School of Electronic Engineering
and Computer Science

# Final Report

**Programme of study:**
BSc Computer Science with Business Management and Accounting

## Project Title:

Chromesthesia and the association between tone and colour: An exploratory research tool

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# Abstract

Chromesthesia is a condition that focuses on the sight and hearing senses, whereby sight is triggered in response to hearing. This project aims to further understanding of chromesthesia through examining the natural associations people make between tone and colour. Chromesthesia as a medical condition is largely unknown to many, but has a prevalence estimated to be between 1: 200 and 1: 100,000. Chromesthetes experience sound not only aurally but also visually, and this ultimately affects the way in which they experience the world. Artists like Kanye West have been known to leverage their chromesthesia to ensure that visuals match up with the music in their music videos. This condition could provide insight into the relationships between sound and colour.

People with chromesthesia have consistent tone-colour associations. A goal is to create an online web interface that can help us identify chromesthetes through the consistency of pairing sound tone to colour. The graphical user interface allows users to select a colour from a palette of options when listening to a sound for five seconds; they are asked to do this for eighteen different sounds. The user is invited to return two weeks later to re-take the test, and the results are compared to the previous tone-colour assignments they made. 25 users took this test, and the similarity, measured by the percentage matches, between the two sets of tone-colour pairs ranged from 0% to 38%. Research shows that chromesthetes would get close to 100% matches in such a test. We set the threshold at 80% for identifying people with chromesthesia tendencies. Given this threshold, none of the 25 participants were chromesthetes, which is not surprising.

As the database of users and results grows, the tool gathers increasingly robust statistics about tone-colour associations people make. The tool can also be used by a general user to self-diagnose for chromesthesia in a similar way in which we conducted the test.

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# 1. Introduction

## 1.1 Project Aims

The project aims to help with the identification of chromesthesia by taking the users visual responses to several auditory stimuli and then repeating the process after a period of time. The results of both tests will provide some indication of whether the user may have synesthesia or not. A synesthete can be expected to produce the same or very similar results over both attempts to most or all the sound clips provided.

## 1.2 Motivation and Challenges

This project will be focusing on a specific type of synesthesia known as chromesthesia. Chromesthesia focuses on the combination of the hearing and sight senses. It can be defined as “the eliciting of visual images (colors) by aural stimuli; most common form of synesthesia” (Makhlin, J., 2014).

This project is important as it allows those with chromesthesia to recognise their condition and better understand it. It can be helpful in raising awareness of the condition as those with it may not realise they have it. It is not a life-threatening condition; however, it can be considered life-altering as it changes how someone would experience the world around them.

## 1.3 Report Structure

The report will be divided into sections and sub sections. Each section will cover different aspects of the project. Section one will cover the introduction, which contains the aims and motivations of the project. Section two will cover the background research into synesthesia, chromesthesia and similar existing applications. Section three will cover will cover the development environment, which consists of the programs and code used to create the application and assist in the creation of the project. Section four will cover the system development life cycles used during development. Section five will cover the project analysis and the requirements of the application. Section six and seven will cover the design and

implementation of the project during each phase. Section eight will cover the results found during testing, displayed using tables and graphs, and section nine will discuss the results shown. Section ten will cover the testing that occurred during and after development. Section eleven will conclude the report with an evaluation of the project.

## 2. Background Research

In this section I will talk about the research conducted on synesthesia and chromesthesia. I will look into details of the conditions and prior research in this area. I will also look at previous methods which have been used and the results that have been found from those experiments.

### 2.1 Synesthesia

Synesthete is the name given to those that are conditioned with synesthesia. Synesthesia is a condition, that can involve a various combination of senses, whereby one sense is triggered in response to another sense (Phillips, M. L.). Synesthetes experience the condition in a way that is unique to themselves (Berman, G., 2017). Each synesthete may have the condition affect a different combination of senses to another synesthete. Additionally, those with the same type of synesthesia may experience different responses to the same stimuli. This creates the challenge of identifying synesthesia and distinguishing the difference between a synesthetic response to an emotional response.

There are two types of synesthetes, as mentioned by Rouw and Scholte, which are ‘projectors’ and ‘associators’. Projectors see synesthetic colour in the outside world and associators see colour in their ‘mind’s eye’ only. They mention that the responses triggered by synesthetes are “automatic in the sense that they are fast and effortless; highly consistent, as the same associations persist from early childhood; and specific, as a particular stimulus elicits a highly specific synesthetic sensation.” Their study found that after conducting experiments and measuring the brain activity between both synesthetes and non-synesthetes, synesthetes had

greater brain activation on parts of the brain when introduced to stimuli (Rouw, R., Scholte, H. S., 2007).

Melissa Lee Phillips mentions, in her article titled '*Synesthesia',* that the estimates for the number of people with synesthesia range from 1 in 200 to 1 in 100,000. The reason for this uncertainty could be due to a lack of awareness of the condition. People with synesthesia may not realise that they have different experiences in response to stimuli compared to those without synesthesia. To emphasise on the uncertainty of synesthesia and how common it is amongst the population, an FAQ page, written by Dr Veronica Gross, answers the question *'How common is synesthesia?'* with "the short answer is no one really knows. The long answer is anywhere from one in every 100,000 people to one in every 5,000 people". The FAQ also goes on to mention that synesthetes are most often female and the condition has a potential genetic component. The FAQ page was written as part of the Synesthesia Project at Boston University.

The book *Synesthesia: A Union of the Senses* (Cytowic, R. E., 2002) mentions the knowledge of synesthesia at the time of publication. It states that synesthesia runs in families "in a pattern consistent with X-linked dominant transmission". This means that the gene for synesthesia is carried in the X-chromosome. The result of this is that female synesthetes predominate by a ratio of 3:1 (Cytowic, R. E., 2002) as females have XX chromosomes and males have XY chromosomes. Cytowic also mentions that synesthetes are mostly left handed.

Many sources also make mention of the male to female ratio and that most synesthetes are left handed, such as the blog synesthesia statistics (Travis, 2011); the Synesthesia Project FAQ page (Gross, V.); and more references made in the paper 'Synaesthesia: The Prevalence of Atypical Cross-Modal Experiences' (Simner, J. et al., 2006). Another source, an FAQ page created by Sussex University, answers the question *'Are women more likely to have synesthesia than men?'* with an answer that doesn't follow the trend of previous papers. It states that women are not more likely to have synesthesia than men. The reason for their answer was that men may have been less likely to come forward and volunteer for research and are less likely to admit they have synesthesia (Sussex University). This point is also

made by Simner in her paper, as the paper states that prior studies relied on self-referral and therefore “no conclusions can be drawn about non-responders, except the very conservative claim they were not synesthetes” (Simner, J. et al. 2006).

## 2.2 Chromesthesia

Chromesthesia is a subset of synesthesia which focuses on the sight and hearing senses. People with chromesthesia, also known as chromesthetes, experience an involuntary reaction in their vision to a heard sound.

Krohn describes pseudo-chromesthesia as a “peculiar faculty of association of the sensorial perceptions, by means of which any primary sensation, or even a purely psychical process can evoke” (Krohn, W. O., 1892). Pseudo-chromesthesia is the term used to describe the phenomena of seeing or experiencing a colour reaction when seeing words or hearing them being spoken. Chromesthesia itself primarily focuses on heard sounds.

According to Calkins, who did a statistical study of pseudo-chromesthesia, only 6.66% of participants had pseudo-chromesthesia (Calkins, M. W., 1893). This shows that the condition is not very common, and it may prove difficult to find participants with chromesthesia.

Chromesthetes experience different types of coloured sounds. They may experience a single colour, such as red or blue; they may experience multiple colours at once, such as red and blue; or in some cases they may experience multiple colours with one dominant colour, such as red with flecks of blue (Cytowic, R. E., and Eagleman, D., 2009). This provides insight into the colour associations chromesthetes may have with different types of sounds as some chromesthetes may not be able to characterise a sound with just a single colour.

From the experiments carried out by Ward, Huckstep and Tsakanikos, they found that chromesthetes chose more “precise colours and are more consistent with their colour choices given a set of sounds of varying pitch, timbre and composition (single notes or dyads)” (Ward, J., Huckstep, B., Tsakanikos, E., 2006). This provides

information that the multiple features of music can provoke different colour responses in chromesthetes. Changing the pitch or timbre of a sound can completely alter the colour perceived by the user as it alters the sound they hear.

## 2.3 Existing Applications

For their research on music-colour associations, Palmer, Schloss and Prado-León used 37 colours during the task. There were 9 colours shown at four different lightness-saturation levels (saturated, light, muted, and dark). The participants listened to 50 second music samples which had varying tempo and mode and were asked to choose 5 colours that were most consistent with the music and 5 colours that were least consistent with the music. Their study found that faster tempi were generally associated with more saturated, lighter and warmer colours; and slower tempi and music in minor mode were associated with less saturated, darker and cooler colours (Palmer, S. E., Schloss, K. B., Xu, Z., Prado-León, L. R., 2013). This research sheds some light on the kinds of colours that can be expected from those that may not have synesthesia and perceive colours due to sensory responses, but rather non-synesthetes which may associate colours to sounds based on the emotion and feeling associated with it.

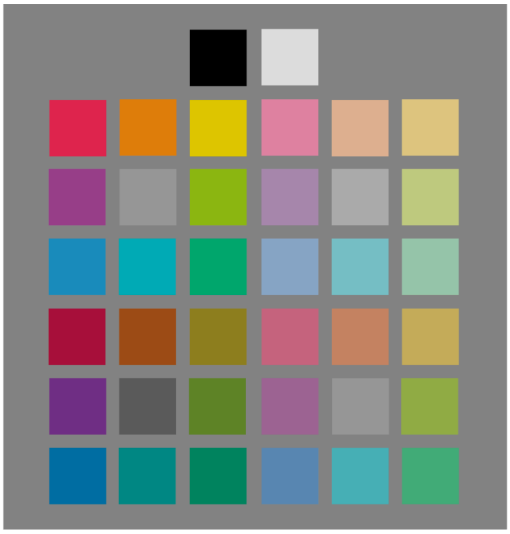

Figure 1 (source: *Music–color associations are mediated by emotion*, 2013)

An issue on *nautil.us* titled '*what color is this song?'* uses the test and colours from figure 1. These colours were mentioned in the Palmer et al research on music-colour associations. For their test they have 22 participants, 11 non-synesthetes and 11

synesthetes. Each user was exposed to 6 selections of music, 3 were fast, major key pieces of music and 3 were slow, minor key pieces of music. From this test, their results provided some insight into the colour responses both groups of users had to the auditory stimuli. They found that the type of music influenced the emotional response in both groups; “These findings show that synesthetes exhibit emotional effects in the colors they spontaneously experience when listening to complex music” (Palmer, S. E., 2015).

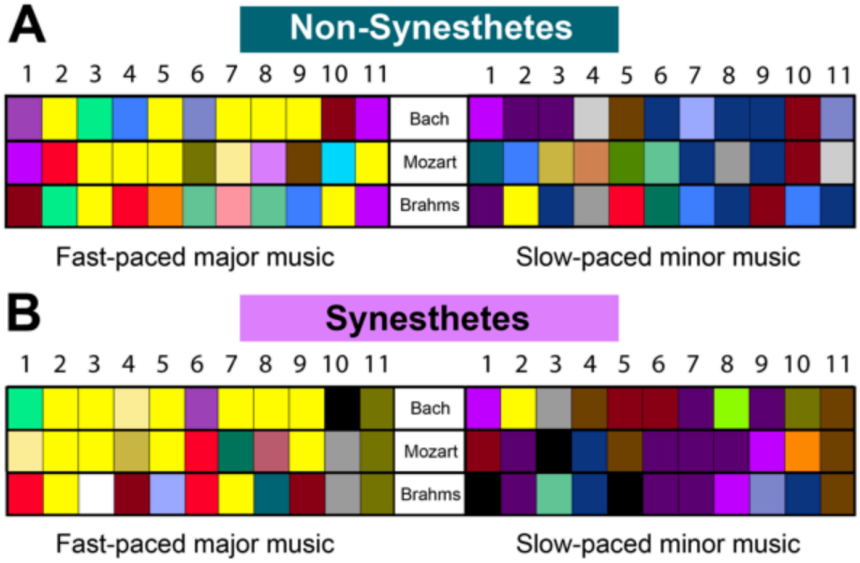


Figure 2 (source: *nautil.us*)

The results from the test shown in figure 2 show that the emotional responses in both synesthetes and non synesthetes are similar as they both show colour selections based on an emotional response to the musical piece. Faster paced music shows lighter colour selections, whereas slower paced music shows darker coloured selections. This provides information as to the kind of colour selections that can be expected from users of the application and the similarities that could be found between synesthetes and non-synesthetes.

*Synesthesia,* a website named after the condition, contains a quiz allowing its users to test if they resonate with synesthesia. It begins by asking the user whether they think they are a synesthete or not. This quiz looks at the link between words and colours and asks the user to select a colour they think the word is, as shown in figure

3. This type of synesthesia is known as grapheme-colour synesthesia. “Grapheme–color synesthesia is a neurological condition in which viewing numbers or letters (graphemes) results in the concurrent sensation of color” (Brang, D. et al, 2011).

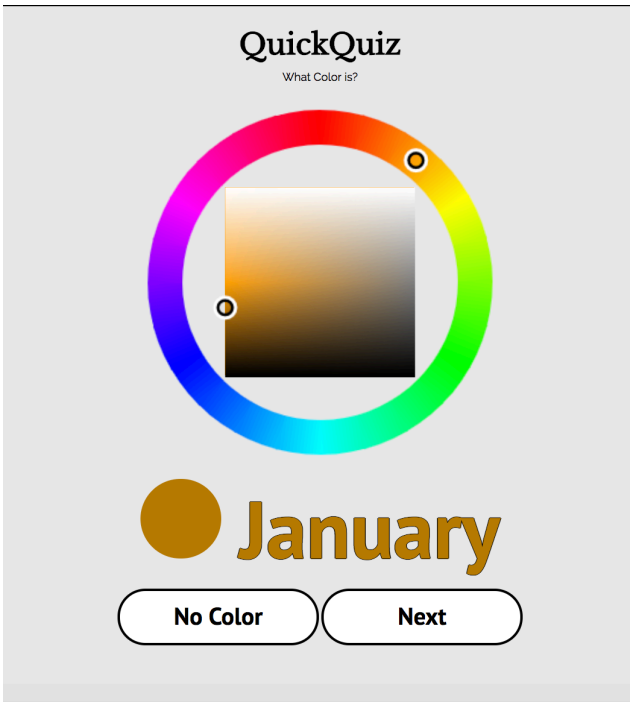


Figure 3 (source: *synesthesia.com*)

After going through the quiz and selecting colours it shows an evaluation screen as shown in figure 4. The evaluation screen provides some information as to the kind of colours and reaction times shown by those with synesthesia. It also provides the user with an average colour distance score and colour variance score whilst providing the range that those with synesthesia are in. The colour distance and variance scores are calculated using the RGB values produced by the colours selected. It goes on to show the expected colour choices that those with synesthesia would choose. The accuracy of this quiz is unknown as research shows that those with synesthesia usually show colour responses that are independent from others. However, it provides a good understanding of the features involved with synesthesia. It also helps its users understand what those with grapheme-colour synesthesia may see and experience.

