FR8.2** The game shall store the task performance metrics detailed in Table 3.2
- **FR8.3** The game shall repeat each task the number of times detailed in Table 3.2

5.2 Non-functional Requirements

NFR1 The minimum in game frame rate must be 30 frames per second.

NFR2 The average in game frame rate must be greater than 40 frames per second.

NFR3 The game application shall run on the Apple iPad
- **NFR3.1** The game application shall run on iOS7 and iOS 7.1
- **NFR3.2** The game application shall run on the 2014 iPad Mini
- **NFR3.3** The game application shall run on the 2014 iPad Air
- **NFR3.4** The game application shall run on the 2013 iPad Retina

NFR4 The game application must have no memory leaks

NFR5 The game application must support 30 users

NFR6 The game application must support a 10 game history for each user

NFR7 Database requests, when accessing available users, must be completed with a latency less than 0.5s

NFR8 Database requests, when accessing a user's game history, must be completed with a latency less than 0.3s

NFR9 The game must not be perceived as too difficult by users
NFR10 The game must not be perceived as too long by users
NFR11 The game must be playable without explicit instructions
NFR12 The game theme must not be offensive to users
NFR13 The game application must be easy to download by prospective users
NFR14 The game application must not crash under normal use, where normal use is defined as there being free memory on no more than 9 simultaneous touch events
NFR15 Subtasks within the game must not include reading, spelling, or words, other than those in titles and on navigation buttons
NFR16 The game application programming must be complete by 01/02/2014, allowing time for experiments
NFR17 The device running the game must not be modified outside of the manufacturers terms
NFR18 It must be possible to modify and extend the screening tasks with little change to public APIs
NFR19 It must be possible to port the game application to other platforms including *Android*

6 Quality Attributes

Having defined the non-functional requirements of the system, its quality attributes can be examined. Quality attributes are defined by [62] to be:

"A measurable or testable property of a system that is used to indicate how well the system satisfies the needs of its stakeholders."

By this definition, quality attributes are used to test the fitness of an implementation against the needs of the stakeholders. In the case of this project, the stakeholders are the users and the developer, since there is no business or customer involvement. The non-functional requirements, referred to as *quality attribute requirements* by [62], specify the identified needs of the stakeholders. Below the quality attributes identified as important for the game and game application, extracted from the requirements, are described and discussed.

Performance measures how responsive the system is, often measured by examining the number of events which can be performed within a given time frame [63]. **NFR1**, **NFR2**, **NFR7**, and **NFR8** define the level of performance required by the game application.

Modifiability of a system is a measurement of how cost effective system changes will be [63]. The cost may be in money, in time, or in personnel. **NFR18** defines that the game application must have a high utility of this quality attribute.

Portability is the ability of the system to run under different software and hardware configurations [63]. **NFR3** and **NFR19** suggest that the game application will need a high utility of this quality attribute, as it will be required to run across an array of mobile devices and operating systems.

Usability measures the user's ability to effectively and efficiently use a system, normally the user interface design plays the largest role in achieving high usability [63]. **NFR9** – **NFR13** all require a high utility of this quality attribute as the game aims to make the user feel engaged, and immersed in the experience. If the game application is not very usable then the user experience is likely to be negatively affected.

Testability defines how easy it is to find faults within the system through testing [62]. A high utility of this attribute means that if a fault exists it will be found by current test suites. The mere fact that the system has requirements means that it must be testable, as otherwise the requirements cannot be verified. In order to meet all requirements the system must therefore have a high utility of this quality attribute.

6.1 Tactics

Having identified the systems important quality attributes, research must be done into the most effective methods to achieve a high utility of these qualities; these methods are known as tactics[62]. Each tactic used within this project was either used to increase the utility of a quality attribute, or to reduce risks within the project development, such as loss of work or missing deadlines.

6.1.1 Risk Management

The identified risks surrounding this project include:

1. Failure to meet deadlines
2. Loss of work due to hardware faults
3. Loss of work due to user error
4. Failure to implement a system meeting the requirements
5. Low quality, buggy code

The tactics described below were used throughout the project to mitigate these risks.

Project Management Software The *Mingle* project management software was used in order to ensure all requirements and user stories had been accounted for within the game application. *Mingle* allows requirements to be categorised based on importance, as well as provides bug tracking facilities[64]. Use of this software mitigated the risk of failing the meet the project deadline and not fulfilling the requirements specification.

Automated Testing Automated unit, regression, and integration testing can be performed using *XCUnit* to insure the software was stable and free of major errors. *XCUnit* allows test suites to be defined and regularly run, in addition, a visual interface is provided showing which test cases passed and failed [60]. Static testing can also be completed throughout development using the type checkers and code profilers built in to the *XCode* development environment.

Version Control In order to mitigate the risk of loss of work, due to hardware or user error, version control in the form of *Git* can be used for the project. Git keeps a decentralised, reversible, history of all changes made to the codebase meaning that in the case of a user error, code can be rolled back to a previous version. If a hardware fault occurs, only the latest, un-pushed, changes to the codebase will be lost.

6.1.2 Increasing System Quality

The tactics used to increase the important quality attributes of the system can be represented by software design patterns. Design patterns are solutions to commonly faced problems when implementing parts of a system[65]. Using common patterns for solving complex problems is useful, as the method is known to work and to be testable. In addition, patterns often help decrease coupling within the code and increase cohesion, else they would not be so popular and easily integrated into a range of domains. Use of a particular design pattern implicitly realises one or more tactics, below the design patterns to be utilised within this project are described and discussed.

Model-View-Controller In order to increase usability, modifiability, and portability, the model-view-controller pattern can be used. This pattern separates the domain logic of a system from its visual representation, meaning changes can be freely made to the view without changing the model [65]. This is useful for this project as the development process is iterative and visual components may change throughout. In addition, the separation of domain logic means that additional views can be added without changing the model. For example, if the game application was to be ported to OSX or iPhone the model could be reused.

Observer This pattern uses an observer object to automatically update the state of subscribed objects, a change in the observer's state causes a list of subscribed objects to also be updated[66]. A common example of this pattern in practice is the use of callbacks in Java. This pattern will be useful within the game application implementation as the screening tasks must be subscribed to the platform game and automatically shown or hidden in response to state changes.

Table Data Gateway This design pattern involves creating an object (gateway) which wraps all interaction with an SQL database table. The gateway normally includes methods for querying records, inserting, updating, and deleting them; parameters to these methods are then used in SQL statements[65]. This pattern abstracts away all direct interactions between the rest of the code and the database. This means that the database can be modified or changed without the need to modify the public API, increasing modifiability and testability.

Row Data Gateway This pattern involves creating a gateway object which wraps a single database record, every field in the database table becomes a field in the object[65], meaning this object is normally immutable. This is particularly helpful for this project as it is necessary to store both user data and game data. Using gateways would mean that domain objects would not need to know about database structure, reducing coupling and increasing system modifiability.

7 System Architecture

Having derived the use cases, requirements, and quality attributes of game and game application, it could then be built according to the development plan, using three development cycles.

7.1 Development Cycle One

This development cycle aimed to produce the menu system for the game application, set up the database to hold user accounts and game histories, and design the initial game graphics. Upon completion of this cycle **GA-UC1** – **GA-UC4** should be fulfilled.

7.1.1 Menu System

Creating the menu system for the game application is a reasonably trivial task as the *XCode* development environment for Objective-C uses storyboarding as a method of User Interface (UI) design. Storyboarding allows subclasses of the basic user interface object `UIView` to be added and configured graphically, it also allows buttons to be connected to their targets using *Segues*. With this system the entire menu system can be built without writing a single line of code. The storyboarding interface means testing is done by inspection for **GA-UC1** and **GA-UC4** as well as for parts of **GA-UC2** and **GA-UC3**. Figure 4.2 shows a screenshot of the storyboard for the game application, in order to fulfil the use cases and requirements the entire application needed only nine screens.

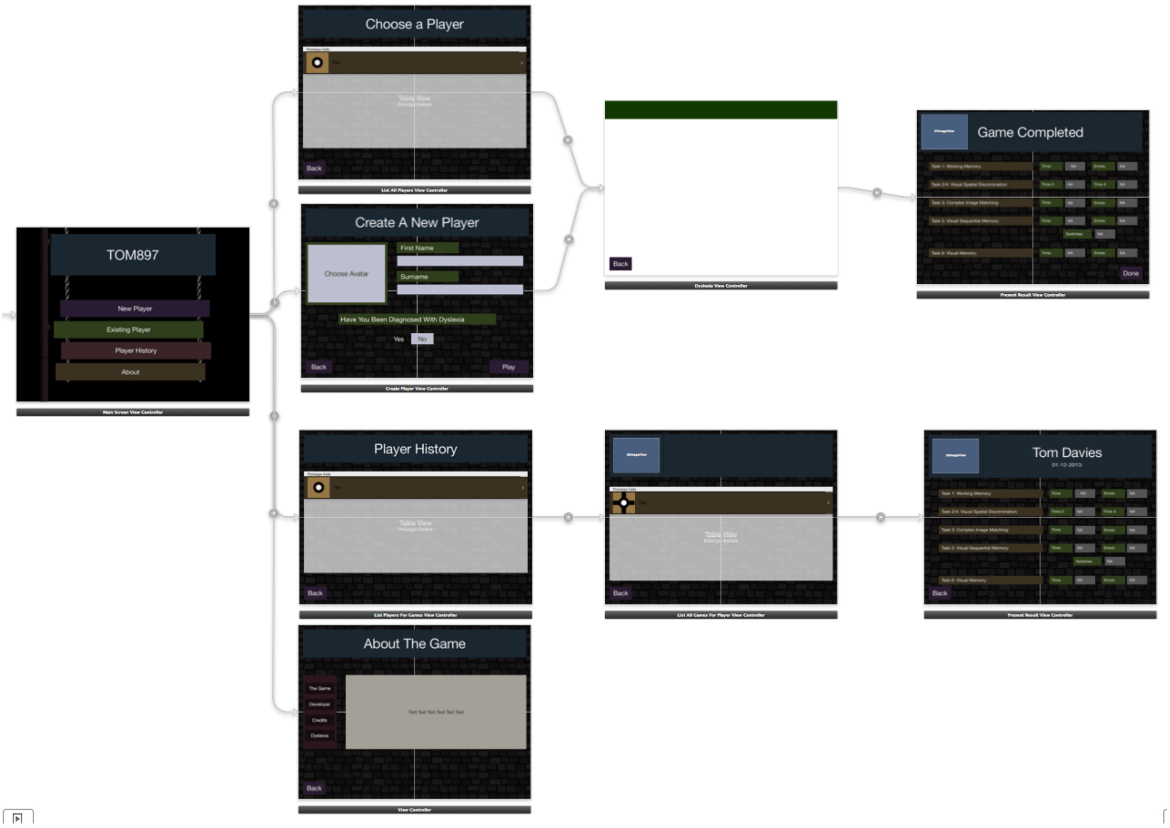


Figure 4.2: The *XCode* storyboard for the game application

7.1.2 Database Design

Before designing the game application database, the requirements and use cases needed to be examined in order to extract data schemas. There are clearly two types of data that need to be stored: information about the users and information about individual games. When considering the user information that needs to be collected, **GA-UC1** and **FR1** suggest the following fields:

- Unique identifier
- First name
- Surname
- Avatar

It was also decided that when performing user experiments, the application should store whether or not the user had been diagnosed with dyslexia as this information would be vital when analysing results. The primary key for this data would be the unique identifier, an automatically generated value.