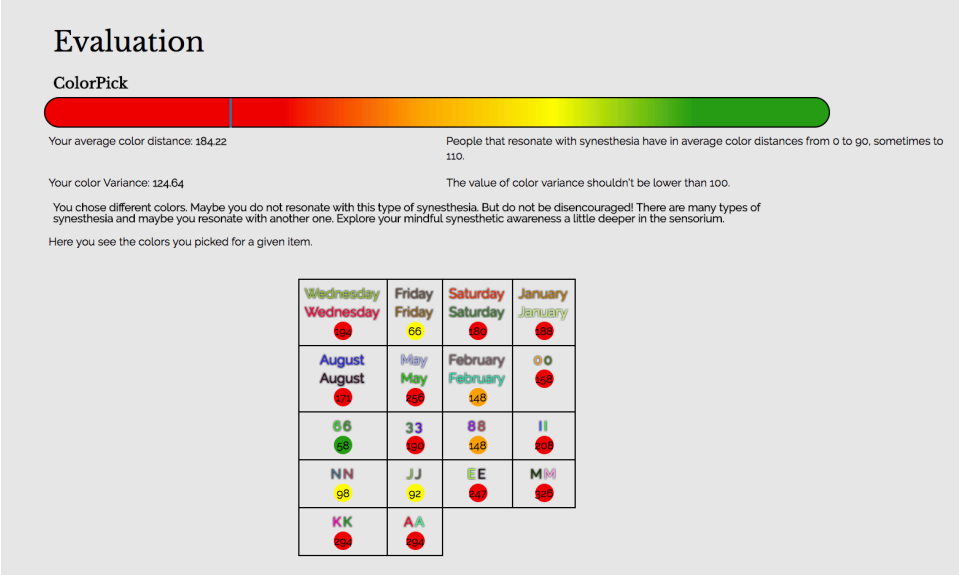


Figure 4 (source: synesthesia.com)

## 2.4 Proposal of New Application

My application will aim to help with the identification of chromesthesia through providing a test which allows users to select colours based on heard sounds. From research conducted, users experience a multitude of colours when listening to musical pieces. This results in the user having to choose one colour to describe the entire piece, resulting in some difficulties in classifying a piece with a single colour.

My application aims to solve this problem by playing a single note and also gives the user a wider range of colours to choose from. It includes 12 different colour hues with 5 different shades of each hue, resulting in 60 colours with another 4 colours added – white, grey, dark grey and black – totalling 64 colours.

There are 18 sounds made up of 6 different instruments. Each instrument is played in 3 different registers, and the user has 5 seconds to select a colour before automatically moving on to the next sound. The reason for this is because the reactions experienced in those with chromesthesia are involuntary and automatic and do not require users to think about it.

# 3. Development Environment

In this section I will talk about the research conducted on various programs and programming languages that were used to create the application. I will look at the benefits and disadvantages of possible options and also evaluate the options to come up with the most suitable.

## 3.1 Relational Database Management Systems

A Relational Database Management System, RDBMS for short, is a “database management system that is based on the relational model as introduced by E.F. Codd” (tutorialspoint.com). According to E.F. Codd, the RDBMS is superior to other models in several respects (Codd E. F., 1970). The relational model is considered superior as it sorts data into tables. Each table contains a primary key which can be used to reference the table with another table in the database. This allows the creation of relationships between tables, linking data together.

### 3.1.1 SQLite

SQLite is a relational database, released in 2000. It exists as a file inside the application it serves as opposed to running independently (Owens, M. and Allen, G., 2010). As the file resides in the application, there is no configuration or administration required. It also allows the database to be accessed via terminal, allowing direct access to tables and data. This means SQL queries can easily be carried out on the database, allowing data to be updated, inserted or analysed using the relevant query. According to Owens, SQLite was designed to be portable and accessible across many platforms without configuration changes. It is also compact, lightweight and self-contained (Owens, M. and Allen, G., 2010).

### 3.1.2 MySQL

MySQL is a database system that is used on the web and runs on a remote server. Unlike SQLite, a database file is not stored with the application it is used for. Applications remotely access the server using login credentials which the application uses. MySQL thrives in situations where the database experiences many reads and few writes. It is fast and reliable and can meet the demands of internet speed (Suehring, S. 2002).

### 3.1.3 Evaluation of Relational Database Management Systems

SQLite and MySQL both provide benefits to help a web application run fast and smooth. SQLite uses a single file allowing the database to be portable and easy to access. SQL queries are also easy to execute, allowing for easy manipulation of data when needed. Database files can be duplicated and altered without causing disruptions or changes in the main database. The file-based database also allows for easy testing on the database.

MySQL includes a visual GUI on its server, making it easier to user and navigate. It is also considered to be faster and more secure with built in security features. However, the configuration required in the set-up of MySQL could result in complications with the connection to database if the password was to be altered or changed.

In conclusion, I have opted to use SQLite as the file-based system and the ability to duplicate the database file and carry out tests on the database has meant that the application was easier to create. In future iterations, MySQL may be considered if the project were to scale up due to the speed and other benefits it offers.

## 3.2 Server-Side Scripting Languages

“The main idea behind scripting languages is their dynamic nature, that allows them to treat data as a program and vice versa” (Kanavin, A., 2002). Server-side scripting languages are designed so the process runs on the server side rather than the client side. This helps keep control of the source code as it is unavailable to clients, preventing the manipulation of code on the client side.

### 3.2.1 Python

Python is an easy to write and expressive language, allowing fewer lines of code needed to be written for an application compared to another language, such as Java. It is a cross-platform language that can run on many different platforms such as Windows, Linux or Mac OS X. One of its greatest strengths is that it comes with a

complete standard library allowing multiple functions to be achieved with only a few lines of code (Summerfield, M., 2010).

### 3.2.2 Java

Java is a “general-purpose, concurrent, class-based, object-oriented language” (Gosling, J., 2000). It is a strongly typed language, unlike python, meaning that each declared variable needs to have a pre-determined type – such as string, int or boolean. The design goals for Java are for the language to be simple, object oriented and familiar; robust and secure; architecture neutral and portable; high performance; interpreted, threaded, and dynamic (Gosling, J. and McGilton, H., 1995).

### 3.2.3 Evaluation of Server-Side Scripting Languages

In conclusion, I have opted to use Python as the programming language of choice. Python provides a quick and easy to use language and allows many complex functions of the website to be executed in fewer lines of code than Java. This results in a cleaner and easier to understand application, which is also easy to adjust for future iterations.

## 3.3 Client-Side Scripting Languages

Client-side scripting languages are used to write lines of code that run on the client’s machine. This code is accessible and viewable to the user, and therefore isn’t used to interact with objects on the server side. Client-side scripting allows for the building of interactive web pages that do not need to interact with the server side for each event (Meijer, E., Leijen, D. and Hook, J., 1999).

### 3.3.1 Hyper Text Mark-up Language (HTML)

HTML is used to create static web pages. It uses elements to build the website and define the content of the web pages. Browsers run HTML code to render the content of the page.

### 3.3.2 JavaScript and JQuery

JavaScript is used alongside HTML to create dynamic web pages through interactions and events between the client and web page. JQuery is a JavaScript library designed to simplify client-side scripting of HTML (Wikipedia).

### 3.3.3 AJAX

Ajax allows web applications to send a retrieve data from a server while a web page is active. It interacts with the server in the background without changing the state of the page. The data can be accessed using JavaScript to dynamically display the new information. This is useful when the requirements of a web page involve displaying updated information to the user without refreshing or reloading the page.

### 3.3.4 Cascading Style Sheets (CSS) and Bootstrap

CSS is used with HTML and JavaScript in the creation of web pages. CSS is used to present a web page in the desired format. It allows HTML elements to be positioned and formatted however the programmer desires on the web page. It can be used to control the layout of multiple web pages without repeating code (w3schools). Bootstrap is a front-end library that contains HTML and CSS based design templates for multiple interface components on a web page (Wikipedia). It allows for consistent design over all pages using the CSS classes provided by bootstrap.

## 3.4 Web Framework

Web frameworks are designed to support the development of web applications. They provide tools which act as a base for the application to be built upon. It allows developers to use the tools provided by the framework to add various elements to their web application without having to create it themselves.

### 3.4.1 Django

Django is an example of a web framework. It is “a high-level python web framework that encourages rapid development and clean, pragmatic design” (djangoproject.com). It allows for easy creation of web applications created in python, providing various tools aiding with development.

### 3.5 Additional Programs

This section will briefly explore the additional programs that were used during the project.

#### 3.5.1 OpenShift

Openshift is used to deploy the web application and make it available to the public. Openshift is a container application that “automates the provisioning, management and scaling of applications” (openshift.com).

#### 3.5.2 Visual Paradigm

Visual Paradigm was used to create an entity relationship diagram. An entity relationship diagram is “a database design tool that provides graphical representation of database tables, their columns, and inter relationships” (visual-paradigm.com).

#### 3.5.3 GarageBand

GarageBand was used to create the sounds used in the test. GarageBand is a music creation application equipped with “a complete sound library that includes instruments, presets for guitar and voice, and an incredible selection of session drummers and percussionists” (apple.com).

#### 3.5.4 Pencil Project Prototyping Tool

Pencil Project Prototyping Tool was used in the initial stages of design to create a sample interface. The tool is built for the purpose of creating samples of a website in popular desktop platforms (pencil.evolus.vn).

## 4. System Development Life Cycles

This section will cover the system development life cycles that were used during the project. System development life cycles focus on the planning, developing and testing of a system. Each section will cover briefly what the cycle is, and it’s features.

### 4.1 Build and Fix model

The Build and Fix model is the simplest system development life cycle model, “the product is constructed with minimal requirements, and generally no specifications nor any attempt at design, and testing is most often neglected” (Paquet, J. 2013).

This model offers flexibility as it allows the developer to add the necessary features and create further requirements and a design as development progresses. This model was used to start the project as there were minimal requirements for the website. It allowed for developing as requirements became clearer and easy adjustments and updates to existing features.

### 4.2 Increment Implementation model

The model consists of multiple development cycles, divided into smaller, easier managed modules (Kumar, S). This model allows the developer to focus on smaller sections of the project at once. This makes work seem smaller and easier to manage. Modules are also completed to a suitable standard, so they do not need to be revisited and improved, unless the requirements change.

## 5. Project Analysis

This section will cover the requirements of the project and how they were gathered. Requirements are an important tool for every project as they give the developer clear aims and targets that need to be met for the website to be functional. Requirements also help to create a more user-friendly design.

### 5.1 Requirements Gathering

For this project, requirements were gathered using focus groups, observations and prototyping.

#### 5.1.1 Focus Groups

Focus groups involved the supervisor of the project along with peers in the same year group. The project was displayed to them in order to gather feedback on its usability and overall design. Requirements were adjusted or added according to the

feedback from the focus group. Feedback was focused on the design of the website as opposed to its usability due to the focus group being held in the early stages of the project.

### 5.1.2 Observations

Observations were carried out during use of the website by users. Verbal feedback was received to help improve the usability of the website, its ease of use and navigation. This involved minor changes to the design to make features clearer and the flow of the website easier to follow.

### 5.1.3 Prototyping

Prototypes were created and presented to users during different stages of development, for example when a new feature was added. This allowed feedback to be received on the new feature, such as how easy it was to find or use, and whether it was beneficial to the user.

## 5.2 Requirements Specification

This section will list the requirements for the project. It will list functional requirements, and non-functional requirements. Functional requirements present how the system will function from the user's perspective, and non-functional requirements specify the attributes of the system rather than what the system will do (McEwan, S., 2004).

### 5.2.1 Functional Requirements

Requirements for the user:

1. Users should be able to sign up, log in and edit their profile details
2. Users should be able to choose the attempt they wish to complete
3. Users should be able to hear sound clips clearly and on time
4. Users should be able to select a colour for each sound clip
5. Users should be able to view the results page after attempts have been completed

Requirements for the admin:

1. Admin should be able to view all accounts currently signed up

2. Admin should be able to view the results page for each account

Requirements for the database:

1. Store all user details
2. Store all colour details
3. Store all sound details
4. Store all attempt details for both attempt one and two

### 5.2.2 Non-Functional Requirements

1. Users should be able to see the sign up and log in buttons clearly on home page
2. Users should be provided the necessary information on the topic
3. Users should be able to navigate through the website with ease
4. Users should be able to easily find the start and choose their attempt
5. Users should be able to easily identify the colours available to them
6. Users should be able to find the results page
7. Users should be able to understand the results shown to them on the results page

# 6. Design

This section will focus on the design of various elements of the project. It will look at the database design, using an entity relationship diagram; and the application design in the build and fix stage and iterative development stage, with images to demonstrate the development.

## 6.1 Database Design

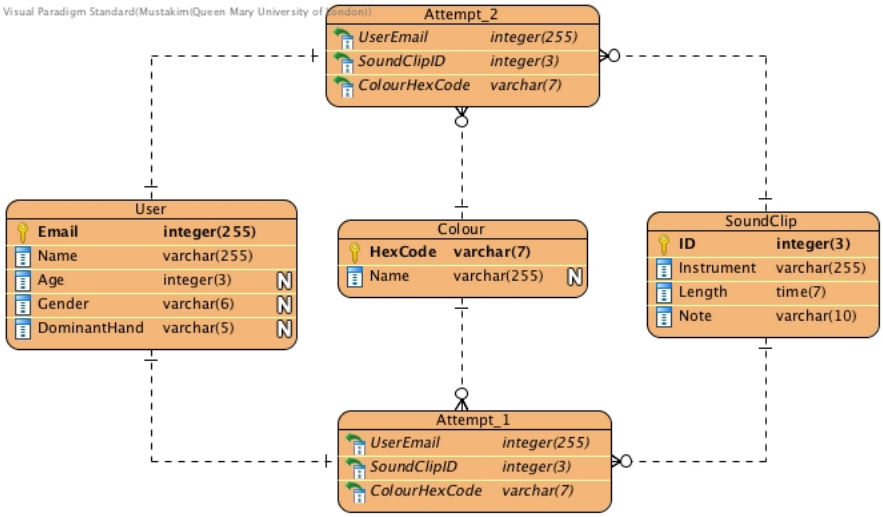


Figure 5 – Database Entity Relationship Diagram

This is a design of the database tables. The database will have 5 tables. The ‘User’ table will hold all user information. The email will be a unique value, and along with it will be stored all other relevant information for the user. The ‘Colour’ table will hold the hex code for each colour and the name of the colour to easily identify it. The ‘SoundClip’ table will hold a unique ID for each sound, it will also hold the instrument being played, the length of the sound and the note played on the instrument. There will also be ‘Attempt_1’ and ‘Attempt_2’ tables. These tables will hold the unique values from each of the 3 tables as a single entry for each selection made. This would allow for easy analysis of data as queries could be made to check trends in the data, such as checking the results in attempt 1 for a user or checking the results in attempt 1 for one of the sound clips.

## 6.2 Application Design

### 6.2.1 Build and Fix Phase

This section will look at the development that took place during the early stages of the project. For this phase, the Build and Fix model was used.

### *6.2.1.1 Home Page*

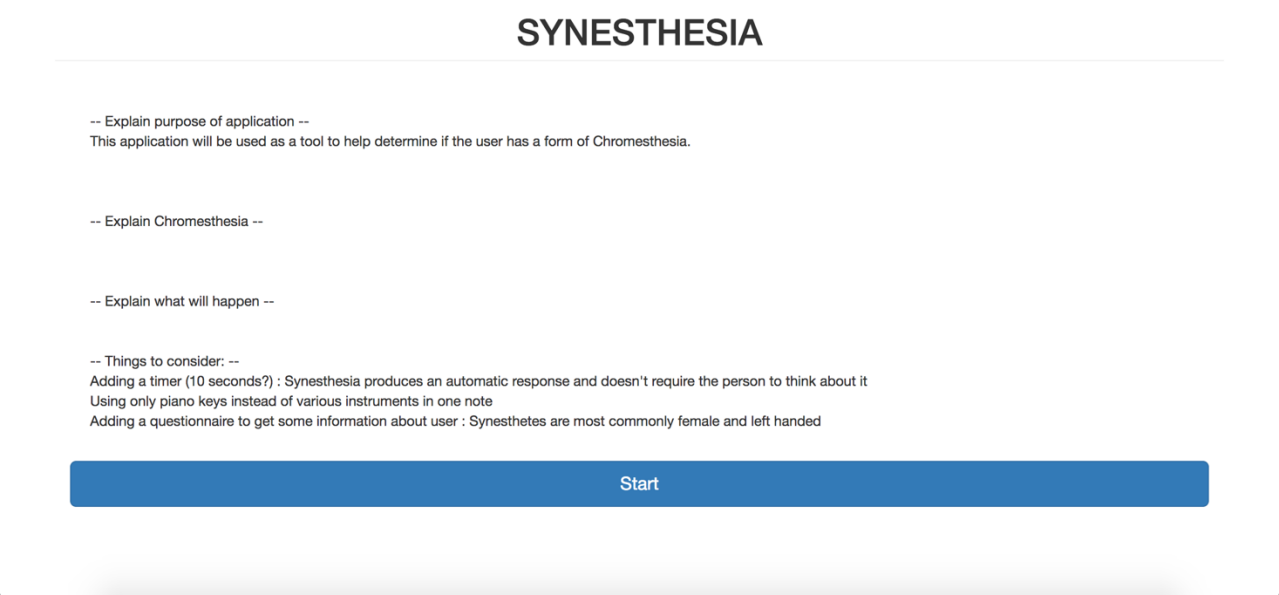


Figure 6 – Sample Home Page

This is a representation of the homepage. On this page, there will be an explanation of what the application aims to achieve and its purpose. It will also explain chromesthesia to the user. The reason for this is so that the user can continue to use the application understanding what the application is looking for as well as raise awareness of the condition. The home page will also explain what the user can expect to happen in and the steps to follow.

### *6.2.1.2 Main Sound Pages*


Figure 7 – Sample Sound Page

This is a sample of the sound clip page. Each page would tell the user the sound clip they are on so they can track their progress as they use the application. It will provide an audio bar for the user to see the kind of sounds they can expect in the application and the set of colours that are available to them. The page currently features 24 colours of different hues. Due to the experimental phase, it also features a colour wheel to give users a wider variety of colours to choose from, as well as changing the shades of colours chosen. Users are also required to submit their choice before moving on to the next page.

#### *6.2.1.3 Sign up*

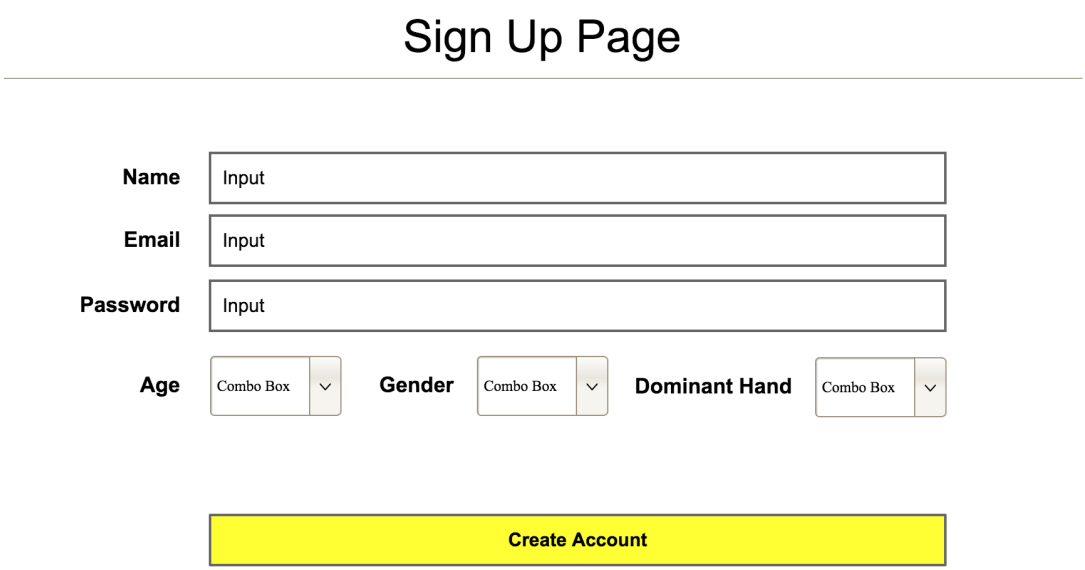


Figure 7 – Sample Sign Up Page

This is a design of the sign-up page. Each user will be required to create an account before using the application. The reason for this is to allow tracking of the user's results. These results will be used to provide analysis of the user's selections from two different attempts. The page asks for the user's name to identify the user, an email as a unique log in, and a password to secure their account. It also asks for their age, gender and dominant hand as research has shown that these factors play a role in determining whether the user is likely to have chromesthesia or not.

#### *6.2.1.4 Login Page*

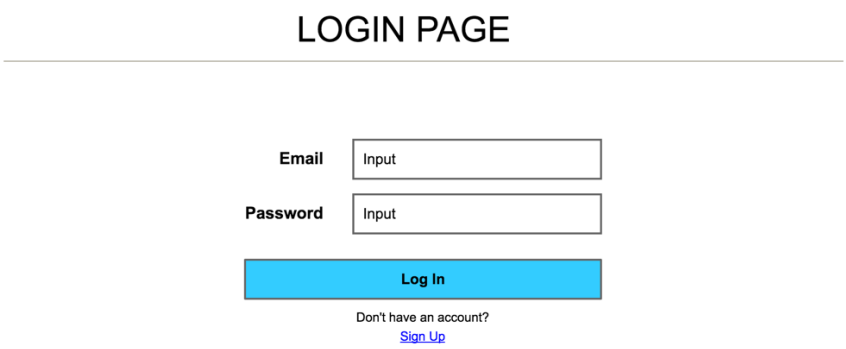


Figure 8 – Sample Login Page

This is a design of the login page. It asks for the email of the user as this is the unique identifier for each account. Each email can only be used once when signing up. The page also provides a link to redirect to the sign-up page, should the user not already have an account.

### 6.2.2 Iterative Implementation Phase

This section will look at the development that took place during the later stages of the project. For this phase, the Iterative Implementation model was used.

#### *6.2.2.1 Iteration 1*

During this iteration, the sound pages were the main focus. These pages are the core of the application and are designed to be simple to understand and easy to choose from, whilst also providing the user with enough choice.

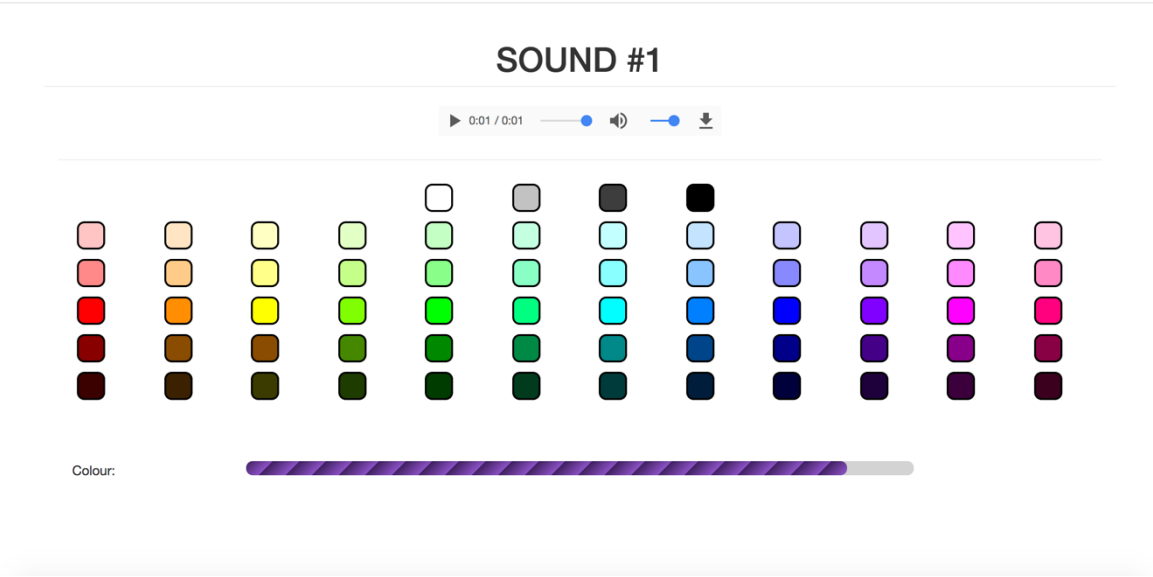


Figure 9 – Sound page

The page features 64 colours, as opposed to the 24 from the previous phase. The colours are divided into 12 different hues, with 5 shades of each hue not including white, grey, dark grey and black. This provides the user with the choice of selecting a colour based on hue while also providing a wider variety of choice with the addition of shades. Shades of a colour are important as they provide the user with the choice to better express the colour they see or feel that best relates to the sound.

The page also features a timer in the form of a loading bar. When the bar fills up, the page automatically moves to the next page. This is an improvement from the previous build as there are fewer buttons to press. The design of the loading bar also helps differentiate it from the changing background colours.

#### *6.2.2.2 Iteration 2*

This iteration focused on the login, sign up and edit profile pages. These pages are required to be simple and easy to complete. Sign up should take no longer than a minute in order to not deter users from completing the process.

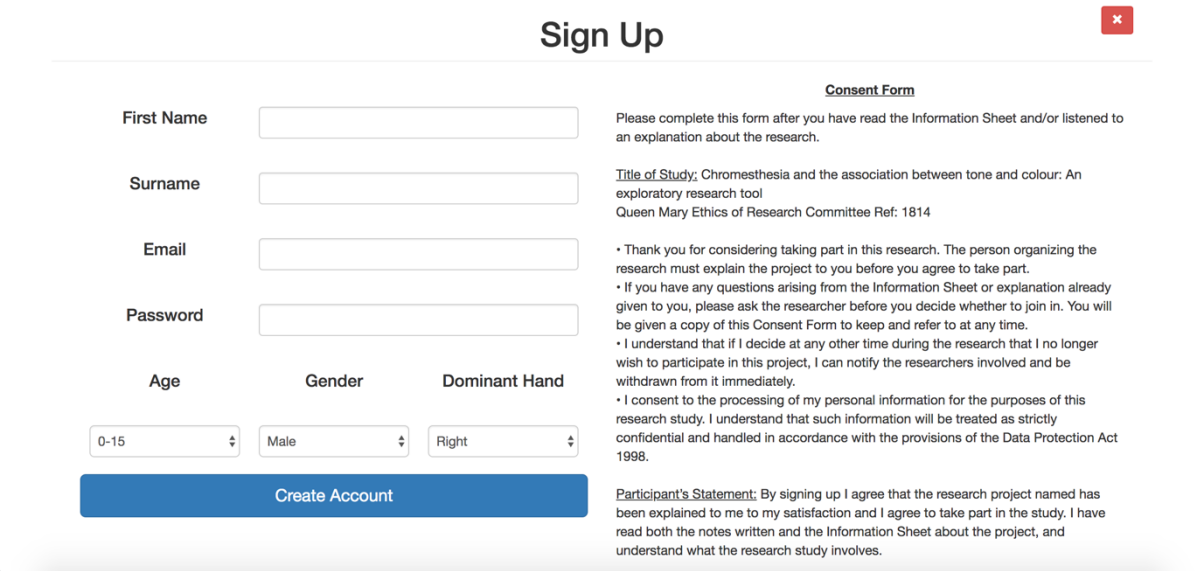


Figure 10 – Sign Up Page

The sign-up page is accessible from both the home page, and the login page of the website. It features an exit button which returns the user to the home page of the website. The input fields are similar to the design in the previous phase, however the name field was separated into two fields, first name and surname. This was to make it clearer of what was expected. This page also features a consent form for the user to read before signing up.