Timestamp	PlayerID	Metric 1	....	Metric 11	Result
DATE	INTEGER	DOUBLE	DOUBLE	DOUBLE	BOOLEAN

PlayerID	First Name	Surname	Avatar Reference	IsDyslexic
INTEGER	STRING	STRING	STRING	BOOLEAN

Figure 4.3: Database table schemas for the game application

When considering the data required to represent a game, the refinements of **FR8** explicitly define eleven metrics about the game subtasks which must be stored, in addition to this, **FR2** requires game records to be timestamped and related to the user who played the game. In the final version of the game another field would also be needed, the result, detailing whether the application identified the user as likely to have dyslexia. To save having to migrate the database at a later date, this field was added at this stage of the project, but was not used. The primary key for this data would be the game timestamp, since two games cannot be played simultaneously on the same device.

The above led to the abstract database schema shown in Figure 4.3, it is quite obvious from the structure of the data that a relational database would most applicable to this type of well structured data. It was decided to not use an external service such as *Heroku* or *MySQL*, as there was not enough time to correctly handle the security implications and the data being collected is highly personal. Instead, a local *SQLLite* database was used within the device, a lightweight relational database management system embedded in the application.

When developing the database, the *TableDataGateway* pattern, as described in section 6.1.2, was used to create a layer of abstraction between the database itself and the rest of application. This meant that any changes to the database would only cause code alterations in this abstraction layer.

As per the TDD methodology before each function was implemented a test was created, when implementing the database this testing was normally done using unit testing, specifically *XCTest*. The tests created for this development cycle are shown in Figure 4.4. Each test was created before the accompanying function code, minimising the chance of introducing faults. A conceptual diagram of the game application architecture at this point is shown in Figure 4.6, and was exported from the developed code.

Database mocking was used within the unit tests, to reduce the coupling between units. The API provided by the `PlayerTableGateway` was then integrated with the menu screen allowing the user to set up an account, and the two components were integration tested.

Initial graphics were also created in preparation for the second development cycle. The first development cycle was actually completed one week earlier than planned, allowing the second

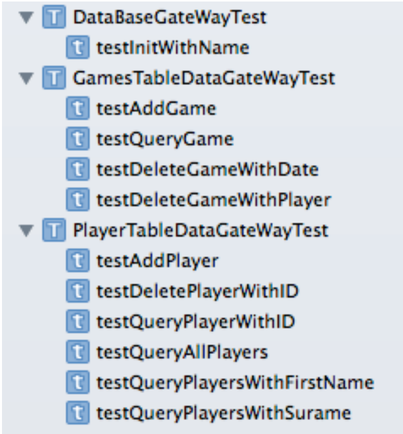


Figure 4.4: Testing suite for code related to the database implementation

cycle to commence early.

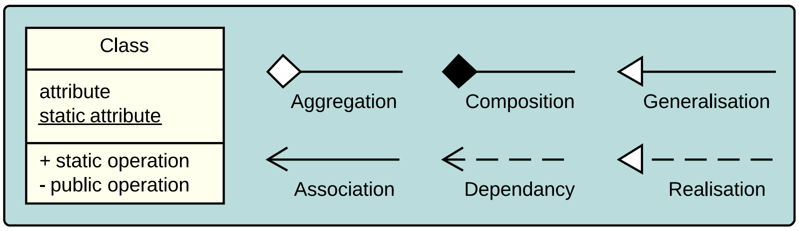


Figure 4.5: Key for the conceptual diagrams, notation similar to UML2

7.2 Development Cycle Two

This cycle aimed to produce the platform game, creating the game world, sprites, a level editor, and a level parser. Upon completion of this cycle **IG-UC1** – **IG-UC2** should be fulfilled, as well as **FR4** – **FR8**.

7.2.1 Level Editor

Before implementing the game itself the decision was made to create the level editor, this made logical sense as the levels need to be clearly defined before they can be parsed by the game application. The level editor application could have been made in Objective-C like the game application, however, it may need to be used on Windows or Linux for future versions of the game, making Java a better language choice. The Java *Swing* library was utilised allowing the quick creation of a simple UI.

To store the level files languages such as XML and JSON could have been used, as these are popular, well supported, and minimise impedance mismatch. JSON seemed like a better choice as it is more lightweight and is very human readable, making debugging easier.

The level editor GUI, shown in Figure 4.7, consists of a menu panel and a level display panel. Using the menu users can add objects to the level display panel and position them. A conceptual diagram of the level editor architecture is shown in Figure 4.8

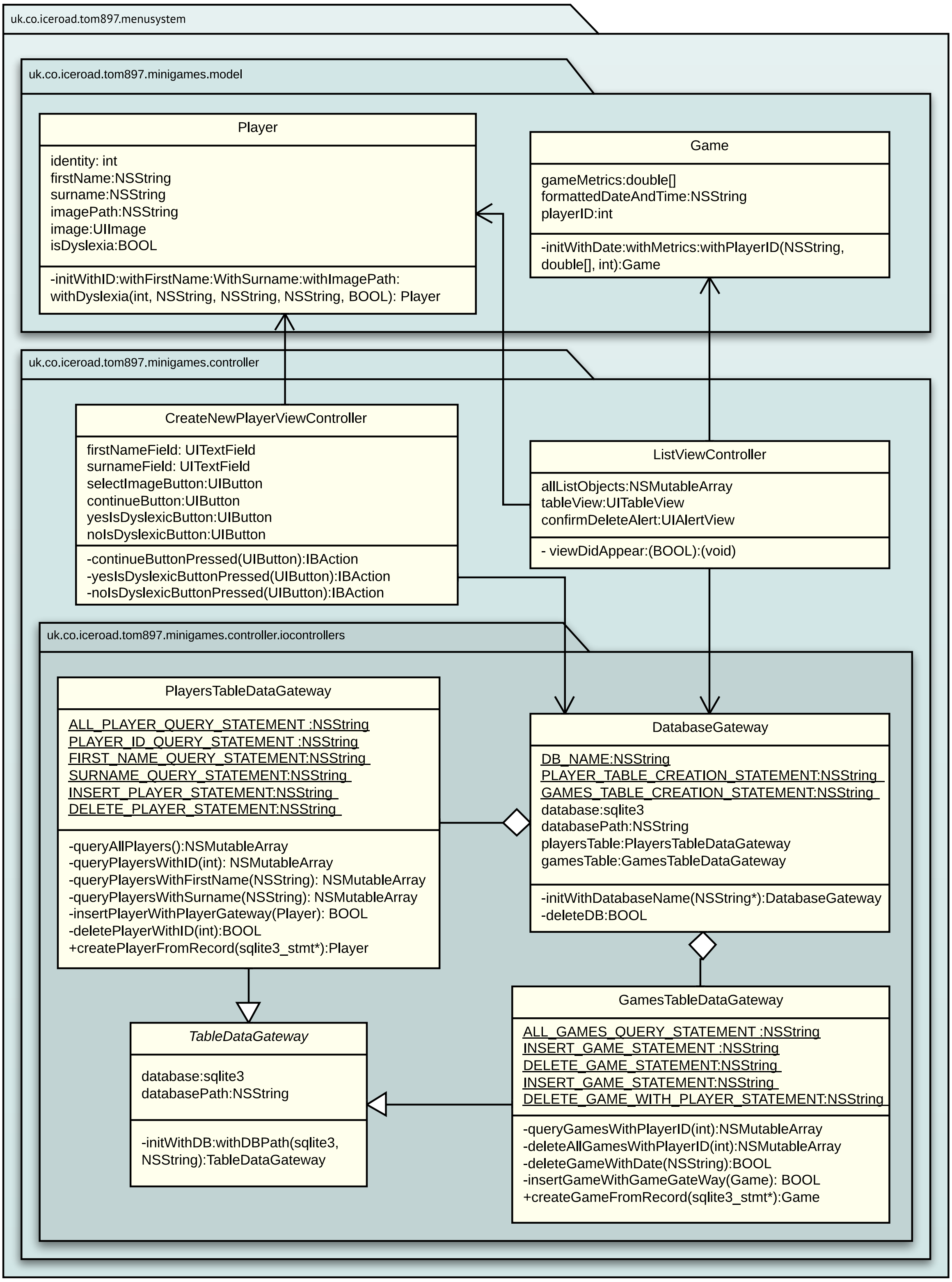


Figure 4.6: Conceptual diagram of the menu system architecture, key shown in Figure 4.5

`Entity` objects are used to represent objects within the level. `Entity` objects have four key attributes: an x-axis position, a y-axis position, a texture name and an entity type. The type of an `Entity` corresponds to the object types identified in the game design, Chapter 3. The texture name is stored so that the game application can select the correct sprite texture.

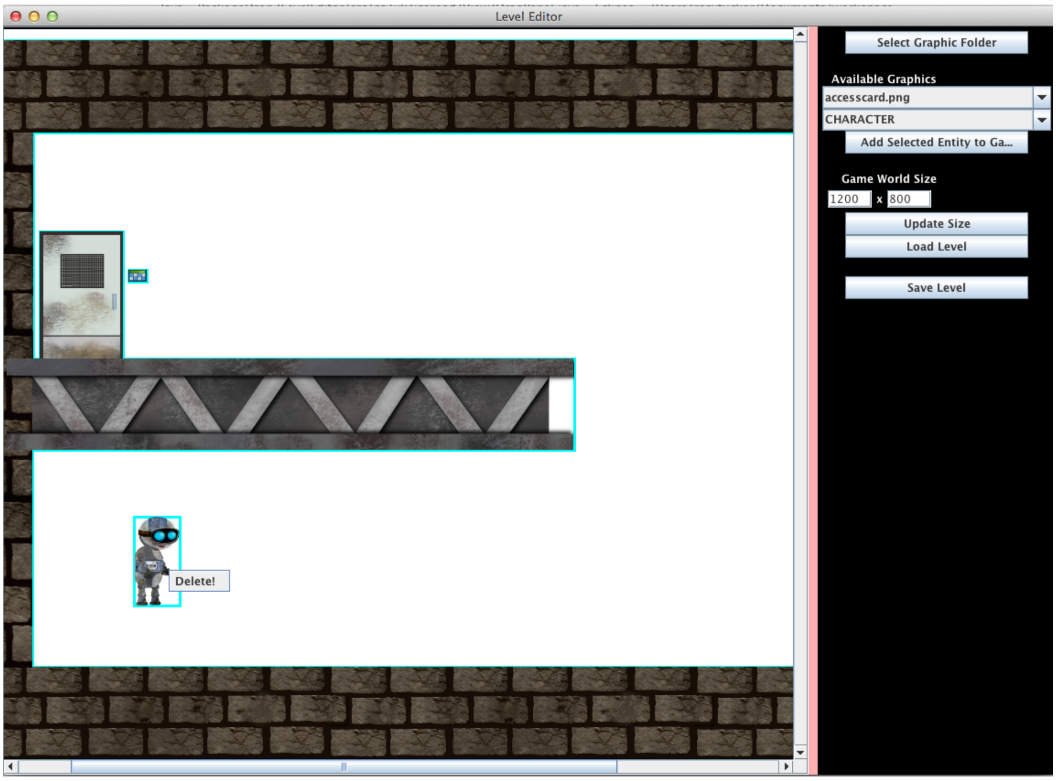


Figure 4.7: A screenshot of the level editor interface

The game level itself has a size which can be used to automatically generate the level background within the game application, as placing the tiles in the level editor would be tricky. Levels can be saved or loaded using a `JFileChooser`.

7.2.2 Platform Game

Having designed the level structure, a system for parsing the levels within the game application could be created along with the platform game itself. A conceptual diagram of the platform game architecture is shown in Figure 4.9.