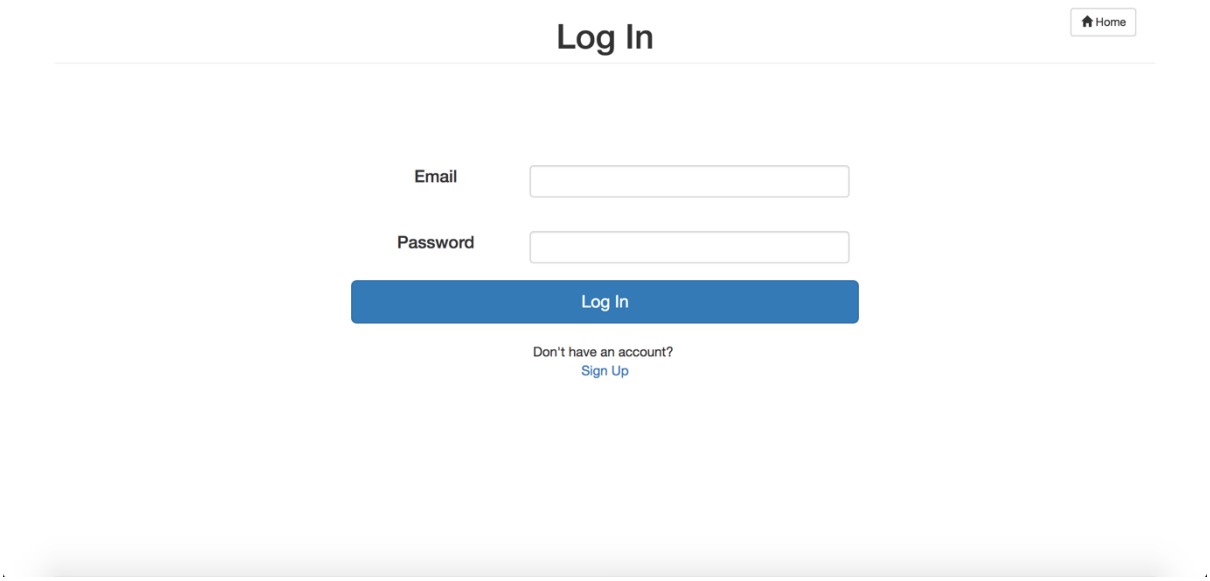


Figure 11 – Login Page

The login page is similar to the previous phase with the addition of a home button to allow the user to return to the home page. This page is designed to be simple without many complicated or distracting features.

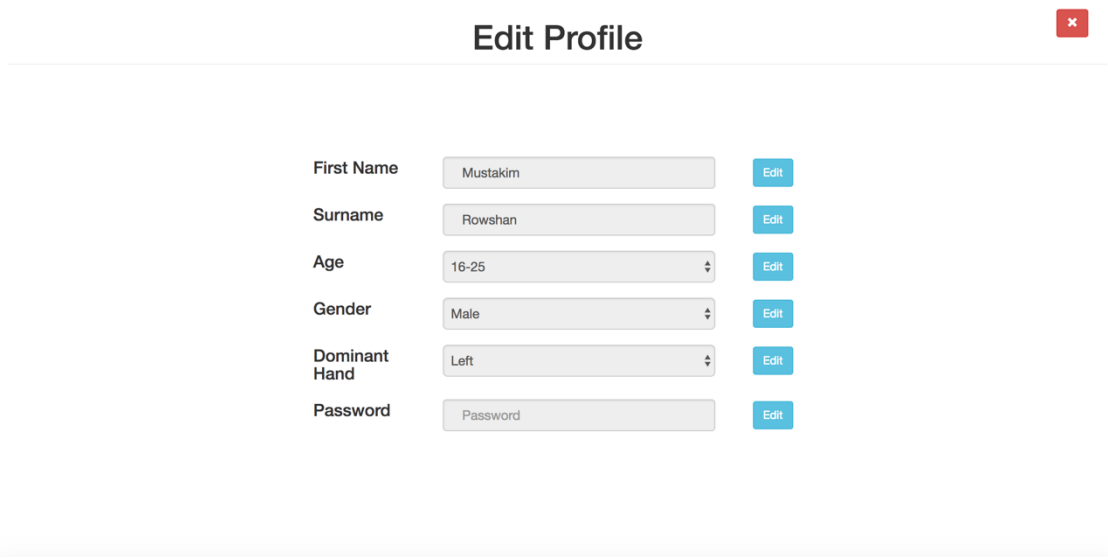


Figure 12 – Edit Profile Page

The edit profile page allows the user to edit the details they signed up with. This could be to alter any mistakes made during sign up or update information. The email is un-editable as it is used as an identifier. This page allows the user to update all of the information they signed up, except email, using simple edit and save buttons. Each field is un-editable on entry; the user is required to click the edit button for the field they wish to edit. This makes the field editable and the edit button is replaced with a save button. For the password field, the user is required to enter their current password before they can enter a new password. The user is also required to confirm their new password before they can save.

#### *6.2.2.3 Iteration 3*

This iteration focused on the results page and displaying information back to the user after they have completed both attempts.

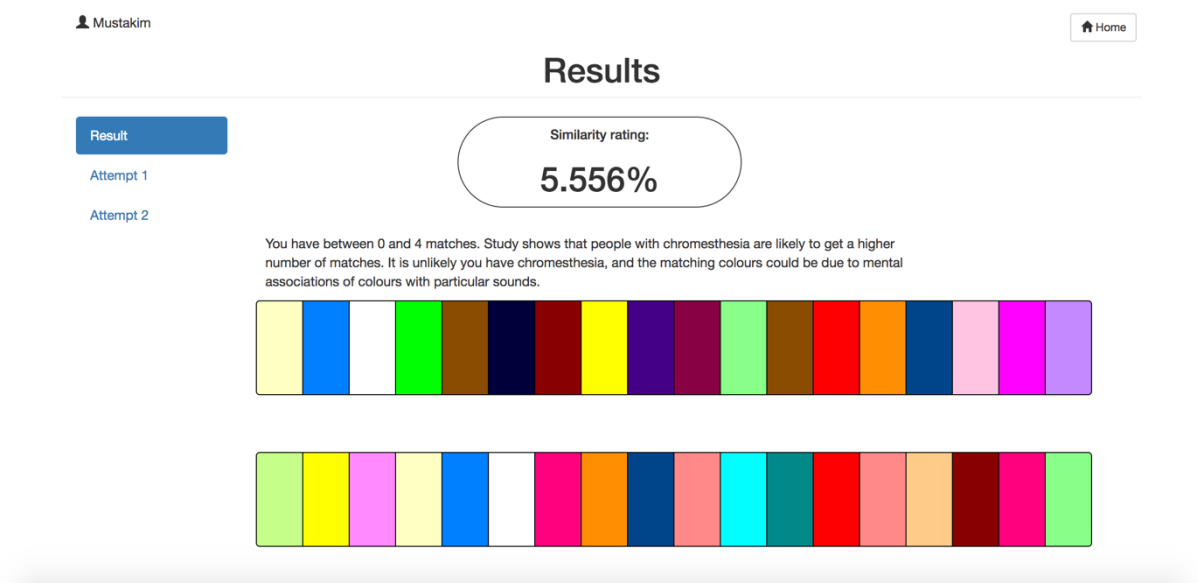


Figure 13 – Results Page

This page shows the users name and a home button for the user to return to the home page in the top corners of the page. It has a navigation tab displaying the overall results, and results for attempt one and two individually. The results tab shows the similarity rating between the two attempts. The similarity rating increases when the user has colours matching between the two attempts for the same sound.

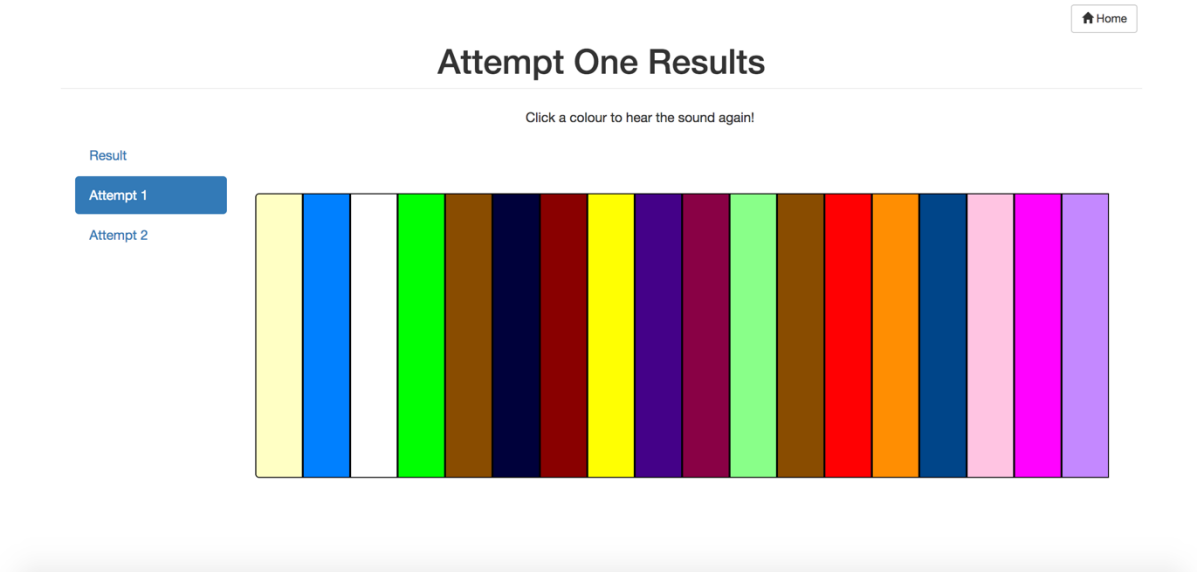


Figure 14 – Attempt One Tab on Results Page

The individual results pages feature a keyboard like display with all the colour selections. Users can click each colour to hear the sound again if they would like to review their colour choices.

#### *6.2.2.4 Iteration 4*

This iteration focused on the home page and the welcome page for the website. These are the first pages the user sees, so they are required to be inviting but also informative for the user.


Figure 15 – Welcome Page

The welcome page is the first page the user sees upon visiting the website. It features a colourful background with the name of the research topic in the centre. The page also features a button which allows the user to continue to the home page of the website. The page is designed to be colourful and inviting.

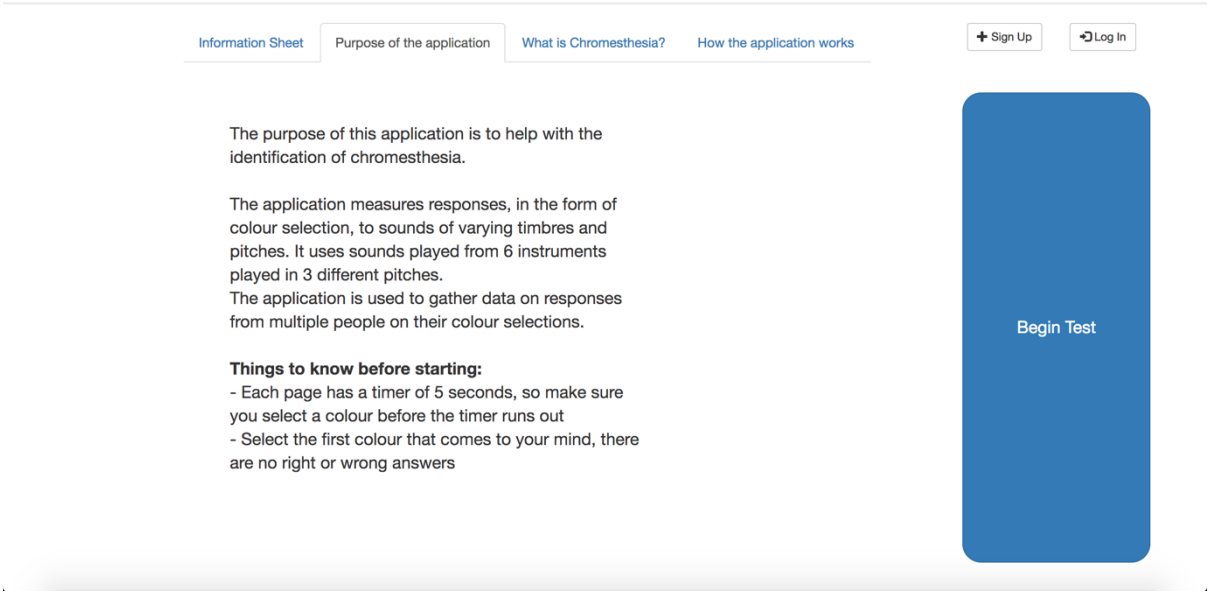


Figure 16 – Home Page when Logged Out

This is the home page that is seen by users that are not logged in. It features 4 tabs to provide users with all the information they need if they wish to learn more about the application or the condition. It also features an information sheet with a summary of the project. The button has a sign up and log in button as users are required to have an account before starting the project. The begin test button directs users to the sound sample page. This page prompts visitors to log in if they are not already.

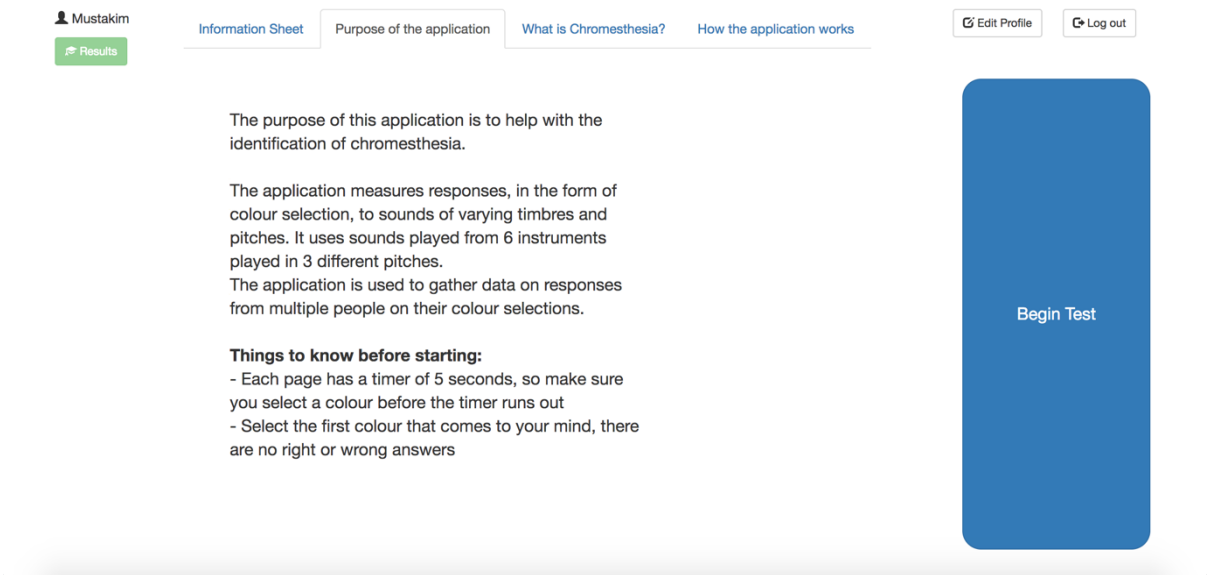


Figure 17 – Home Page when Logged In

This is the home page seen by users after the log in. If features the same content as the home page for users not logged in. It has the user's name in the top corner to identify who is logged in, it also has a results button which is unavailable if the user hasn't completed both attempts. This page also replaces the sign up and log in buttons with edit profile and log out.

#### *6.2.2.5 Future Iterations*

Future iterations of the website will involve adding more functionality to the website so that it can be self-serving and work independently. Due to time constraints, this could not be achieved.

Planned features include adding email functionality along with a verification service. Users would be required to verify their email upon signing up. They would still have access to both attempts and would be able to complete them without verification. However, unverified accounts would be unable to view the results at the end. The reason for this would be to encourage users to sign up with real emails. This would also lead on to the website using the email functionality to send out a notification email to the user. The email would remind the user that the two weeks waiting time between attempts is over, and the user should complete attempt two if they wish to.

The website should also have a timer feature, whereby the time of completion for attempt one is recorded. The website can then automatically calculate when the next attempt should be available to the user and store this value in the database. The button to access the attempt would be locked until the current time matches the time stored in the database. This will ensure that users can only access attempt two after the two-week period has passed.

## 7. Implementation

This section will cover the implementation during different iterations of the project development phase. Areas of the project covered in each increment are highlighted in the design section. Here we will analyse some of the code and the difficulties faced during development.

## 7.1 Build and Fix Phase

This section will cover the implementation that occurred during this phase. This section will focus on setting up the database with all the relevant tables and database connectivity. It will also look at the application being hosted online to be made publicly available.

### 7.1.1 Database

The database was created and updated throughout the lifetime of the project. This was because as data was added, from adding sound and colours to adding users and user attempts, changes were made to make the communication between the website and database easier. The database was created using Django's model. Each model represents a table, with columns and data type.

```
# User model
class User(models.Model):
    email = models.CharField(max_length=100, primary_key=True)
    firstname = models.CharField(max_length=255)
    surname = models.CharField(max_length=255, default='')
    age = models.CharField(max_length=255)
    gender = models.CharField(max_length=30)
    dominanthand = models.CharField(max_length=30)
    password = models.CharField(max_length=255, default='')
```

Figure 18 – Code for Creating User Table

Django uses the code shown in the figure above to create tables in the specified database file or location. In this case, the SQLite file. Tables, and contained data, can be viewed on Django's admin page by registering the database to the website.

```
# Register models to admin page
admin.site.register(User, UserAdmin)
admin.site.register(Colour, ColourAdmin)
admin.site.register(Sound, SoundAdmin)
admin.site.register(AttemptOne, AttemptOneAdmin)
admin.site.register(AttemptTwo, AttemptTwoAdmin)
```

Figure 19 – Registering Tables to Admin Page

### 7.1.2 Hosting the Application Online Using OpenShift

The application was hosted online using an open source container application that supports applications developed using Django. It is also supported by QMUL, hence why it was the primary choice. The application was hosted on the OpenShift server by following the instructions provided on the website with all the relevant details. The files are accessed and updated using GitHub's cloning and pushing features.

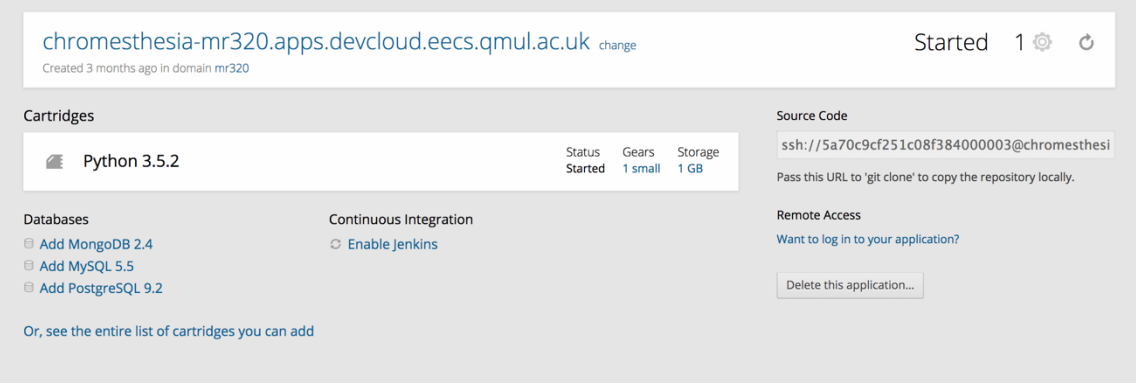


Figure 20 – Application on OpenShift

## 7.2 Iterative Implementation Phase

This section will focus on the implementation covered during each iteration of the project. It will focus on the pages and the development behind them as well as future implementation prospects of the application.

### 7.2.1 Iteration 1

This iteration focused on the sound pages. They were the primary focus of the website as these are the pages that collect data from the user and the pages the user will spend the most time interacting with. The requirements for this page were clear; each page was required to play a sound on loading, allow the user to select a colour, switch the background to the selected colour, and finally upload the selected colour to the database. This presented the issue of learning how to submit the colour selection at a particular time as opposed to when a colour is selected. This is important as the user should not be able to submit multiple colours by selecting multiple colours for one sound. After research on JavaScript and jQuery methods, the setTimeout() function allowed me to submit data after a set period of time.

```
// On document load run this function
  $(document).ready(function()
  {
    // Run the function 'sendcolour()' after 4990ms or 4.990seconds
    setTimeout(function()
    {
      sendColour();
    },4990);
  });
```

Figure 21 – Function to Send Colour to Database

### 7.2.2 Iteration 2

This iteration focused on the login, signup and edit profile pages. These pages are a vital part of the application as users are required to have an account before completing the tests, therefore it is important that the pages are able to properly communicate with the database to send and retrieve information. Forms are used to collect user input, which is sent to the back end to be uploaded to the database. Before the input can be uploaded to the database, it needs to be sanitised and verified. This is so that special characters cannot be entered into the database. Special characters can be used to attack the website, such as through SQL injections. Regular expressions are used in order to make sure that users cannot enter some specified special characters.

```
// Input sanitisation - prevent people signing up with these characters
if (fn.match(/[<>'"",!;,:\]\[]/i) || sn.match(/[<>'"",!;,:\]\[]/i) || em.match(/[<>'"",!;,:\]\[]/i) || pw.match(/[
  <>'"",!;,:\]\[]/i))
{
    alert("Special characters are not allowed")
    return false;
}
```

Figure 22 – Input Sanitisation on Sign Up Page

### 7.2.3 Iteration 3

This iteration focused on creating the results pages to accurately display the results back to the user and show them a similarity rating. It does this by going through both tables simultaneously and comparing the values for each sound. It then adds a fixed value to a variable every time a colour matches between both attempt tables for a single user.

```python
# Main results page
@loggedin
def adminresults(request):
    ue = request.session['uemail'] # Get email from session
    # Get colourOne tuples(rows) from table where the column userOne = email
    aOne = AttemptOne.objects.filter(userOne=ue).values_list('colourOne', flat=True)
    # Get colourTwo tuples(rows) from table where the column userTwo = email
    aTwo = AttemptTwo.objects.filter(userTwo=ue).values_list('colourTwo', flat=True)
    percent = 0 # Initialise percent variable
    # For each entry in table one and two
    # zip() ends the for loop at the shortest table (when there are no more entries in a table)
    for colOne, colTwo in zip(aOne, aTwo):
        # If the two colour values match from both tables
        if colOne == colTwo:
            # Add value to the percent variable
            # This value is equal to (1/18)*100 to 11 decimal places
            percent += 5.55555555556
    # Round the final result to 3 decimal places using the round(value, decimal places) method
    percent = round(percent, 3)
    getresultsOne = AttemptOne.objects.filter(userOne=ue).values_list('colourOne', flat=True)
    getresultsTwo = AttemptTwo.objects.filter(userTwo=ue).values_list('colourTwo', flat=True)
    # Pass the value to the page
    return render(request, 'admin/adminResults.html', {'firstname': ue, 'percent': percent, 'getresultsOne': getresultsOne, 'ge
```

Figure 23 – Calculating Percentage Similarity from Result Tables

### 7.2.4 Iteration 4

This iteration focused on the home and welcome page. These pages do not need to communicate with the backend or take in user input, therefore they were low priority pages. The home page features if statements from the Django framework in the html template to differ the content shown based on if a user is logged in or not.

```
{% if loggedin %} <!-- If user is logged in, run this code -->
<div class="row">
  <br>
  <!-- Buttons on the top right corner -->
  <!-- Logout button with bootstrap icon -->
  <button type="button" class="btn btn-default btn-sm logInOut" onclick="logout()">
      <span class="glyphicon glyphicon-log-out"></span> Log out
  </button>
  <!-- Edit profile button with bootstrap icon -->
  <button type="button" class="btn btn-default btn-sm editProfile" onclick="editProfile()">
    <span class="glyphicon glyphicon-edit"></span> Edit Profile
  </button>
```

Figure 24 – Using Django's HTML If Statements

The function 'loggedin' checks for an email in the current session to determine if a user is logged in.

```
# Decorator function, mark user as logged in
def loggedin(f):
    def test(request):
        if 'email' in request.session:
            return f(request)
        else:
            return render(request, 'base.html')
    return test
```

Figure 25 – Function to Check If User Is Logged In

### 7.2.5 Future Iterations

For future iterations, additional functionalities such as emails will be considered. The application will need to be connected to an email account, as shown in the figure below.

```
# Email
EMAIL_BACKEND = 'django.core.mail.backends.smtp.EmailBackend'

# Host for sending e-mail.
EMAIL_USE_TLS = True
EMAIL_HOST = 'smtp.gmail.com'
EMAIL_PORT = 587
EMAIL_HOST_USER = 'synesthesia.mr320@gmail.com'
EMAIL_HOST_PASSWORD =
```

Figure 26 – Settings to Connect to Email Account

The application will also need to be able to send emails to user. An example of this is shown below to demonstrate the feature. The figure below shows the email content that is to be sent to the user after they sign up. The link given to the user will allow them to verify their account.

```
# Add email and firstname to session
request.session['email'] = e;
request.session['firstname'] = fn;
# Set subject of email, sender and receiver
subject, from_email, to = 'Verify your account', 'synesthesia.mr320@gmail.com', e
# Plain text version of email if user cannot view html content
text_content  = 'If there is no link to the page, reply to this email to verify your account or visit this link '
text_content += 'http://chromesthesia-mr320.apps.devcloud.eecs.qmul.ac.uk/verify/effce4b9b850453984689a1c18adb6fa.'
# Html content of email with link to verify account
html_content =  '<strong>Thank you for signing up!</strong> '
html_content +=  '<br><br>'
html_content +=  'Verify your email address to complete account set up. '
html_content +=  '<br><br>'
html_content +=  '<a href="http://chromesthesia-mr320.apps.devcloud.eecs.qmul.ac.uk/verify/effce4b9b850453984689a1c18adb6fa"><button>verify</bu
html_content +=  '<br><br>'
html_content +=  'If you have not signed up to http://chromesthesia-mr320.apps.devcloud.eecs.qmul.ac.uk/ '
html_content +=  'please ignore this email.'
# Send text content of email
msg = EmailMultiAlternatives(subject, text_content, from_email, [to])
# Attach alternative html content of email if applicable
msg.attach_alternative(html_content, "text/html")
# Send email
msg.send()
```

Figure 27 – Content of Email

## 8. Results

This section will display the results gathered from the application. It will display the results in tables and graphs. As there are 25 users with 36 different colour selections, all 900 inputs cannot be shown. Therefore, this section will display the percentage similarity results gathered from each user, and the user's gender, dominant hand and age.

| ***Users*** | **Percentage** | **Age** | **Gender** | **Dominant Hand** |
|---|---|---|---|---|
| *User 1* | 11.111% | 46-55 | Female | Right |
| *User 2* | 5.556% | 16-25 | Male | Right |
| *User 3* | 11.111% | 16-25 | Male | Right |
| *User 4* | 5.556% | 16-25 | Male | Right |
| *User 5* | 5.556% | 16-25 | Male | Right |
| *User 6* | 0.000% | 16-25 | Male | Right |
| *User 7* | 16.667% | 16-25 | Male | Right |
| *User 8* | 38.889% | 16-25 | Female | Right |
| *User 9* | 0.000% | 16-25 | Male | Right |
| *User 10* | 27.778% | 16-25 | Male | Right |
| *User 11* | 16.667% | 16-25 | Male | Right |
| *User 12* | 11.111% | 16-25 | Male | Right |
| *User 13* | 0.000% | 16-25 | Male | Right |
| *User 14* | 27.778% | 26-35 | Male | Left |

| | | | | |
|---|---|---|---|---|
| *User 15* | 22.222% | 16-25 | Male | Right |
| *User 16* | 22.222% | 46-55 | Female | Right |
| *User 17* | 5.556% | 46-55 | Male | Right |
| *User 18* | 0.000% | 26-35 | Female | Left |
| *User 19* | 5.556% | 16-25 | Female | Right |
| *User 20* | 11.111% | 16-25 | Male | Left |
| *User 21* | 5.556% | 16-25 | Male | Right |
| *User 22* | 5.556% | 16-25 | Male | Right |
| *User 23* | 0.000% | 16-25 | Male | Right |
| *User 24* | 0.000% | 16-25 | Male | Right |
| *User 25* | 0.000% | 16-25 | Female | Left |