As per the *TDD* methodology the task of parsing a level was broken up into small and testable units, the first of which was creating a `Sprite` object. A `Sprite` represents an object within the game world. The *SpriteKit* library includes an `SKSpriteNode` object which the `Sprite` object extends by adding a constructor allowing the initial position of the object, within the game world, to be set, and the object type to be stored. `CharacterSprite` extends this model by including methods for movement, and an inventory of items. `EffectSprites` do not inherit from the `Sprite` class as they do not need the functionality provided by `SKSpriteNode` or the `type` field, instead they extend the basic `SKNode` provided by *SpriteKit*. Dynamic and platform objects include a physics body, allowing them to interact with the character realistically.

An `ObjectParser` was then created to provide an API for tackling the impedance mismatch between the JSON and the sprites. Each public method of the `ObjectParser` either produces a sprite or an array of sprites. A `LevelParser` was then created to extract the JSON objects from the JSON file, and produce a `Level` gateway object representing a platform game level.

The final required components, to be added in this cycle, were a method of interpreting user

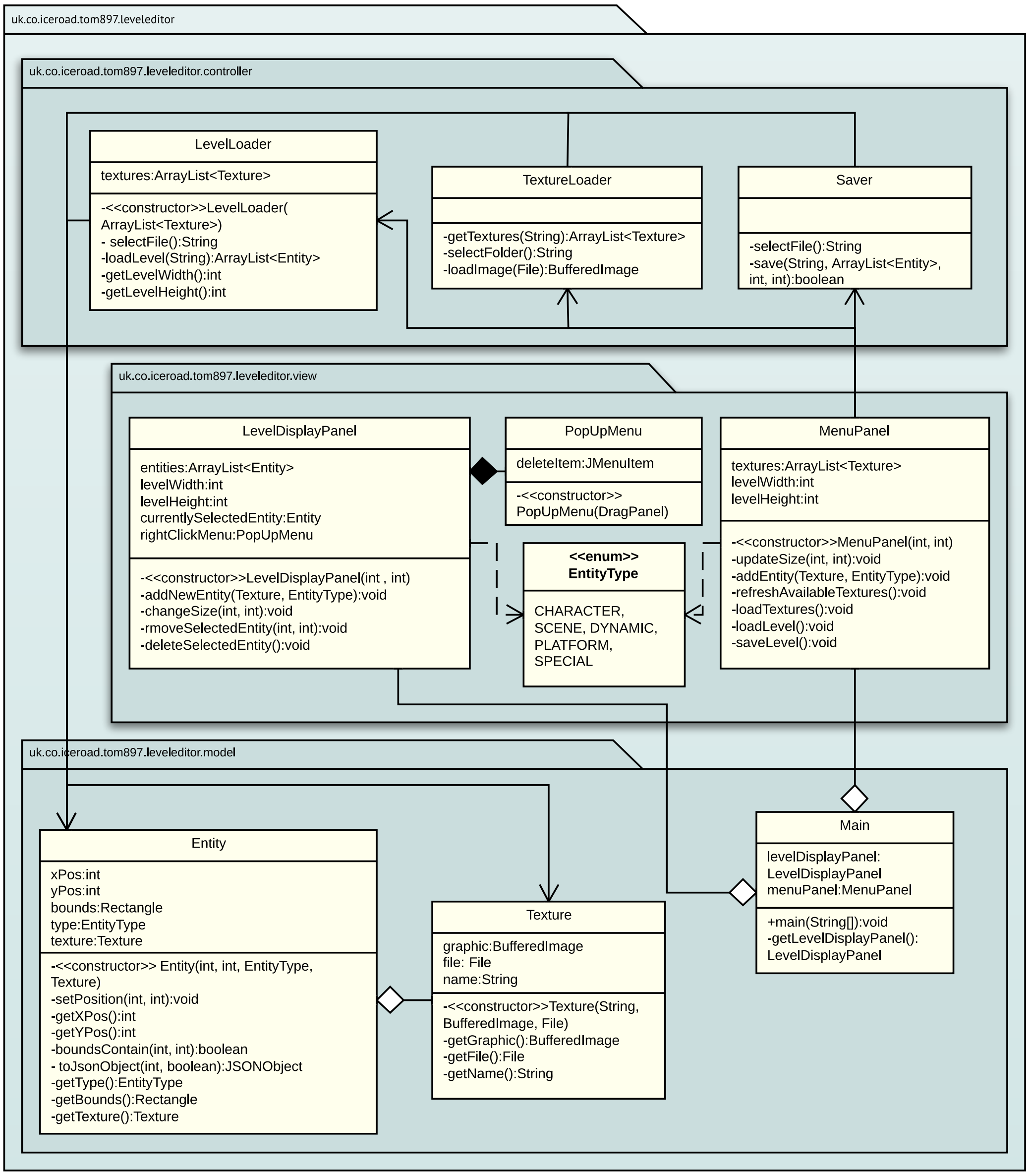


Figure 4.8: Conceptual diagram of the level editor architecture, key shown in Figure 4.5

input and a way of displaying the objects to the screen, these two tasks are quite heavily coupled. In Objective-C subclasses of the `UIViewController` object are used to display content to the screen and to handle menu functions, such as returning to the home screen. The `MainViewController` object holds an `SKScene` object which presents and controls the platform game, handling user touches and updating the state of game objects. The scene also updates the physics world every frame, looking for collisions and special events.

After implementing the components described above, the whole system was integration and regression tested, to ensure the menu system and the platform game work correctly together and that changes had not broken existing work. Informal UX testing was also performed and identified some required changes to the graphics and character mechanics.

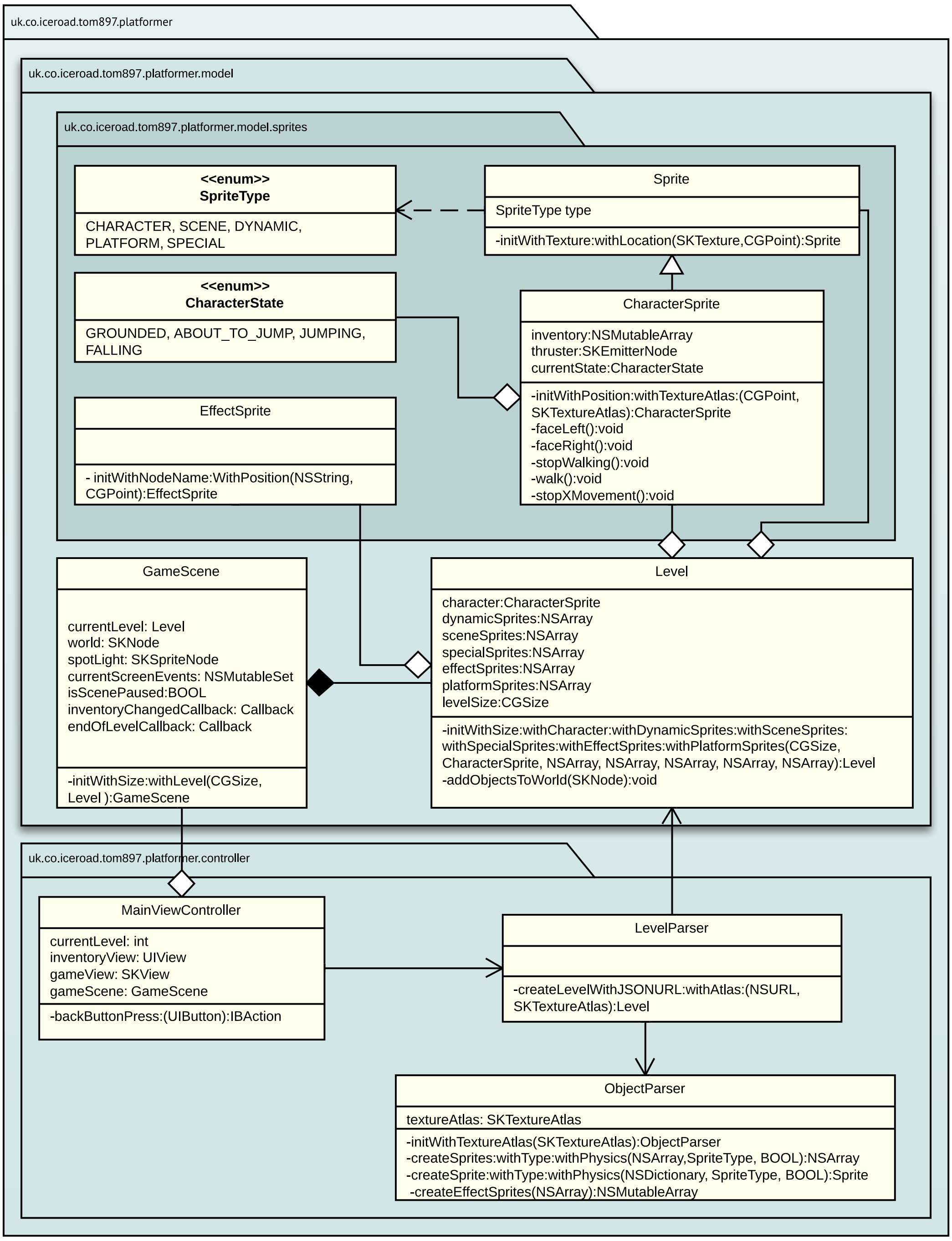


Figure 4.9: Conceptual diagram of the platform game architecture, key shown in Figure 4.5

7.3 Development Cycle Three

The final development cycle was dedicated to integrating the dyslexia screening tasks into the platform game. A conceptual diagram of the architecture of the screening task system, created in this cycle, is shown in Figure 4.10.

Since there would be multiple screening tasks within the game, it seemed sensible to create an abstract type describing the common properties. An `AbstractMiniGame` is a `UIView` which overlays the platform game, it can have a title, a subtitle, and a start button which starts the task. There are also two modal dialogs which an `AbstractMiniGame` can show, one when the user made an error and one when the screening task is complete.

With the abstract implementation of a screening task defined, some concrete implementations could be created, screenshots and informal descriptions of these are given in Appendix E which shows a behavioural view of the platform game. The created screening tasks correspond to those described previously in Chapter 3 and Table 3.2. The screening task system was very easy to write unit tests for as components did not need to be coupled.