Figure 28 – Table of User Percentages and Details

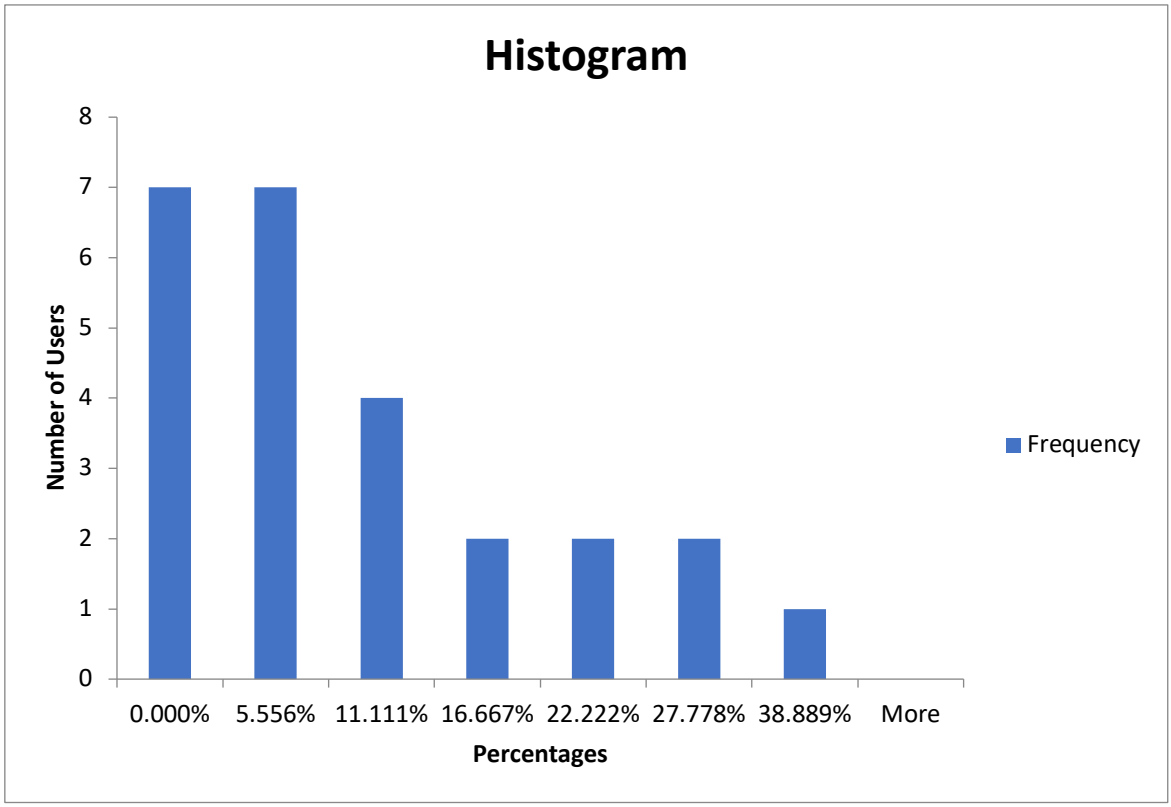


Figure 29 – Histogram Showing Percentage Distribution Amongst Users

Using Excel, and the formula's provided by Excel, the most common colour for each sound was calculated based on user results. The following formula was used:

=INDEX (M3:M27, MODE (MATCH (M3:M27, M3:M27, 0))), where M3:M27 represents all colour choices for a particular sound ID.

| *Sound ID* | Attempt One | Attempt Two |
|---|---|---|
| *2* | #ffff00 | #e2c4ff |
| *3* | #89ffc4 | #89ff89 |
| *4* | #00ff00 | #89ff89 |
| *5* | #ffffff | #ffffc4 |
| *6* | #89c4ff | #ffcb89 |
| *7* | #004589 | #0000ff |
| *8* | #ff0080 | #ff0080 |
| *9* | #ff8f00 | #ff8f00 |
| *10* | #894d00 | #001e3b |
| *11* | #89ff89 | #ff8989 |
| *12* | #ffff00 | #ffff89 |
| *13* | #894d00 | #003b00 |
| *14* | #ff0000 | #ff0000 |

| | | |
|---|---|---|
| *15* | #c2c2c2 | #c2c2c2 |
| *16* | #ffffff | #3d3d3d |
| *17* | #ff0000 | #ff0000 |
| *18* | #ff8f00 | #ffff00 |
| *19* | #ffff89 | #ffff89 |

Figure 30 – Table Showing Most Popular Colour Choice for Each Sound

# 9. Discussion

In this section we will discuss the results shown above. Discussion will focus on the meaning of results and information that can be inferred from the data.

## 9.1 Evaluation of Results

Figure 28 shows a table of users with the percentage similarity given to them by the application after completing both attempts. The table includes personal information, such as age, but omits information, such as the user's name. Each user has been given a number to be able to refer to them whilst maintaining privacy and anonymity.

The table shows a group of twenty-five users, composed of six females and nineteen males. The majority of participants are within the 16-25 age range with five users outside the mentioned range. The data also displays the dominant hand of each users, of which four are left-handed and twenty-one are right-handed. The table goes on to show the percentage similarity for all users. From these percentages we can see that of the six females, two received results of 0% and the remaining four received results above 5%. Out of all participants, a female user received the highest percentage similarity with 38.889%. From the males, the lowest percentage received was 0% by four users and the highest percentage received was 27.778% by two

users. Of all left-handed users, two received results of 0%, the remaining received a result of 27.778% and 11.111%.

From this data we can see that the range of results are fairly high and vary between users with no clear trends between variables. Research suggests that females are more likely to have chromesthesia than males, which can be seen through the results as the highest percentage received was by a female user. However, the quantity of users and difference between user groups means that a clear trend or cause cannot be justified using this data alone. Further tests will need to be conducted with larger user groups in order to get a clearer insight.

Figure 29 displays percentage distribution amongst all users. It displays the frequency of users to get each percentage value recorded in figure 28. From this data we see that seven users received a score of 0%, and another seven received a result of 5.556%. These percentage values represent 0 and 1 match out of 18 respectively.

From this we can understand that out of twenty-five users, the majority had only 0 or 1 match. This can justify research that mentions chromesthesia is a rare condition occurring in only 1 in 200,000 people approximately. The remaining users received similarly low scores, with a declining frequency of users as the percentage increases. As none of these percentages are particularly high enough to give proper justification that a user has chromesthesia, we can assume that none of the participants had chromesthesia. Similar to above, in order to receive a better understanding of results more participants will need to be tested using the application.

Figure 30 displays a table not related to chromesthesia. This table displays the most chosen colours for each sound clip based on user choices. This can provide insight into the types of colours people see when introduced to sounds of various tones. This can benefit research into chromesthesia as it can help further understanding on the colours chromesthetes see and whether it is influenced by past experiences. Colours chosen by non-chromesthetes can be assumed to be due to past experiences or associations of sounds with objects of a particular colour. An

example may be relating the sound of a ship's horn to the colour blue as it reminds users of the ocean.

Through the colours displayed in the table we can see some similarities between the two attempts and deduce the colours most people are likely to see due to sound-colour associations. This can aid future research on chromesthesia and provide insight into the colours chromesthetes see, and if it is influenced in a similar way.

The table shows that sounds with ID's 2 to 6 lead users to choose lighter colours with a softer shade. The 5 sounds are played by two different instruments named "classic-clean" and "classic-electric-piano", a guitar and piano respectively. The sounds produced by these instruments can be assumed to be mellow sounds which leads users to select colours that are not too harsh, such as bright or dark colours. The next sound, with ID 7, was also produced by the piano instruments however lead users to choose a darker blue colour. This can be assumed to be due to the low pitch the sound was played on. From sound 14 to 19 we can see that users chose mostly the same colours for both attempts. This could be due to associations with the sounds present for this section of the test. The colours chosen are bright colours, particularly red orange and yellow. The instruments for the set of sounds are the subby bass and wedding organ. These instruments produce high pitch, loud sounds which causes the user to select brighter, more vibrant colours.

While the results of the test reflected the choice of the user and the overall consensus of colour choice per sound, the test could be improved to produce more reliable and accurate results. Future testing will include revisions of the time given to users per sound page. Currently, users have 5 seconds per page to process all the colours, listen to the sound and select a colour. Whilst the user is able to view all the colours available to them prior to starting the test, the number of colours could cause hesitation in the user's selection. Further analysis into the use of the application will allow for a more optimal time allocation to be delivered to users. The optimal amount of time should allow users to listen to the sound and select the colour they think fits best, however the choice should be instinctive as it is for chromesthetes. Therefore, users should not be given too much time to rethink their colour decisions as this affects the test for chromesthesia.

# 10. Testing

This section will cover the testing of the application which occurred throughout development. It will look into the methods used and the purpose for the testing method. As the application was tested through production, this section will be split into sub-sections to cover the methods used during various stages.

## 10.1 Build and Fix Phase

During this phase, testing focused on connectivity of the database and accessing the application after it had been hosted online.

### 10.1.1 Database Connectivity

Testing during this phase consisted of creating dummy accounts using the sample sign up and login pages created during this phase. At this stage, the login and signup pages were created to be able to access the database. However, they did not check for existing email addresses when users signed up and other features as they had not been fully developed. Users were created, edited and deleted to ensure that the pages were able to communicate with the database.

## 10.2 Iterative Implementation Phase

During this phase, testing was done after each iteration to make sure that the page or pages focused on were fully functional.

### 10.2.1 Iteration 1

This section furthered the testing on database connectivity. It was essential that the pages were quick to communicate with the database when uploading sound selections. Data is uploaded to the database every 5 seconds for each person currently doing the test, for this reason it is important that the database can process each request and not lose data. After testing, it was found that sending data to the database 1ms before the page switch resulted in some data being lost. This was amended by increasing the time to 10ms. Further increases of the time could result in users making split second colour decisions which will not be registered as the page would have already sent the previous selected colour. For this reason, 10ms

was considered to be a fair amount of time although future iterations may revisit this to make the website more efficient.

#### 10.2.2 Iteration 2

This section tested the input validation and text boxes present on each of the login, signup and edit profile pages. Testing involved inputting various combinations of letters and symbols to ensure the website correctly processed and dealt with the input correctly before submitting data.

#### 10.2.3 Iteration 3

This section focused on ensuring the website correctly displayed results from user attempts. It made sure the application was able to communicate with the database to retrieve the data for the user specified and display all their colour choices for the correct sound in the correct order. It was also concerned with being able to display the correct feedback message depending on the users results. This was tested by creating various accounts with multiple result possibilities. This ensured that all, or most, result possibilities were covered, and everyone received the correct feedback.

#### 10.2.4 Iteration 4

This section focused on ensuring that information was properly displayed on the home page. This is important as users should be properly informed and have the information available to them at all times. Testing was done using Django's capabilities to host the application offline on localhost. Additions were added offline to make sure the website displayed the changes before being added to the public website.

### 10.3 Additional Testing

This section will cover the additional testing done on the application after development was completed

#### 10.3.1 W3C Mark-Up Validation

Additional testing was done after the application was completed. This involved using the W3C mark-up validation service. The validator "checks the markup validity of

web documents in HTML, XHTML, SMIL, MathML, etc" (validator.w3.org). Each page was run through the validator and any errors displayed were fixed in order to comply with the mark-up validity

### 10.3.2 Google PageSpeed Insights

Google's PageSpeed Insight (developers.google.com) was used to test the speed and responsiveness of the website. After running the website through the service, it received a score of 61/100 for mobile and 77/100 for desktop. The website was created for desktop with mobile compatibility in mind. However, future iterations will definitely consider improving the website on mobile to make the website more accessible.

### 10.3.3 Nibbler Testing Tool

The Nibbler Testing Tool (nibbler.silktide.com) was used to generate a report on the overall usability and appearance of the website. It scored an overall of 5.3, with individual scores of 8.3 for accessibility, 6.4 for experience, 0.5 for marketing, and 8.0 for marketing. Further scores show a 7.0 for server behaviour, which can be improved by introducing GZIP encoding. It also received a 10.0 for URL format, printability, internal links, images and page titles. From testing done, future iterations can focus on improving the speed of the website through compression and a bigger social media presence.

## 11. Conclusion

This project aimed to create a tool to assist with the self-diagnosis of chromesthesia and also provide a better understanding of the condition itself. It aims to increase understanding of tone-colour associations through data gathering and general use of the application.

From existing applications, such as Palmer's test which had 1040 participants as of 2015, it is visible that increasing the number of participants reveals clearer trends and provides better insight into tone-colour associations. The test could then be further improved if given a few more months to collect a larger array of data to be

examined and analysed. Similarly, the test could be improved by gathering data from users confirmed to have chromesthesia. This will allow data of new users to be compared against chromesthetes to provide a better comparison and similarity threshold when advising users.

The application could be extended to further benefit testing by adding a variety of newer sounds, including sounds heard on a day to day basis as opposed to instruments. The order of sounds could also be dynamic and change order, this will reduce the amount of predictability when re-taking the test, a second time. It will also allow the test to be re-taken multiple times as users will not be able to identify the order of sounds after multiple attempts. More colours could be added to the colour palette to give users a wider variety of choice to better express themselves. Research has shown that chromesthetes do not only see one static colour, therefore patterns could also be added, such as spots or stripes, which can also be coloured to better reflect what chromesthetes experience when listening to sound.

Further improvements of the application could focus on a redesign of the application that follows a more efficient design template which gives users a variety of choices but is also compact enough for the user to be able to quickly process and select their desired choice. Further research into Fitts's and Hick's Law can aid this to provide a more optimal design.

In conclusion, the project has been a success as a tool was created to help with the diagnosis of chromesthesia whilst also providing insight into tone-colour associations. The tool is also publicly available with the elements to provide and deepen understanding of chromesthesia.

## 12. Acknowledgements

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APPENDIX A – Attempt one results for each sound and user

| Colour | Sound ID | Colour | Sound ID | Colour | Sound ID | Colour | Sound ID |
|---|---|---|---|---|---|---|---|
| #ffc4ff | 2 | #89ffc4 | 3 | #00ff80 | 4 | #ffe5c4 | 5 |
| #c4c4ff | 2 | #89ffff | 3 | #0080ff | 4 | #ffffc4 | 5 |
| #c4ffff | 2 | #89ffc4 | 3 | #00ffff | 4 | #c4c4ff | 5 |
| #89ffc4 | 2 | #ff8f00 | 3 | #00ff00 | 4 | #c489ff | 5 |
| #ffc4e2 | 2 | #c4ffc4 | 3 | #00ff00 | 4 | #e2c4ff | 5 |
| #e2c4ff | 2 | #89c4ff | 3 | #008989 | 4 | #ffc4ff | 5 |
| #c4ffe2 | 2 | #ffff00 | 3 | #00ff00 | 4 | #c4e2ff | 5 |
| #c4ffff | 2 | #00ff80 | 3 | #008900 | 4 | #e2c4ff | 5 |
| #008900 | 2 | #80ff00 | 3 | #ff8f00 | 4 | #ffff89 | 5 |
| #c4e2ff | 2 | #89c4ff | 3 | #ffff89 | 4 | #c489ff | 5 |
| #89ff89 | 2 | #00ff00 | 3 | #ffff89 | 4 | #ff89ff | 5 |
| #89c4ff | 2 | #00ff00 | 3 | #008900 | 4 | #c4e2ff | 5 |
| #0080ff | 2 | #003b3b | 3 | #89ffff | 4 | #ff89ff | 5 |
| #ffff00 | 2 | #894d00 | 3 | #8000ff | 4 | #ffffff | 5 |
| #0000ff | 2 | #458900 | 3 | #ffffc4 | 4 | #ffffff | 5 |
| #ffff00 | 2 | #ff0000 | 3 | #00ffff | 4 | #89c4ff | 5 |
| #ffff00 | 2 | #890000 | 3 | #00ff80 | 4 | #ffffff | 5 |
| #ffff89 | 2 | #8989ff | 3 | #89ffc4 | 4 | #00ff00 | 5 |
| #008900 | 2 | #ffffc4 | 3 | #004589 | 4 | #894d00 | 5 |
| #0000ff | 2 | #89ffff | 3 | #00ff00 | 4 | #ff0000 | 5 |
| #ffffc4 | 2 | #0080ff | 3 | #ffffff | 4 | #00ff00 | 5 |
| #89c4ff | 2 | #008989 | 3 | #ffff89 | 4 | #ffc4e2 | 5 |
| #89ff89 | 2 | #ffff00 | 3 | #c4ffc4 | 4 | #ffc4e2 | 5 |
| #ffffff | 2 | #89ff89 | 3 | #0080ff | 4 | #ffffff | 5 |
| #ffff00 | 2 | #00ff80 | 3 | #008900 | 4 | #ffffc4 | 5 |

| Colour | Sound ID |
|---|---|
| #89c4ff | 6 |
| #ffcb89 | 6 |
| #c2c2c2 | 6 |
| #89c4ff | 6 |
| #0080ff | 6 |
| #ffff89 | 6 |
| #8989ff | 6 |
| #8000ff | 6 |
| #e2c4ff | 6 |
| #c4c4ff | 6 |
| #ffc4e2 | 6 |
| #00ffff | 6 |
| #008900 | 6 |
| #0080ff | 6 |
| #ffcb89 | 6 |
| #ff0080 | 6 |
| #8000ff | 6 |
| #3b003b | 6 |
| #ffff89 | 6 |
| #89c4ff | 6 |
| #894d00 | 6 |
| #450089 | 6 |
| #c2c2c2 | 6 |
| #ffff89 | 6 |
| #8989ff | 6 |

| Colour | Sound ID |
|---|---|
| #004589 | 7 |
| #894d00 | 7 |
| #004589 | 7 |
| #000089 | 7 |
| #00003b | 7 |
| #1e3b00 | 7 |
| #008989 | 7 |
| #000089 | 7 |
| #004589 | 7 |
| #004589 | 7 |
| #004589 | 7 |
| #001e3b | 7 |
| #00003b | 7 |
| #3b001e | 7 |
| #000000 | 7 |
| #ffff00 | 7 |
| #000000 | 7 |
| #3b001e | 7 |
| #3b2100 | 7 |
| #00ff00 | 7 |
| #00003b | 7 |
| #004589 | 7 |
| #ffffff | 7 |
| #ff00ff | 7 |
| #450089 | 7 |

| Colour | Sound ID |
|---|---|
| #ff89c4 | 8 |
| #ff0080 | 8 |
| #890089 | 8 |
| #ff0080 | 8 |
| #ffe5c4 | 8 |
| #ff8989 | 8 |
| #ff89ff | 8 |
| #ffc4c4 | 8 |
| #890000 | 8 |
| #ff0080 | 8 |
| #ffcb89 | 8 |
| #890045 | 8 |
| #c4e2ff | 8 |
| #e2ffc4 | 8 |
| #ff89ff | 8 |
| #80ff00 | 8 |
| #ffcb89 | 8 |
| #ff0000 | 8 |
| #0000ff | 8 |
| #004589 | 8 |
| #890000 | 8 |
| #ff8f00 | 8 |
| #3d3d3d | 8 |
| #3b001e | 8 |
| #ff89c4 | 8 |

| Colour | Sound ID |
|---|---|
| #ff8f00 | 9 |
| #890089 | 9 |
| #ffff00 | 9 |
| #80ff00 | 9 |
| #ff8f00 | 9 |
| #0080ff | 9 |
| #ffcb89 | 9 |
| #ffcb89 | 9 |
| #00003b | 9 |
| #ff8f00 | 9 |
| #ffff00 | 9 |
| #80ff00 | 9 |
| #ff0000 | 9 |
| #004589 | 9 |
| #ffff89 | 9 |
| #0080ff | 9 |
| #ff8f00 | 9 |
| #ffffc4 | 9 |
| #c4ff89 | 9 |
| #ffffc4 | 9 |
| #ffff00 | 9 |
| #89c4ff | 9 |
| #0080ff | 9 |
| #3d3d3d | 9 |
| #0080ff | 9 |

| Colour | Sound ID |
|---|---|
| #894d00 | 10 |
| #450089 | 10 |
| #003b3b | 10 |
| #004589 | 10 |
| #894d00 | 10 |
| #00003b | 10 |
| #890089 | 10 |
| #894d00 | 10 |
| #00003b | 10 |
| #894d00 | 10 |
| #894d00 | 10 |
| #00003b | 10 |
| #3b2100 | 10 |
| #00003b | 10 |
| #ffff00 | 10 |
| #890045 | 10 |
| #004589 | 10 |
| #1e003b | 10 |
| #450089 | 10 |
| #001e3b | 10 |
| #450089 | 10 |
| #00003b | 10 |
| #0000ff | 10 |
| #ffffc4 | 10 |
| #008989 | 10 |

| Colour | Sound ID |
|---|---|
| #ff0080 | 11 |
| #89ff89 | 11 |
| #ff89c4 | 11 |
| #8000ff | 11 |
| #ffc4c4 | 11 |
| #ffff00 | 11 |
| #89ff89 | 11 |
| #ffc4e2 | 11 |
| #00ff00 | 11 |
| #ffcb89 | 11 |
| #008989 | 11 |
| #ffff00 | 11 |
| #890045 | 11 |
| #c2c2c2 | 11 |
| #ffffff | 11 |
| #8989ff | 11 |
| #ffcb89 | 11 |
| #458900 | 11 |
| #c489ff | 11 |
| #ff8989 | 11 |
| #890045 | 11 |
| #ffffff | 11 |
| #8000ff | 11 |
| #ffc4c4 | 11 |
| #ff8f00 | 11 |

| Colour | Sound ID |
|---|---|
| #ffff00 | 12 |
| #ffff00 | 12 |
| #ffc4ff | 12 |
| #ffff89 | 12 |
| #ffff00 | 12 |
| #c4ffc4 | 12 |
| #ffff89 | 12 |
| #ffff89 | 12 |
| #ffff00 | 12 |
| #ffff00 | 12 |
| #ffffc4 | 12 |
| #ffff00 | 12 |
| #ffff89 | 12 |
| #00ff00 | 12 |
| #ff8f00 | 12 |
| #00ff80 | 12 |
| #ffffff | 12 |
| #c4ffc4 | 12 |
| #ff89ff | 12 |
| #ffff89 | 12 |
| #89ff89 | 12 |
| #ffff89 | 12 |
| #c489ff | 12 |
| #008989 | 12 |
| #00ff80 | 12 |

| Colour | Sound ID |
|---|---|
| #008989 | 13 |
| #894d00 | 13 |
| #008989 | 13 |
| #ffffff | 13 |
| #894d00 | 13 |
| #008945 | 13 |
| #c2c2c2 | 13 |
| #894d00 | 13 |
| #894d00 | 13 |
| #008989 | 13 |
| #894d00 | 13 |
| #004589 | 13 |
| #003b00 | 13 |
| #004589 | 13 |
| #3b2100 | 13 |
| #ffcb89 | 13 |
| #3b003b | 13 |
| #c4e2ff | 13 |
| #89ffff | 13 |
| #8989ff | 13 |
| #894d00 | 13 |
| #00ff80 | 13 |
| #80ff00 | 13 |
| #00003b | 13 |
| #004589 | 13 |

| Colour | Sound ID |
|---|---|
| #ff0080 | 14 |
| #ff89c4 | 14 |
| #ff0000 | 14 |
| #ffc4c4 | 14 |
| #ffc4e2 | 14 |
| #890045 | 14 |
| #3b001e | 14 |
| #890045 | 14 |
| #890000 | 14 |
| #890045 | 14 |
| #ff8989 | 14 |
| #ff0000 | 14 |
| #890000 | 14 |
| #ffffff | 14 |
| #ffffff | 14 |
| #c4ffff | 14 |
| #c2c2c2 | 14 |
| #ffff89 | 14 |
| #ff00ff | 14 |
| #c4ffc4 | 14 |
| #ff0000 | 14 |
| #3b0000 | 14 |
| #ff8f00 | 14 |
| #c4c4ff | 14 |
| #ffff89 | 14 |

| Colour | Sound ID |
|---|---|
| #00ff80 | 15 |
| #ff00ff | 15 |
| #890000 | 15 |
| #c2c2c2 | 15 |
| #ff0080 | 15 |
| #00ff00 | 15 |
| #ffffff | 15 |
| #ffffff | 15 |
| #ffffc4 | 15 |
| #ffffc4 | 15 |
| #c2c2c2 | 15 |
| #3d3d3d | 15 |
| #c2c2c2 | 15 |
| #c4ffff | 15 |
| #c4ffe2 | 15 |
| #c2c2c2 | 15 |
| #80ff00 | 15 |
| #ffe5c4 | 15 |
| #000089 | 15 |
| #c4e2ff | 15 |
| #ff8f00 | 15 |
| #c2c2c2 | 15 |
| #ff0000 | 15 |
| #ff00ff | 15 |
| #ffcb89 | 15 |

| Colour | Sound ID |
|---|---|
| #003b3b | 16 |
| #3b001e | 16 |
| #ffffff | 16 |
| #ffffff | 16 |
| #c2c2c2 | 16 |
| #ffffff | 16 |
| #ffffff | 16 |
| #c2c2c2 | 16 |
| #3d3d3d | 16 |
| #0080ff | 16 |
| #3d3d3d | 16 |
| #000000 | 16 |
| #c2c2c2 | 16 |
| #000000 | 16 |
| #ff8f00 | 16 |
| #ffe5c4 | 16 |
| #894d00 | 16 |
| #00003b | 16 |
| #ff8f00 | 16 |
| #c489ff | 16 |
| #004589 | 16 |
| #c4ff89 | 16 |
| #3d3d3d | 16 |
| #ff89ff | 16 |
| #89c4ff | 16 |

| Colour | Sound ID |
|---|---|
| #890045 | 17 |
| #ff8989 | 17 |
| #ffff00 | 17 |
| #ff0080 | 17 |
| #ff0000 | 17 |
| #c489ff | 17 |
| #c4ffff | 17 |
| #890045 | 17 |
| #000000 | 17 |
| #ff0000 | 17 |
| #ff0000 | 17 |
| #3b0000 | 17 |
| #3b001e | 17 |
| #c4ffc4 | 17 |
| #ffc4c4 | 17 |
| #c4c4ff | 17 |
| #ffffff | 17 |
| #c4e2ff | 17 |
| #890089 | 17 |
| #ff0000 | 17 |
| #ffc4e2 | 17 |
| #c4c4ff | 17 |
| #ff0000 | 17 |
| #c4e2ff | 17 |
| #894d00 | 17 |

| Colour | Sound ID | Colour | Sound ID |
|---|---|---|---|
| #89ff89 | 18 | #c4e2ff | 19 |
| #ff0000 | 18 | #ffff89 | 19 |
| #ffcb89 | 18 | #e2ffc4 | 19 |
| #ff8f00 | 18 | #ffff00 | 19 |
| #ff8f00 | 18 | #ffff89 | 19 |
| #8000ff | 18 | #e2c4ff | 19 |
| #ffff89 | 18 | #ffe5c4 | 19 |
| #ffff00 | 18 | #ffffc4 | 19 |
| #ffff89 | 18 | #ffcb89 | 19 |
| #ffff89 | 18 | #ffe5c4 | 19 |
| #8989ff | 18 | #e2c4ff | 19 |
| #008900 | 18 | #ffcb89 | 19 |
| #c4ff89 | 18 | #ffffc4 | 19 |
| #80ff00 | 18 | #458900 | 19 |
| #3b001e | 18 | #00003b | 19 |
| #c4ff89 | 18 | #ffff89 | 19 |
| #008989 | 18 | #450089 | 19 |
| #e2c4ff | 18 | #ffe5c4 | 19 |
| #ffff00 | 18 | #000000 | 19 |
| #ffcb89 | 18 | #00ffff | 19 |
| #ff00ff | 18 | #c489ff | 19 |
| #ffff00 | 18 | #894d00 | 19 |
| #00ff00 | 18 | #e2ffc4 | 19 |
| #3d3d3d | 18 | #00003b | 19 |
| #ff8f00 | 18 | #008900 | 19 |