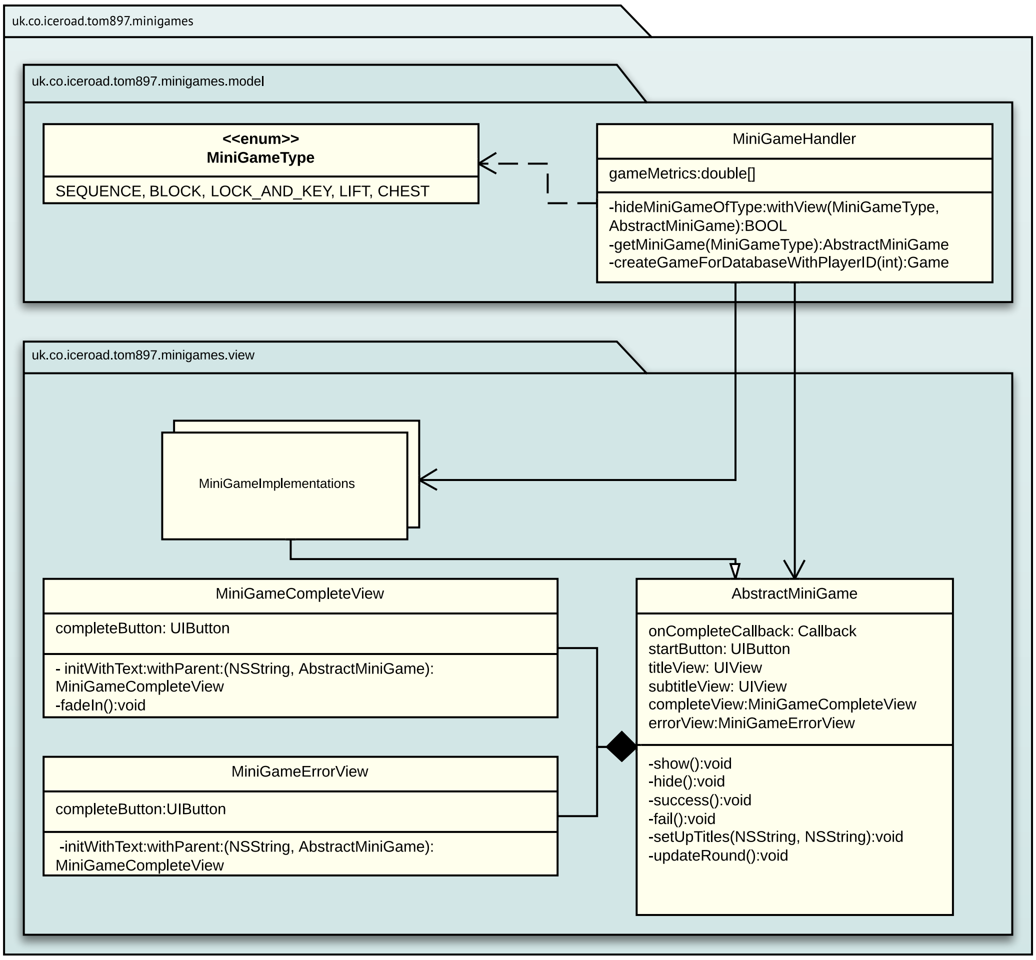


Figure 4.10: Conceptual diagram of the screening task system architecture, key shown in Figure 4.5

Having created the screening task implementations they needed to be integrated into the platform game, for this the *Observer pattern* was utilised though the `MiniGameHandler` object. A `MiniGameHandler` notifies subscribed screening task instances when the state of the platform game changes and a screening task must be displayed or hidden. The `MiniGameHandler` class was integration tested with the screening task implementations and the rest of the game application. Regression testing revealing no faults had been introduced to the existing code. At this point in the development it was known that the screening tasks could be instantiated, but not *how*.

It was decided that there must be a map of *special* objects within a `Level`, with the platform game determining whether the player had reached any of these objects, and the `MiniGameHandler` notifying the appropriate screening task instance.

The final phase of this cycle was to connect the database to the platform game allowing the game results to be stored, this was relatively simple as unit tests had already been created for the database, meaning only a method, creating a `Game` object from the screening task results and passing that to the database, needed to be added and tested.

8 Summary

In summary, this chapter has focussed on implementing the game design detailed in Chapter 3. Specifically the approach to software development has been described as TDD, and the software architecture has been presented both through text and conceptual diagrams. Requirements and use cases for the implementation were extracted from the game design and refined to provide concrete implementation decisions. The quality attributes of the software have been analysed and tactics such as design patterns have been employed to increase their utility. The project risks have also been analysed and further tactics, such as the use of automated testing and version control, have been used in order to mitigate these risks.

Three development cycles have been explained, showing the system architecture and detailing the key steps in creating the game implementation, including the development of a level editor, a database system, a menu system, the platform game, and the screening tasks. These implementation cycles fulfilled the outlined requirements, though some non functional constraint requirements detailing the systems portability and modifiability could not be explicitly verified.

CHAPTER 5

Evaluation

In this chapter, a study aiming to test the created game is designed and conducted. The method, materials, and procedures of the study, are defined and the results are discussed.

1 Introduction

Using the game developed in Chapter 4, an experiment aiming to test the games effectiveness as a screening test, and its overall usability, could be designed.

The games purpose, as previously explained, is to screen children and young adults for dyslexia, in order to ascertain whether this is possible a study must be conducted. In this study participants both with and without dyslexia will play the game and performance metrics, as described in Chapter 3 and Table 3.2, will be compared and analysed to determine if there are any significant differences between the metrics achieved by the two groups. If differences are found then, in the future, new users could be classified into one of the two groups based on the metrics they attain.

The null hypothesis for this study is therefore:

NH.1: *There is no observable difference between the game metrics achieved by those with dyslexia and by those without*

In addition, the usability of the game can be explored as part of the study, in order to determine whether the design and structure of the game meets user expectations. When considering the usability of the game, a questionnaire can be used to gain insight into the users opinion on game aspects such as controls, theme, duration, and difficulty. The results of this questionnaire can be used to help guide future development and alterations to the game design and structure.

2 Method

The following sections explain in detail the method of the study, including the design, the participants, the materials, and the experimental procedure. The experiment method is explained in enough detail for others to replicate it. When describing the participants some information, such as the specific schools involved in the study, is purposefully excluded for the reasons explained in Chapter 1.

2.1 Design

The study is designed to determine if dyslexic users of the game can be identified from non-dyslexic users though a series of performance metrics extracted from their game play, including the time taken to complete certain tasks and numbers of errors made. The study therefore has a one way unrelated samples independent variable (IV) design.

Whether or not participants have dyslexia cannot be controlled or manipulated meaning it is not actually an IV, however, it will be treated as such for the purpose of the study, making it a pseudo-IV. There are therefore two groups of participants, those diagnosed with dyslexia and controls, for this reason the experiment is conducted *between subjects* since a participant is either diagnosed with dyslexia or not[67]. It is recognised that dyslexia is a continuum and there is not merely a binary separation between participants, however, with such limited time and resources extracting ordinal information from the results is unfeasible.

Due to epistemic uncertainty about the pseudo-IV, including the level to which participants with dyslexia are effected by the learning disorder, a large number of dependent variables were included. There are eleven dependent variables within the experiment, detailed in Table 5.1, extracted from Table 3.2 in Chapter 3, including time taken to complete tasks and the number of errors made.

When considering the environment in which the study is to take place, participants were to complete the study in a typical, quiet, working environment with a desk and chair. This environment was chosen as, if successful, it is hoped that the game will be used by schools, colleges, and universities to quickly screen children and young adults.

Task ID	Name	Dependent Variables
1	Working Memory	Time (s), No. Errors
2	Spatial Orientation	Time Round 1 (s), Time Round 2 (s)
3	Visual-spatial Discrimination	Time (s), No. Errors
4	Visual Sequential Memory	Time (s), No. Errors, No. Switch Presses
5	Visual Memory	Time (s), No. Errors

Table 5.1: The dependent variables used the game study

2.2 Apparatus and Materials

In order to run the study the following apparatus and materials are required:

- The game, previously created in this project.
- An iPad test device with the game installed.
- An informed consent form, detailing what is expected from the participants throughout the study.
- A questionnaire designed to collect subjective information from the participants about the usability, and accessibility, of the game.

The iPad used for testing was a 2014 Apple iPad Mini with a 7.9-inch multi-touch screen, players were able to hold the device in their hands or stand it upon a table, depending on how they felt most comfortable. The prototype game incorporated the five tasks shown in Table 5.1 and detailed in Table 3.2.

The informed consent form, to be presented to the user before entering into the study, is shown in Appendix A and informs the user of what is expected of them throughout their involvement in the study. It does not inform them of the independent and dependent variables within the study to avoid bias, although users could be told this information in a post-study debriefing.

2.2.1 Questionnaire

The questionnaire used in this study is shown in Appendix B and allows participants to feedback on the usability of the game whilst providing information about themselves, including their gender, age, familiarity with games and touch screen devices.

The questionnaire has two main purposes, the first is to ascertain basic information about the participant to be used when analysing results, and the second to discover the participants feelings about their experience with the game. Since the subjective information being collected is not related to the hypothesis this study is testing, meaning its reliability and validity need not be maximised, it was decided to use the *Likert Scale* for these questions. Participants were asked to what level they agree with given statements, from *Strongly Agree* to *Strongly Disagree* [67].

Questions concerning participants familiarity with games and touchscreen devices were included in order to validate the decision to create the screening test game on a mobile touchscreen device. If participants in the target age group are highly familiar with these concepts then the decision was correct.

Questions concerning the usability of the game were included in order to validate decisions concerning the games design and structure, including its duration, its difficulty, and whether it was an enjoyable experience. One of the reasons for using a game as a dyslexia screening test was to make the experience more enjoyable and less like a test, positive responses to these questions will therefore confirm that this goal was achieved.

2.3 Pilot Study

Pilot studies are performed in order to ensure no serious problems with the game or study design had been overlooked[68]. The pilot study for this game was conducted on four participants, recruited within the Computer Science Department of the University of York. The participants of the pilot study found a problem within one the game levels, which made it very difficult to advance through the platform part of the game, this was quickly rectified. They also identified two small grammatical mistakes on the questionnaire. With these problems resolved the main study could be conducted.

2.4 Participants

42 participants were recruited for the study, aged from 11 to 24, with a mean age of 16.83 years (SD=3.07). 7 participants were diagnosed with dyslexia, leaving a control group of size 35.

Participants were all native English speakers and were either undergraduate students at the University of York, or high school students. University undergraduates were a convenience sample, recruited by the experimenter. High school students were selected by the school administrative staff, they were specifically chosen to provide a mix of children diagnosed with dyslexia and those who appear to show no signs. This selection was chosen so as not to corrupt the results by including children who may have undiagnosed dyslexia in the control group.

2.5 Procedure

Participants in the study were assessed individually in a typical working environment, either at school or at university.

Participants were relayed the instructions shown in Appendix C, so as not to make those with dyslexia feel uncomfortable or pressured to read. After being relayed the instructions, participants were informed that the experiment is likely to take up to 15 minutes of their time and is investigating dyslexia and games.

Participants aged 18 years and over were asked to sign the consent form, shown in Appendix A, ensuring they were happy to continue. Parents and guardians of participants under 18 consented on their behalf. Consenting participants were then presented with the iPad test device, loaded with the game. Without any assistance from the experimenter participants played the game once, until completion, taking approximately 10 minutes.

After completing the game participants were asked to fill in the questionnaire shown in Appendix B detailing their experience with the game, including how they rate the controls, aesthetics, theme, and difficulty. Finally participants were debriefed, with those wishing to know more details about the game and the experiment being informed.

3 Results

In this section, the results of the study are presented. This includes both the results of the questionnaire, and the results of the main game study, attempting to identify users with dyslexia using their game performance.

3.1 Game Usability Questionnaire Results

The questionnaire presented to participants after they had played the game, shown in appendix B, included two questions designed to gauge the participants exposure to games and touch screen devices, this was done to validate the use of a game and the use of the mobile platform. There were also six questions about the user's experience with the game, these questions were included to validate the design decisions included the game theme and structure. In this section the responses to each of those questions are analysed.

Q3) How Frequently do you Play Games?: The response for this question, shown in Figure 5.1, shows that 86% of those asked play games at least once a week, with the majority playing most days. This result is a positive sign, showing that those in the target age group are likely to relate to a screening test in the form of a game, as they already have a lot of interaction with games.