APPENDIX B – Attempt two results for each sound and user

| Colour | Sound ID | Colour | Sound ID | Colour | Sound ID | Colour | Sound ID |
|---|---|---|---|---|---|---|---|
| #e2c4ff | 2 | #8989ff | 3 | #89ff89 | 4 | #ffffc4 | 5 |
| #e2c4ff | 2 | #89c4ff | 3 | #8989ff | 4 | #ff89ff | 5 |
| #e2ffc4 | 2 | #c4ffe2 | 3 | #ffffc4 | 4 | #ff89ff | 5 |
| #c4ffff | 2 | #89ff89 | 3 | #008945 | 4 | #c4e2ff | 5 |
| #c4ffe2 | 2 | #c4ff89 | 3 | #008900 | 4 | #c4e2ff | 5 |
| #c4ffff | 2 | #8989ff | 3 | #c4ffe2 | 4 | #ffffc4 | 5 |
| #e2c4ff | 2 | #e2ffc4 | 3 | #ffcb89 | 4 | #ffc4e2 | 5 |
| #c4ffe2 | 2 | #c4ff89 | 3 | #80ff00 | 4 | #c4e2ff | 5 |
| #ffe5c4 | 2 | #ff8f00 | 3 | #80ff00 | 4 | #ffc4ff | 5 |
| #89ffc4 | 2 | #89ff89 | 3 | #80ff00 | 4 | #c489ff | 5 |
| #e2ffc4 | 2 | #89ff89 | 3 | #00ff80 | 4 | #ffc4e2 | 5 |
| #89ff89 | 2 | #00ff80 | 3 | #008900 | 4 | #c4e2ff | 5 |
| #c4ff89 | 2 | #80ff00 | 3 | #00ff00 | 4 | #ffffc4 | 5 |
| #ffcb89 | 2 | #89ff89 | 3 | #c4ff89 | 4 | #c4ffe2 | 5 |
| #0080ff | 2 | #ffff89 | 3 | #89ff89 | 4 | #ffc4ff | 5 |
| #89ff89 | 2 | #ffcb89 | 3 | #c4ffff | 4 | #ff89ff | 5 |
| #ffff00 | 2 | #ff8f00 | 3 | #89ffff | 4 | #ffffff | 5 |
| #ffffff | 2 | #008900 | 3 | #ff8f00 | 4 | #ffffff | 5 |
| #c4e2ff | 2 | #ffffc4 | 3 | #ffffc4 | 4 | #c4e2ff | 5 |
| #00ff80 | 2 | #ffff00 | 3 | #8000ff | 4 | #ff89ff | 5 |
| #008900 | 2 | #00ff80 | 3 | #0080ff | 4 | #3b2100 | 5 |
| #89ffff | 2 | #450089 | 3 | #458900 | 4 | #ffff89 | 5 |
| #ffff00 | 2 | #004589 | 3 | #89ff89 | 4 | #ffc4ff | 5 |
| #c4ff89 | 2 | #ffff00 | 3 | #ff89ff | 4 | #ffffc4 | 5 |
| #ffff00 | 2 | #458900 | 3 | #89ffc4 | 4 | #ffffc4 | 5 |

| Colour | Sound ID |
|---|---|
| #ffcb89 | 6 |
| #c4ff89 | 6 |
| #8989ff | 6 |
| #ffff89 | 6 |
| #c489ff | 6 |
| #ffff89 | 6 |
| #ff8989 | 6 |
| #89ffc4 | 6 |
| #89c4ff | 6 |
| #c4c4ff | 6 |
| #ffcb89 | 6 |
| #89c4ff | 6 |
| #ffcb89 | 6 |
| #89c4ff | 6 |
| #8989ff | 6 |
| #c2c2c2 | 6 |
| #ff0000 | 6 |
| #0080ff | 6 |
| #89ffff | 6 |
| #890045 | 6 |
| #ffff89 | 6 |
| #e2ffc4 | 6 |
| #8000ff | 6 |
| #0080ff | 6 |
| #008989 | 6 |

| Colour | Sound ID |
|---|---|
| #008900 | 7 |
| #0000ff | 7 |
| #00003b | 7 |
| #001e3b | 7 |
| #008989 | 7 |
| #3b3b00 | 7 |
| #008900 | 7 |
| #004589 | 7 |
| #0000ff | 7 |
| #000089 | 7 |
| #894d00 | 7 |
| #004589 | 7 |
| #000089 | 7 |
| #00003b | 7 |
| #001e3b | 7 |
| #0000ff | 7 |
| #000000 | 7 |
| #001e3b | 7 |
| #ffff00 | 7 |
| #3b0000 | 7 |
| #80ff00 | 7 |
| #004589 | 7 |
| #000089 | 7 |
| #ffffff | 7 |
| #1e003b | 7 |

| Colour | Sound ID |
|---|---|
| #ff8989 | 8 |
| #ffcb89 | 8 |
| #3b001e | 8 |
| #ff8989 | 8 |
| #ff0080 | 8 |
| #ff8989 | 8 |
| #ff0080 | 8 |
| #ffc4c4 | 8 |
| #ff0000 | 8 |
| #ff0080 | 8 |
| #ff0000 | 8 |
| #890045 | 8 |
| #ff0000 | 8 |
| #890000 | 8 |
| #ff0000 | 8 |
| #ffffff | 8 |
| #ff00ff | 8 |
| #c2c2c2 | 8 |
| #ffc4e2 | 8 |
| #e2ffc4 | 8 |
| #0000ff | 8 |
| #ff00ff | 8 |
| #ffcb89 | 8 |
| #ff0080 | 8 |
| #ffe5c4 | 8 |

| Colour | Sound ID |
|---|---|
| #0000ff | 9 |
| #ff8f00 | 9 |
| #ff8f00 | 9 |
| #000089 | 9 |
| #894d00 | 9 |
| #894d00 | 9 |
| #ff8f00 | 9 |
| #8989ff | 9 |
| #894d00 | 9 |
| #ffff89 | 9 |
| #ffff00 | 9 |
| #c489ff | 9 |
| #004589 | 9 |
| #0080ff | 9 |
| #004589 | 9 |
| #ffff89 | 9 |
| #0080ff | 9 |
| #ffe5c4 | 9 |
| #e2c4ff | 9 |
| #c2c2c2 | 9 |
| #89ffc4 | 9 |
| #c4ffe2 | 9 |
| #0080ff | 9 |
| #ff8f00 | 9 |
| #008945 | 9 |

| Colour | Sound ID |
|---|---|
| #004589 | 10 |
| #894d00 | 10 |
| #3b2100 | 10 |
| #001e3b | 10 |
| #894d00 | 10 |
| #001e3b | 10 |
| #004589 | 10 |
| #00003b | 10 |
| #3b2100 | 10 |
| #001e3b | 10 |
| #894d00 | 10 |
| #00003b | 10 |
| #00003b | 10 |
| #00003b | 10 |
| #00003b | 10 |
| #000089 | 10 |
| #001e3b | 10 |
| #000000 | 10 |
| #ffff00 | 10 |
| #008989 | 10 |
| #c4ffc4 | 10 |
| #001e3b | 10 |
| #008989 | 10 |
| #004589 | 10 |
| #004589 | 10 |

| Colour | Sound ID |
|---|---|
| #c2c2c2 | 11 |
| #ff8989 | 11 |
| #00ffff | 11 |
| #ff89c4 | 11 |
| #ff89c4 | 11 |
| #ff89ff | 11 |
| #8000ff | 11 |
| #ff0000 | 11 |
| #890045 | 11 |
| #890045 | 11 |
| #ff89c4 | 11 |
| #ff8f00 | 11 |
| #89ffff | 11 |
| #c489ff | 11 |
| #89ffc4 | 11 |
| #ff89ff | 11 |
| #00ff80 | 11 |
| #e2ffc4 | 11 |
| #c4c4ff | 11 |
| #ffe5c4 | 11 |
| #004589 | 11 |
| #ff00ff | 11 |
| #ff8989 | 11 |
| #ff8989 | 11 |
| #ffff00 | 11 |

| Colour | Sound ID |
|---|---|
| #ffff89 | 12 |
| #c4c4ff | 12 |
| #89ff89 | 12 |
| #89ff89 | 12 |
| #ffffff | 12 |
| #ff89c4 | 12 |
| #ffff89 | 12 |
| #ffff89 | 12 |
| #ffff00 | 12 |
| #ffff00 | 12 |
| #c489ff | 12 |
| #ffff89 | 12 |
| #c4ff89 | 12 |
| #ffff89 | 12 |
| #ffff00 | 12 |
| #ffff89 | 12 |
| #ffffff | 12 |
| #894d00 | 12 |
| #89ffc4 | 12 |
| #e2c4ff | 12 |
| #00ff00 | 12 |
| #ffffff | 12 |
| #ffff00 | 12 |
| #00ffff | 12 |
| #89ff89 | 12 |

| Colour | Sound ID |
|---|---|
| #ffffff | 13 |
| #001e3b | 13 |
| #008945 | 13 |
| #003b00 | 13 |
| #3d3d3d | 13 |
| #0080ff | 13 |
| #003b3b | 13 |
| #008989 | 13 |
| #004589 | 13 |
| #ffffc4 | 13 |
| #000089 | 13 |
| #008900 | 13 |
| #004589 | 13 |
| #003b00 | 13 |
| #ffff89 | 13 |
| #89ff89 | 13 |
| #894d00 | 13 |
| #ffcb89 | 13 |
| #ffff89 | 13 |
| #ffff00 | 13 |
| #ff89ff | 13 |
| #c4ffc4 | 13 |
| #450089 | 13 |
| #008989 | 13 |
| #8989ff | 13 |

| Colour | Sound ID |
|---|---|
| #000000 | 14 |
| #ff0080 | 14 |
| #ff0000 | 14 |
| #ff0080 | 14 |
| #3b0000 | 14 |
| #890000 | 14 |
| #ff0080 | 14 |
| #890045 | 14 |
| #3b0000 | 14 |
| #ff0000 | 14 |
| #c2c2c2 | 14 |
| #890000 | 14 |
| #000000 | 14 |
| #890000 | 14 |
| #3b0000 | 14 |
| #ff0000 | 14 |
| #ffc4c4 | 14 |
| #ffffc4 | 14 |
| #c4e2ff | 14 |
| #ffffff | 14 |
| #450089 | 14 |
| #ff0000 | 14 |
| #ff0000 | 14 |
| #ff0000 | 14 |
| #ffffc4 | 14 |

| Colour | Sound ID |
|---|---|
| #ff89c4 | 15 |
| #c2c2c2 | 15 |
| #000000 | 15 |
| #ffc4ff | 15 |
| #ff0000 | 15 |
| #ff0000 | 15 |
| #c4e2ff | 15 |
| #ffffff | 15 |
| #3d3d3d | 15 |
| #c2c2c2 | 15 |
| #c2c2c2 | 15 |
| #3d3d3d | 15 |
| #ffffff | 15 |
| #c2c2c2 | 15 |
| #c2c2c2 | 15 |
| #000000 | 15 |
| #00ff00 | 15 |
| #ffc4c4 | 15 |
| #89ffc4 | 15 |
| #89c4ff | 15 |
| #ffcb89 | 15 |
| #000000 | 15 |
| #89ff89 | 15 |
| #ff8989 | 15 |
| #ffff89 | 15 |

| Colour | Sound ID |
|---|---|
| #890089 | 16 |
| #3d3d3d | 16 |
| #000000 | 16 |
| #c2c2c2 | 16 |
| #ffc4c4 | 16 |
| #000000 | 16 |
| #c2c2c2 | 16 |
| #000000 | 16 |
| #ff0000 | 16 |
| #3d3d3d | 16 |
| #3d3d3d | 16 |
| #ffffff | 16 |
| #008989 | 16 |
| #3d3d3d | 16 |
| #c2c2c2 | 16 |
| #ffffff | 16 |
| #c4ff89 | 16 |
| #c4e2ff | 16 |
| #c4ffc4 | 16 |
| #ff89ff | 16 |
| #ffff89 | 16 |
| #ff89ff | 16 |
| #450089 | 16 |
| #ffcb89 | 16 |
| #c4ff89 | 16 |

| Colour | Sound ID |
|---|---|
| #ff0080 | 17 |
| #ff8f00 | 17 |
| #c2c2c2 | 17 |
| #ff0000 | 17 |
| #ff8f00 | 17 |
| #3d3d3d | 17 |
| #ff89ff | 17 |
| #3b001e | 17 |
| #890045 | 17 |
| #890000 | 17 |
| #ff0000 | 17 |
| #890000 | 17 |
| #000000 | 17 |
| #3b001e | 17 |
| #890045 | 17 |
| #ff0080 | 17 |
| #e2c4ff | 17 |
| #c4ffc4 | 17 |
| #ffc4c4 | 17 |
| #ffc4c4 | 17 |
| #004589 | 17 |
| #890045 | 17 |
| #ff0000 | 17 |
| #890000 | 17 |
| #ffe5c4 | 17 |

| Colour | Sound ID | Colour | Sound ID |
|---|---|---|---|
| #ff8f00 | 18 | #ffe5c4 | 19 |
| #ffcb89 | 18 | #c4ffc4 | 19 |
| #89ffff | 18 | #c4e2ff | 19 |
| #004589 | 18 | #ffff89 | 19 |
| #ffff00 | 18 | #ffffc4 | 19 |
| #89ffc4 | 18 | #89ff89 | 19 |
| #ffcb89 | 18 | #e2ffc4 | 19 |
| #ffcb89 | 18 | #ffff89 | 19 |
| #ff8f00 | 18 | #ffff00 | 19 |
| #ffff00 | 18 | #ffffc4 | 19 |
| #ffff00 | 18 | #894d00 | 19 |
| #ffff00 | 18 | #ff89c4 | 19 |
| #8989ff | 18 | #ffff00 | 19 |
| #ffff00 | 18 | #ffffc4 | 19 |
| #0080ff | 18 | #00ff80 | 19 |
| #008945 | 18 | #ffff89 | 19 |
| #89ffff | 18 | #c4e2ff | 19 |
| #894d00 | 18 | #894d00 | 19 |
| #ffcb89 | 18 | #c4ffff | 19 |
| #89ff89 | 18 | #ffff00 | 19 |
| #ffc4c4 | 18 | #ffc4e2 | 19 |
| #ff89c4 | 18 | #008989 | 19 |
| #8989ff | 18 | #89ffff | 19 |
| #ff0080 | 18 | #89ff89 | 19 |
| #89ffc4 | 18 | #89ffff | 19 |