Q4) How Frequently do you Use Touchscreen Devices?: The response for this question, shown in Figure 5.1, shows that 100% of those asked use touchscreen devices every week, with 88% using them daily. This information confirms that using a touchscreen mobile device was a good choice for the target audience. It also shows that potential

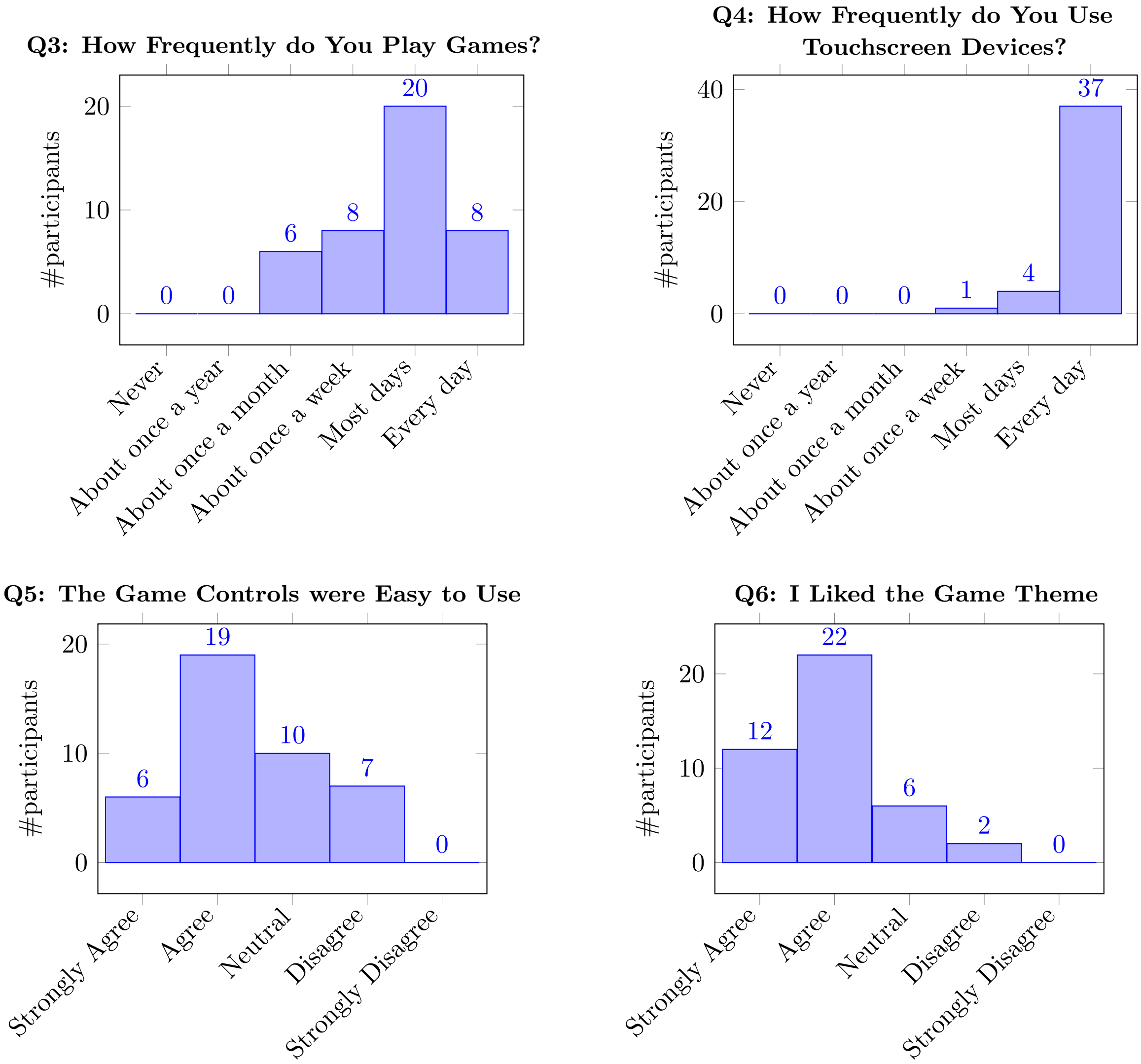


Figure 5.1: Frequency of responses for questionnaire questions Q3-Q6

users are likely to be familiar with touchscreen concepts, such as the gestures used within the game.

Q5: The Game Controls were Easy to Use Figure 5.1 shows that 60% of those asked agreed or strongly agreed that the controls were easy to use. Though this is the majority, it is not as many as hoped and it is important that the users find the controls easy to use to prevent them from becoming frustrated with the game and losing interest. When asked, the majority of participants who chose neutral or disagree said that they found jumping difficult, it may be worth examining other options for the jump control in later versions of the game.

Q6: I Liked the Game Theme The responses for this question, shown in Figure 5.1 show that 81% of participants agree or strongly agree with this statement, such a high percentage means the game theme is likely to be suitable for the target audience.

Q7: The Game was too Challenging Figure 5.2 shows that 98% of participants did not agree with this statement and though this is a positive sign, this does not show that the game is the correct difficulty for the target age group, the game must also not be too easy, in order to keep users engaged.

Q8: I Enjoyed Playing the Game Figure 5.2 shows that 83% of participants agreed or strongly agreed with this statement, a very positive response. In addition, only a single participant felt the experience was negative.

Q9: The Game Took too Long to Play Figure 5.2 shows that 95% of participants did not agree with this statement, a very good response. For this question, it is important that users do not think the game is too long as they need to be engaged in order to get the most accurate results. It is not of concern that many participants felt the game was too short, as the primary goal of the game is to screen for dyslexia as efficiently as possible.

Q10: The Game was too Easy Figure 5.2 shows that 93% of participants did not feel strongly either way about this statement. The ideal response would be for all participants to feel neutrally about this statement meaning that the game is the correct difficulty. The results for this statement, coupled with the response for Q7, are promising and suggest that the difficultly of the game is inline with what the target audience expect.

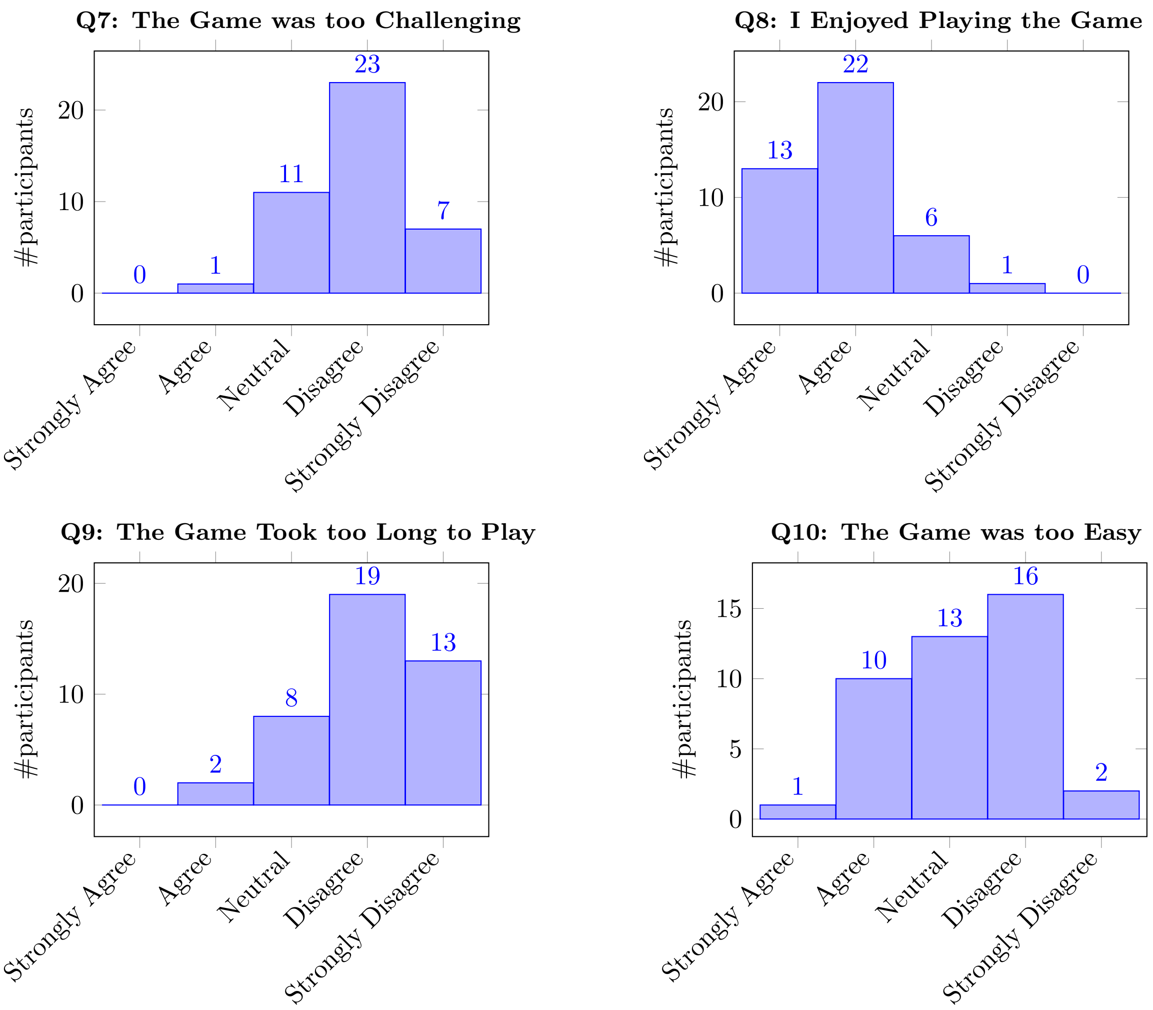


Figure 5.2: Frequency of responses for questionnaire questions Q7-Q10

3.2 Identifying Participants with Dyslexia Results

In this section the results of the game study are presented and analysed, in relation to null hypothesis **NH.1**, testing whether significant differences between the performance metrics achieved by the two groups exist, and whether it is possible to correctly classify participants into the correct groups. A summary of the results obtained from the study, are presented in Table 5.2 and include basic participant information and game play metrics.

	With Dyslexia		Controls		Mann-Whitney U
Game Metric	Mean	SD	Mean	SD	Significance
Time Task 1	58.77	23.79	69.85	60.95	0.843
Errors Task 1	1.57	1.90	2.11	4.33	0.869
Time Task 2 (Round 1)	59.30	33.79	53.06	27.30	0.644
Time Task 2 (Round 2)	43.01	9.78	43.04	25.59	0.574
Time Task 3	44.55	15.64	38.93	12.51	0.353
Errors Task 3	3.00	2.58	2.69	2.93	0.668
Time Task 4	42.29	11.32	38.50	11.24	0.370
Errors Task 4	4.86	2.91	0.86	1.06	**<0.001**
Switch Presses Task 4	6.71	2.43	8.54	4.88	0.426
Time Task 5	33.54	8.87	26.73	9.48	**0.045**
Errors Task 5	1.00	0.82	0.83	1.20	0.370

Table 5.2: Summary of the results obtained by the study, all times are given in seconds.

A *Mann-Whitney U* significance test was performed on each of the game metrics to determine if the observed differences between the results achieved by the two groups are significant. The significance level used was $p = 0.05$, such that there is at most a 5% probability that the results are drawn from the same distribution. The results of this significance testing, also shown in Table 5.2, show that two of the eleven performance metrics show significant differences between the two groups: the number of errors made in task 4 and the time taken to complete task 5.

The group with dyslexia made significantly more errors on task 4, the task designed to test visual sequential memory, previous work presented in Chapter 2 support this result, suggesting that controls would perform better in this task. The group with dyslexia were also significantly slower when completing task 5, the task designed to test visual memory. This was also expected, as the research in Chapter 2 suggested that the problem of rotating and reversing letters seen in some individuals with dyslexia, could cause them to perform worse than controls in this task.

Having determined which individual tasks identify significant differences between the two groups, the problem can be approached as one of classification:

Can a model be built from the game performance metrics which can predict which class an individual belongs to?

When attempting to answer this question, methods such as *Principal Component Analysis* (PCA) and *Linear Discriminant analysis*(LDA) were considered for data preprocessing. PCA reduces dimensionality by identifying a smaller set of variables, which are linear combinations of the original inputs, which preserve the majority of the variance in the data[69]. LDA is similar, however, exploits knowledge of the desired output class for each data record by attempting to model the differences between the classes. However, both PCA and LDA make a lot of assumptions about the data and are unlikely to be suitable for use on such a small dataset.

Instead, *Logistic Regression* (LR) was used to create a model capable of classifying the data collected in this study, and to reduce overfitting. LR classifies data records by calculating the conditional probability $P(Y = 1|X = x)$, where $Y = 1$ is a positive output and in this case means that the participant belongs in the group with dyslexia. x is the dependant variables used as input[70], in this case the performance metrics collected during game play. LR allows non-linear relationships between the inputs and the output to be modelled, reducing the inputs to a single probability score, such that individuals what a probability score ≥ 0.5 will be classified in the group with dyslexia.

Using all of the game metrics as inputs to the LR model is likely to seriously overfit to the data, and impede generalisation. Instead, only the variables which identified significant differences between the two groups were used for the model, the number of errors made in task 4 and the time taken to complete task 5.

An LR model was fitted to the data using the *Binary Logistic Regression Tool* available in the *SPSS Statistics* software. Step 0 of the model, with no inputs included as predictors, achieved 83.3% accuracy by assuming that all participants fell into the control group. One further step was performed, adding the number of errors made in task 4 to the model as a predictor, no further steps were performed as adding the time taken to complete task 5 made no significant difference to the model.

The final model equation, shown in equation 5.1, can be used as part of equation 5.2 to find the probability that an individual with performance metrics x belongs in the group with dyslexia. When classifying, a probability < 0.5 means the individual belongs in the control group, a probability ≥ 0.5 means that the individual belongs in the group with dyslexia. When examining the data collected in this study, this model achieved an accuracy of 95.2% when attempting to classify participants into one of the two classes. 5 of the 7 participants with dyslexia were correctly classified, all other participants were classified as controls.

$$\text{logit}(p(x)) = -6.921 + 2.140 \cdot E_4 \tag{5.1}$$

where E_4 is the number of errors made in task 4.

$$p = \frac{\mathrm{e}^{\text{logit}(p(x))}}{1 + \mathrm{e}^{\text{logit}(p(x))}} \tag{5.2}$$

4 Discussion

In this section the results presented in section 3 are discussed in order to establish their meaning.

4.1 Discussion of the Significance and Logistic Regression Results

Section 3.2, found that using the *Mann-Whitney U* significance test, significant results were seen for two of the game play metrics, meaning there is at least a 95% confidence that the values achieved by the two groups are drawn from different distributions. The *Mann-Whitney U* test was chosen as it is a non-parametric test capable of comparing two independent classes, there was no reason to believe that the data collected in this study had a normal distribution therefore tests such as the *Students T-Test* would have been unsuitable. These results mean that null hypothesis **NH.1** could be rejected, as there is an observable and indeed significant difference between the results achieved by the two groups, although only in two of the eleven metrics. Though this is a positive sign, it is important to consider that the dataset used for this analysis is very small and that only 7 of the 42 participants belonged in the group with dyslexia. This means that it is unlikely that the sample used in this study is truly representative of the actual population, that said, the results provide a good basis for further work and it would be interesting to see if this effect is still observed with a much larger dataset.

The results of the *Logistic Regression* analysis showed that a model can be created using equations 5.1 and 5.2 which can achieve 95.2% accuracy, utilising a game play performance metric as a predictor. This again means that null hypothesis **NH.1** could be rejected, as the model uses a function of the game performance metrics to classify participants. This does not ensure that the model will generalise with a high accuracy to new data as it is likely that, due the small size of the dataset, the model has overfitted to the provided data points. To test the model, unseen data should be presented to it and it should be judged on how well it classifies this data. Ideally this would have been done as part of this project, however, the size of the group with dyslexia is already very small and there was not enough data to exclude samples from the model for use in testing.

What the model does show is promise. The model achieved a high level of accuracy and the null hypothesis could be rejected, meaning there is reason to believe that the game is capable of separating the two classes and thus being used a screening test. The only way to determine whether the model will generalise is to collect more data and test it.

It is worth noting that it was very difficult to find participants with dyslexia within the timeframe of the project and that, despite every effort being made including involving schools in the study, only 7 participants were found that had been diagnosed with dyslexia, making it difficult to come to any definitive conclusions about the capabilities of the game.

4.2 Discussion of the Questionnaire Results

The questionnaire results, presented in section 3.1, were generally positive, suggesting that the decision to embark on this research was justified, with nearly all participants using games regularly and enjoying the produced game. Results also suggest that, on the most part, the decisions made concerning the games structure, theme, and content were correct. When considering the controls of the game the questionnaire found that some players struggled with the jump control. Though this may not seem important as it is not part of a dyslexia screening task, users struggling to navigate the platform game could result in them having an overall negative experience with the game and perhaps not even finishing it. It is therefore important that the difficulties with the jump control are addressed. To ensure issues with the game controls did not bias the results, effecting one group significantly, the answers to this question were tested for significance. No significant difference between the answers given by those with dyslexia and controls was identified, with a significance score of 0.620.

The majority of participants thought that the game did not take too long to play, suggesting that it might even be too short. This is not a concern at this time as the priority at this stage is to refine the predictive power of the game. However, the game ending prematurely may leave some users feeling dissatisfied with the experience and have a negative effect on public opinion. It may therefore be worth examining the duration of the game, or perhaps creating a more interesting and fulfilling ending, in later versions.

The number of questions in the questionnaire was limited, so as not to overwhelm younger participants. It may have been beneficial to have asked for more information, in particular to gain insight into the users opinions of the screening tests. This would help to determine if the screening tasks which show significant differences between the groups are well received by users.

5 Summary

In summary, this chapter has detailed the method and results of experimenting with the game, to determine its validity as a dyslexia screening test and its overall usability. The results and discussion of the experiment show that, with the collected data, the performance metrics collected during gameplay could be used to distinguish between users with dyslexia and users with an accuracy of 95.2%. The discussion highlights the fact that this result is likely to be due to the small amount of data samples, and that more samples will be required in order to make definitive conclusions about the games abilities. Results and discussion of the questionnaire revealed that the majority of choices about the game design and structure were suitable for the target age group, with the vast majority of participants enjoying the game experience. It also revealed a possible issue with the game controls which would need to be investigated in later versions.

CHAPTER 6

Conclusions

This chapter concludes the project report, summarising and reflecting on the work completed, the value of this work, and the lessons learnt along the way. In addition, possible extensions and improvements to this work are examined.

1 Project Summary

In summary, this project aimed to create "A Serious Game For Aiding the Screening of Dyslexia in Children and Young Adults" in the hope of replacing the current screening tests. The work completed has gone a long way towards achieving this goal, despite the time and resource limitations.

In depth analysis was performed in Chapter 2, reviewing the breadth of current knowledge surrounding both dyslexia and games. This knowledge was then utilised to create a game design, specifically engineered to include tasks designed to identify differences between those with and without dyslexia. This design was then rapidly realised, through careful planning and adhering to software engineering principles and methodologies, including the use of TDD, extracting requirements from use cases, and examining the important quality attributes associated with the system.

The game implementation was then tested, both for usability and validity. The results of this testing were positive, however, due to lack of data cannot be taken to be definitive. Some of the screening tasks, have shown that they may be capable of distinguishing between the the two groups, and have allowed null hypothesis **NH.1** to be rejected. Usability testing revealed the strengths and weaknesses of the game design and implementation, with users enjoying the game and the theme as a whole, but finding the controls difficult to grasp.

Overall, though no definitive conclusions could be reached about the games effectiveness as a screening test, due to lack of data, the game certainly proved itself to be an enjoyable experience for users and identified the tasks most likely to have predictive power. Hopefully, with further research, the game developed in this project could be a contender to the current dyslexia screening tests, making the experience more enjoyable and accessible for all.

2 Project Reflection

This section reflects on the choices made throughout the project and the implications of those choices.

This project included both a user study and development of software, meaning time had to be split between the two tasks. The user study was dependant on the game implementation being complete, because of this, little time was left available for recruiting participants and completing the user study. It may have been better to recruit the participants whilst the game was being implemented, this would have allowed for more schools to be contacted, and more participants recruited. Perhaps it is because the recruitment was not done this way, that not enough data was collected to make concrete conclusions about the games abilities. However, it must also be considered that large numbers of participants with dyslexia are difficult to find because they are a minority within the general population. This is something that was somewhat overlooked when proposing this project, however, became quite an issue when attempting to recruit participants. Though efforts were made to overcome this by contacting high schools and arranging to conduct parts of the study there, it was not enough. It would have been beneficial, given enough time, to contact specialist dyslexia schools and centres in an attempt to recruit a large number of participants with dyslexia.

When reflecting on the game development there were a number of big decisions which, if made differently, could have drastically altered to content of this project, including the game platform, and the overall approach to software engineering.

iOS 7, *SpriteKit*, and the Apple iPad were chosen as the game platform and hardware. At the time the reasoning for choosing iOS over other platforms appeared sound, however, a number of small but time consuming problems were met along the way. The *SpriteKit* framework is a new addition to iOS and the implications of that were not thoroughly considered at the time. Throughout the project a number of updates and bug fixes have been applied to this framework, however, a number of large bugs were also introduced. Two major bugs were found in updates to the framework, both of which required large work arounds during the time allocated to experimentation in order to get the game working as desired. That said, it is still likely that more problems would have been encountered if the game was initially created for the Android platform, due the fragmentation of both hardware and software.

A reasonably heavyweight approach to software engineering was taken for this project, despite the use of TDD, with use cases, requirements, and quality attribute analysis being performed. This decision was made for two reasons, firstly because the game application was a vital element to the user study, and secondly because there was no customer explaining what was required from the game. Taking a heavyweight approach mitigated many of the risks associated with those two problems, by allowing the needs of the game to be drawn from the literature, explicitly documented, and referred to throughout development. This kept the development process focussed, without the need to explicitly define the software architecture beforehand, a time consuming process. Taking a lightweight approach, drawing more on the agile methodologies, could have saved time during the development as requirements and use cases would not have been rigorously defined. However, this approach would have been risky as there is nothing to fall back on if something went wrong. It would have allowed for the development to get out of hand with needless features being added. It is therefore felt that the decisions made regarding the approach to software engineering for this project were correct.

3 Further Work

The work completed in this project could be extended in a number of ways, these can be split into three groups: the game platform, the screening tasks, and the data.

3.1 Game Platform and Hardware

Currently the game is only designed to run on the Apple iPad and iPad Mini. In order for the game to be as accessible as hoped for, it would need to be ported to other platforms and hardware. Possible targets include the Apple iPhone and Android devices. Porting the game to the iPhone would be reasonably straight forward as the majority of the existing implementation could be reused, although issues may be faced when considering the difference in screen size. Porting the game to Android would be a more difficult task and it is recommended that the game support only the latest versions of the operating system, as it would be difficult to handle the fragmentation if lower versions were included.

3.2 Screening Tasks

There were a number of screening task ideas included in Chapter 3 which were not included in the game implementation. It may be the case that some of these tasks, or perhaps completely new tasks, would be better at finding differences between the two groups than some of the tasks that have been included. This is worth exploring as model accuracy is important, therefore, anything that could increase this is also important.

In addition, it may also be beneficial to increase the difficulty of the tasks which did not find significant differences between the groups. It may be that they are capable of finding differences but have not been implemented at the correct difficulty level to make those differences apparent. Since participants did not find the game too challenging, it should be possible to do this without negatively impacting the users experience.

3.3 Data

There are two ways in which the work conducted in this project could be advanced by collecting additional data. The first is to better test the model, or improve it. Currently the model relies on very little data and is likely to be overfitted. More data is required in order to properly test it and produce definitive results.

Data could also be collected on an ordinal scale, ranking participants given that the severity of their dyslexia is known. This data would be useful as currently even if the model was capable of generalising, it only produces a binary output. Knowing more information about an each individuals place of the dyslexic continuum could help teachers prioritise and help those most in need first.

APPENDIX A

Informed Consent Form

Games for Dyslexia Study: Informed Consent

1 Who is Running the Study?

The study is being run by Rose Tucker, under the supervision of Dr Paul Cairns, as part of an fourth year MEng Computer Science project for the University of York.

2 What is the Purpose of the Study?

The study investigates the influence of dyslexia on how people play digital games. Therefore, in order to examine the differences, participants that have been diagnosed with dyslexia and participants that have not are required.

3 What is my Role in the Study?

As a participant your task will be to play a game on an Apple iPad for around 10 minutes, completing the tasks within the game. At the end of the game you will be asked to complete a small questionnaire about your experience with the game.

4 Who will Access the Data?

Rose and Paul will have access to the data collected, including your answers to the questions, the questionnaire and your game scores. Your scores and answers will be collated with the scores and answers of all other participants and analysed for patterns.

After analysis, data will be anonymised and your answers and scores will not be able to identify you. Results of the study will be published in Rose's MEng project report and may be published in an academic journal, again you will not be directly identifiable.

5 Do I have to Participate?

Participation in this study is voluntary and you are are under no obligation to participate. If at any time you decide you do not want to continue with the study, mention it to the experimenter who will arrange to have your data destroyed.

6 Am I Allowed to Ask Questions?

You are free to ask any questions leading up to study, however, during the study the experimenter will be unable to answer any questions. Once you have completed the study you are again free to ask any questions.

7 Consent

Signing below means that you have read and understood the above details and agree to take part in the study under the stated conditions.

Name:

Signature:

Date:

APPENDIX B

Questionnaire

Games for Dyslexia Study: Questionnaire

Please answer all questions.

About You

1) What is Your Gender? (Tick one)

M ☐ F ☐

2) What is Your Age? (Write in the space provided)

____

3) How Frequently do You Play Games? (Circle One)

Never About once a year About once a month About once a week Most days Every day

4) How Frequently do You Use Touchscreen Devices? (Circle One)

Never About once a year About once a month About once a week Most days Every day

About the Game

For the following statements, circle the option you feel best represents your opinion.

5) The Game Controls were Easy to Use (Circle One)

Strongly Agree Agree Neutral Disagree Strongly disagree

6) I Liked the Game Theme (Circle One)

Strongly Agree Agree Neutral Disagree Strongly disagree

7) The Game was too Challenging (Circle One)

Strongly Agree Agree Neutral Disagree Strongly disagree

8) I Enjoyed Playing the Game (Circle One)

Strongly Agree Agree Neutral Disagree Strongly disagree

9)The Game Took too Long to Play (Circle One)

Strongly Agree Agree Neutral Disagree Strongly disagree

10) The Game was too Easy (Circle One)

Strongly Agree Agree Neutral Disagree Strongly disagree

APPENDIX C

Participant Instructions

1) Read the informed consent form, and highlight any issues you may have.

2) If you agree with the information on the consent form, and therefore agree to participate in the study, please sign the form.

3) You will be given an Apple iPad, loaded with the game being examined by this study. Your task is to play the game until it informs you that you have finished. This will take around 10 minutes.

4) After playing the game you will be asked to complete a short questionnaire about you, and your experience with the game. This will take around 5 minutes.

5) During the study you must not ask the experimenter any questions, however, when you have completed the questionnaire you are free to ask questions and find out more information about the study.

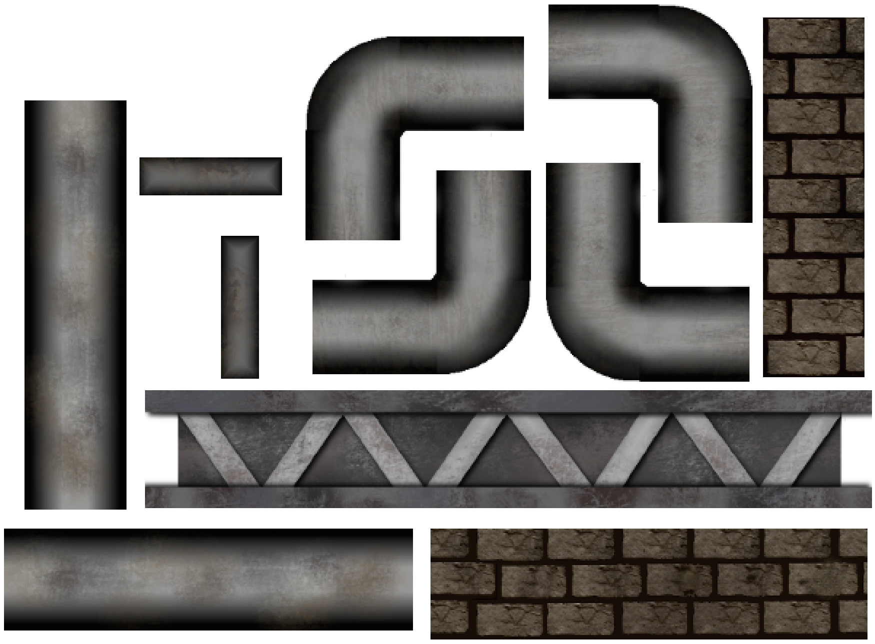
6) If at any time you feel incomparable and do not wish to continue, contact the experimenter and they will arrange to have your data destroyed.

APPENDIX D

Sprite Sheets

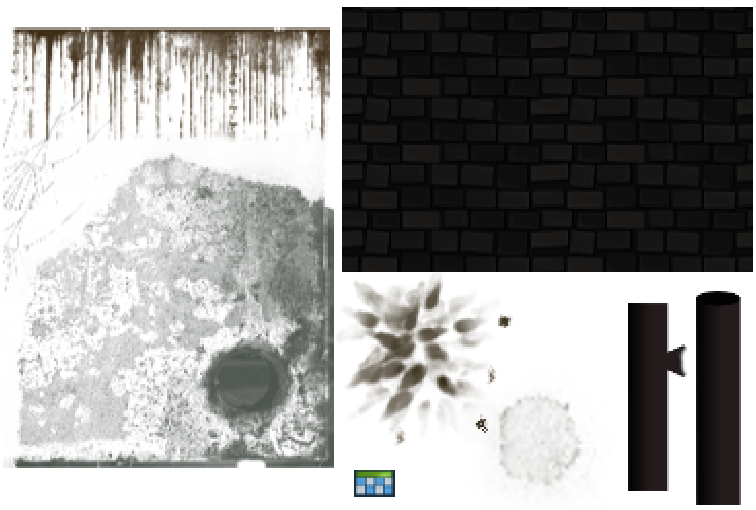
1 Platform Sprites

These sprites acted as platforms within the game, they include walls, girders, and pipes.



2 Scene Sprites

These sprites are added purely to enhance the scene, and could not be interacted with, they include bricks, graffiti, dirt, and small pipes.

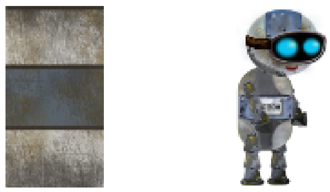


3 Special and Collectable Sprites

These sprites perform special functions when the user interacts with them, such as starting mini games or unlocking areas of the level. Included are doors, buttons, gates, keys and chests.

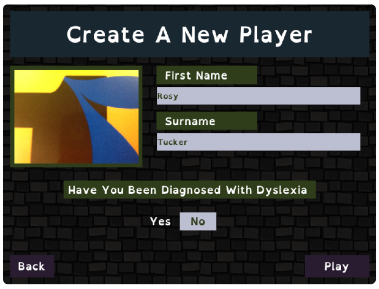
4 Dynamic and Character Sprites

The is a single character sprite and a single dynamic sprite within the game. The character sprite is TOM the robot and the dynamic sprite is a barrel.



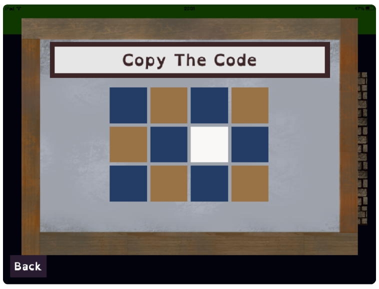
APPENDIX E

Platform Game Behavioural View

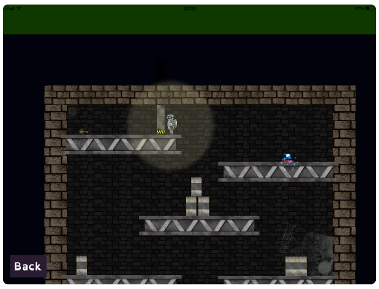


1) User enters their details and selects play.

2) User is shown tutorial overlays, and learns the platform controls.

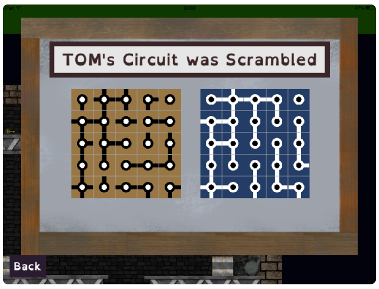


3) User plays the first mini game, designed to test their working memory. A code is displayed to them on the buttons, they must remember and repeat it.



4) User navigates the second level to find a locked gate with a key behind it.

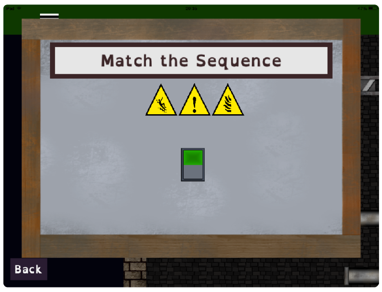
5) User stands on the big red button to open the gate, it electrocutes TOM and scrambles his circuit

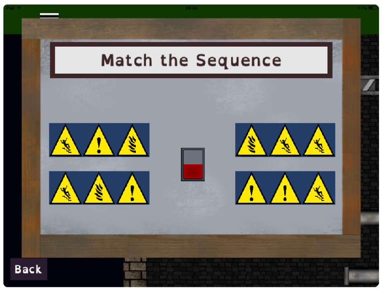


6) User plays the mini game designed to test spatial orientation. They follow the blueprint to fix TOM's circuit and collect the key

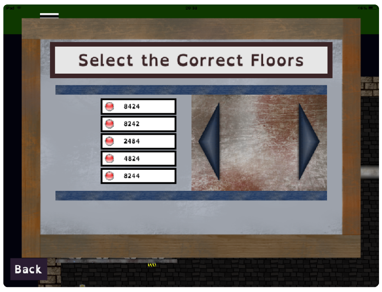
7) User, in possession of the key, attempts to unlock the level exit by playing the mini game designed to test visual spatial discrimination. User matches complex key images to locks.

8) User gains access to the chest by standing on the big red button, again scrambling TOM's circuit and opening the gate.





9) User opens the chest and completes the mini game designed to test visual sequential memory. User matches the sequence of hazard symbols shown in the first screen to the same sequence in shown in the second screen. User is rewarded with an access card upon completion



11) User completes the mini game designed to test visual memory in order to escape the sewer. User is shown the number of the floor they must go to, and selects the matching number from the list

10) User navigates to a lift and uses their access card to gain entry.

Bibliography

[1] C. von Károlyi, "Visual-spatial strength in dyslexia rapid discrimination of impossible figures," *Journal of learning disabilities*, vol. 34, no. 4, pp. 380–391, 2001.

[2] V. Zammitto, "The expressions of colours," 2005.

[3] T. B. D. Association, "About dyslexia," http://www.bdadyslexia.org.uk, 09 2013.

[4] D. Bodenham, A. Fawcett, and R. Nicolson, "The dyslexia adult screening test (dast)," *Iournal of the Application of Occupational Psychology to Employment and Disability*, vol. 2, no. 2, pp. 51–56, 2000.

[5] NHS-Choices, "Dyslexia," http://www.nhs.uk/conditions/dyslexia, NHS, March 2012, (Accessed 27th August 2013). [Online]. Available: http://www.nhs.uk/conditions/dyslexia/Pages/Introduction.aspx

[6] P. Ott, *How to detect and manage dyslexia: A reference and resource manual.* Heinemann, 1997.

[7] J. Rose, "Identifying and teaching children and young people with dyslexia and literacy difficulties: an independent report," 2009. [Online]. Available: http://dera.ioe.ac.uk/14790/1/00659-2009DOM-EN.pdf

[8] M. J. Snowling, *Dyslexia .* Blackwell Publishing, 2000.

[9] L. Peer, "Dyslexia and its manifestations in the secondary school," *Dyslexia: Successful inclusion in the secondary school*, pp. 1–9, 2001.

[10] S.Samant, "Kara tointon: Don't call me stupid," Television Documentary, November 2011.

[11] B. E. Levin, "Organizational deficits in dyslexia: Possible frontal lobe dysfunction," *Developmental Neuropsychology*, vol. 6, no. 2, pp. 95–110, 1990.

[12] J. Smith-Spark, A. Fawcett, R. Nicolson, and J. Fisk, "Dyslexic students have more everyday cognitive lapses," *Memory*, vol. 12, no. 2, pp. 174–182, 2004.

[13] D. Bartlett, S. Moody, and K. Kindersley, *Dyslexia in the Workplace: An introductory guide.* John Wiley & Sons, 2010.

[14] J. Stein and V. Walsh, "To see but not to read; the magnocellular theory of dyslexia," *Trends in neurosciences*, vol. 20, no. 4, pp. 147–152, 1997.

[15] T. Helland and A. Asbjrnsen, "Visual-sequential and visuo-spatial skills in dyslexia: Variations according to language comprehension and mathematics skills," *Child Neuropsychology*, vol. 9, no. 3, pp. 208–220, 2003, pMID: 13680410. [Online]. Available: http://www.tandfonline.com/doi/abs/10.1076/chin.9.3.208.16456

[16] D. Wechsler, *Manual for the Wechsler intelligence scale for children, revised.* Psychological Corporation, 1974.

[17] J. Stein, "The neurobiological basis of dyslexia," *The SAGE Handbook of Dyslexia*, p. 53, 2008.

[18] H. E. Nelson and E. K. Warrington, "An investigation of memory functions in dyslexic children," *British Journal of Psychology*, vol. 71, no. 4, pp. 487–503, 1980.

[19] M. J. Snowling and J. Stackhouse, *Dyslexia, speech and language: a practitioner's handbook.* John Wiley & Sons, 2006.

[20] F. R. Vellutino, D. M. Scanlon, and M. S. Tanzman, "The case for early intervention in diagnosing specific reading disability," *Journal of School Psychology*, vol. 36, no. 4, pp. 367 – 397, 1998. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0022440598000193

[21] G. Brookes, V. Ng, B. H. Lim, W. P. Tan, and N. Lukito, "The computerised-based lucid rapid dyslexia screening for the identification of children at risk of dyslexia: A singapore study," *Educational and Child Psychology*, vol. 28, no. 2, p. 33, 2011.

[22] T. L. People, "Gfk national opinion survey 2007," 08 2007.

[23] A. Gellert and C. Elbro, "Reading disabilities, behaviour problems and delinquency: a review," *Scandinavian Journal of Educational Research*, vol. 43, no. 2, pp. 131–155, 1999.

[24] C. Jamieson and E. Morgan, *Managing dyslexia at university: a resource for students, academic and support staff.* Psychology Press, 2007.

[25] A. J. Fawcett and R. I. Nicolson, "Persistent deficits in motor skill of children with dyslexia," *Journal of Motor Behavior*, vol. 27, no. 3, pp. 235–240, 1995.

[26] P. Clinical, "Dyslexia screening tests," http://www.pearsonclinical.co.uk/, Febuary 2014.

[27] R. I. Nicolson and A. J. Fawcett, "Development of objective procedures for screening and assessment of dyslexic students in higher education," *Journal of Research in Reading*, vol. 20, no. 1, pp. 77–83, 1997.

[28] A. Fawcett and R. Nicolson, "The dyslexia screening test," *London: The Psychological Corporation*, 1996.

[29] J. Juul, *Half-real: Video games between real rules and fictional worlds.* The MIT press, 2005.

[30] K. Salen, *Rules of play: Game design fundamentals.* The MIT Press, 2004.

[31] J. Schell, *The Art of Game Design: A book of lenses.* Taylor & Francis US, 2008.

[32] L. Stege, G. van Lankveld, and P. Spronck, "Serious games in education," *International Journal of Computer Science in Sport*, vol. 10/2011/Edition 1, 2011. [Online]. Available: http://ticc.uvt.nl/~pspronck/pubs/StegeGameDays2011.pdf

[33] T. Susi, M. Johannesson, and P. Backlund, "Serious games: An overview," 2007. [Online]. Available: http://his.diva-portal.org/smash/get/diva2:2416/FULLTEXT01

[34] A. J. Stapleton, "Serious games: Serious opportunities," in *Australian Game Developers" Conference, Academic Summit, Melbourne*, 2004.

[35] K. Squire, M. Barnett, J. M. Grant, and T. Higginbotham, "Electromagnetism supercharged!: Learning physics with digital simulation games," in *Proceedings of the 6th international conference on Learning sciences.* International Society of the Learning Sciences, 2004, pp. 513–520.

[36] J. W. Tanaka, J. M. Wolf, C. Klaiman, K. Koenig, J. Cockburn, L. Herlihy, C. Brown, S. Stahl, M. D. Kaiser, and R. T. Schultz, "Using computerized games to teach face

recognition skills to children with autism spectrum disorder: The let's face it! program," *Journal of Child Psychology and Psychiatry*, vol. 51, no. 8, pp. 944–952, 2010.

[37] C. Buiza, M. F. Gonzalez, D. Facal, V. Martinez, U. Diaz, A. Etxaniz, E. Urdaneta, and J. Yanguas, "Efficacy of cognitive training experiences in the elderly: Can technology help?" in *Universal Access in Human-Computer Interaction. Addressing Diversity.* Springer, 2009, pp. 324–333.

[38] E. S. Association, "2013 sales, demographicand usage data," http://www.theesa.com/facts, May 2013.

[39] O. Gaggi, G. Galiazzo, C. Palazzi, A. Facoetti, and S. Franceschini, "A serious game for predicting the risk of developmental dyslexia in pre-readers children," in *Computer Communications and Networks (ICCCN), 2012 21st International Conference on.* IEEE, 2012, pp. 1–5. [Online]. Available: http://localwww.math.unipd.it/~cpalazzi/papers/Palazzi-D-NIME12.pdf

[40] L. Rello, C. Bayarri, and A. Gorriz, "What is wrong with this word? dyseggxia: a game for children with dyslexia," in *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility.* ACM, 2012, pp. 219–220.

[41] Valve, "Steam store," http://store.steampowered.com, Febuary 2014.

[42] Google, "Google play app store," https://play.google.com/store/apps, Febuary 2014.

[43] Apple, "itunes store," https://www.apple.com/itunes/, Febuary 2014.

[44] M. R. Zentner, "Preferences for colours and colour–emotion combinations in early childhood," *Developmental Science*, vol. 4, no. 4, pp. 389–398, 2001.

[45] C. B. A. CIC, "What is colour blindness," http://www.colourblindawareness.org, 08 2013.

[46] ColourBlindness.com, "Colour blindness, information, identification and solutions," http://www.colour-blindness.com/general/causes/, 09 2013. [Online]. Available: http://www.colour-blindness.com/general/causes/

[47] B. Jenny, "Color oracle," http://colororacle.org, November 2013.

[48] H. H. Hu, A. A. Gooch, S. H. Creem-Regehr, and W. B. Thompson, "Visual cues for perceiving distances from objects to surfaces," *Presence: Teleoperators and Virtual Environments*, vol. 11, no. 6, pp. 652–664, 2002.

[49] S. Lockley, "Dyslexia and higher education: accessibility issues," *Retrieved October*, vol. 24, p. 2003, 2002.

[50] C. Boer, "Dyslexie lettertype," http://www.studiostudio.nl, 04 2012.

[51] A. Gonzalez, "Open dyslexic typeface," http://www.opendyslexic.org, 05 2013.

[52] J. P. Gee, *Good Video Games Plus Good Learning.* Peter Lang, 2007, vol. 27.

[53] Apple, "ipad user guide (ios 7)," Online, October 2013.

[54] G. Smith, M. Cha, and J. Whitehead, "A framework for analysis of 2d platformer levels," in *Proceedings of the 2008 ACM SIGGRAPH Symposium on Video Games*, ser. Sandbox '08. New York, NY, USA: ACM, 2008, pp. 75–80. [Online]. Available: http://doi.acm.org/10.1145/1401843.1401858

[55] D. S. Parlett, *The Oxford history of board games.* Oxford University Press Oxfordˆ eUK UK, 1999, vol. 5.

[56] M. A. Cusumano and S. A. Smith, "Beyond the waterfall: Software development at microsoft," 1995.

[57] T. Dybå and T. Dingsøyr, "Empirical studies of agile software development: A systematic review," *Information and software technology*, vol. 50, no. 9, pp. 833–859, 2008.

[58] D. S. Janzen and H. Saiedian, "Test-driven development: Concepts, taxonomy, and future direction," *Computer Science and Software Engineering*, p. 33, 2005.

[59] M. Dalrymple, "Learn objective-c," 2009.

[60] Apple. (2007) ios dev center. [Online]. Available: developer.apple.com

[61] A. Cockburn, *Writing effective use cases.* Pearson Education, 2001.

[62] L. Bass, P. Clements, and R. Kazman, *Software architecture in practice.* Addison-Wesley Professional, 2003.

[63] P. Clements, R. Kazman, and M. Klein, "Evaluating software architectures: Methods and case studies," 2002.

[64] Thoughtworks, "Mingle: Agile project management," http://www.thoughtworks.com/products, Febuary 2014.

[65] M. Fowler, *Patterns of enterprise application architecture.* Addison-Wesley Longman Publishing Co., Inc., 2002.

[66] A. Eales, "The observer pattern revisited," *Educating, Innovating & Transforming: Educators in IT: Concise paper*, 2005.

[67] P. Cairns and A. L. Cox, *Research methods for human-computer interaction.* Cambridge University Press, 2008.

[68] P. Harris, *Designing and reporting experiments in psychology.* McGraw-Hill International, 2008.

[69] I. Jolliffe, *Principal component analysis.* Wiley Online Library, 2005.

[70] C.-Y. J. Peng, K. L. Lee, and G. M. Ingersoll, "An introduction to logistic regression analysis and reporting," *The Journal of Educational Research*, vol. 96, no. 1, pp. 3–14, 2002.