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Computer Science Department

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Senior Project

Chromesthesia Trainer

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Abstract

The goal of this project is to create a web application that is able to teach users to develop chromesthesia. After the application is built, a short study will take place to verify that the presence of colors improves the users ability to identify relative pitch.

1 Introduction

1.1 Chromesthesia

Synesthesia is a sensation where one sense triggers an involuntary response in another sense. Chromesthesia is a common type of synesthesia where sounds are associated with colors. Someone with chromesthesia experiences seeing colors when listening to music or even hearing everyday things like the hum of a car engine. People with chromesthesia have described the sensation as colors appearing near the edges of their vision.

1.1.1 Perfect Pitch and Relative Pitch

People with chromesthesia tend to have perfect pitch. Perfect pitch is the ability to identify the pitch of a sound without a reference tone. Having chromesthesia helps identifying pitches because the pitch is verified by seeing a unique color. Another skill that comes with chromesthesia is relative pitch. Relative pitch is the ability to identify the difference, or interval, between two pitches. People without chromesthesia can develop relative pitch through ear training.

1.2 Proposed Solution

Most ear training applications work by playing two different pitches and waiting for the user to identify the interval. My proposed solution is to try to teach the user to develop chromesthesia by associating relative pitch to color.

The application will follow the traditional method of playing two pitches and waiting for the user to respond, but it will also display a color on screen. With dedicated use the user may begin to associate each specific color to the related interval.

After developing the tools to learn chromesthesia, I will devise an experiment. I will gather participants and put them into two groups; the control and the experimental group. The control group will use traditional ear training techniques while the experimental group will use my application. At the beginning of the study, participants will take an assessment test to measure their current ability in identifying relative pitches. After the assessment is finished, participants will take a daily quiz over a four week period. This period will help participants develop the necessary skills to identify intervals. When four weeks have passed, the assessment will be taken again.

1.2.1 Previous Studies

Despite being an interesting topic, there have not been many studies on synesthesia. The only study that I came across was a study in 2014 where 33 individuals spent nine weeks reading certain text that corresponded with a specific color[1]. After the nine week period, some participants noted that they were still able to see the text in color even though it was printed in black and white.

1.2.2 Motivation

The main motivation behind this project is to help people in the music field. If the participants are able to develop chromesthesia to help with relative pitch, it may be possible to develop chromesthesia with perfect pitch. Other applications may help improve overall memory.

2 Application

The application is a basic web page. Each part of the experiment is categorized into tabs. Users are able to access the application on any device that has a web browser. However, some functionality is limited to a desktop environment.

2.1 Account

Before starting the actual experiment, I asked users to sign up for an account in order to track their usage and results from the assessments and tests. The page consists of two text fields (email and password) and four buttons described below:

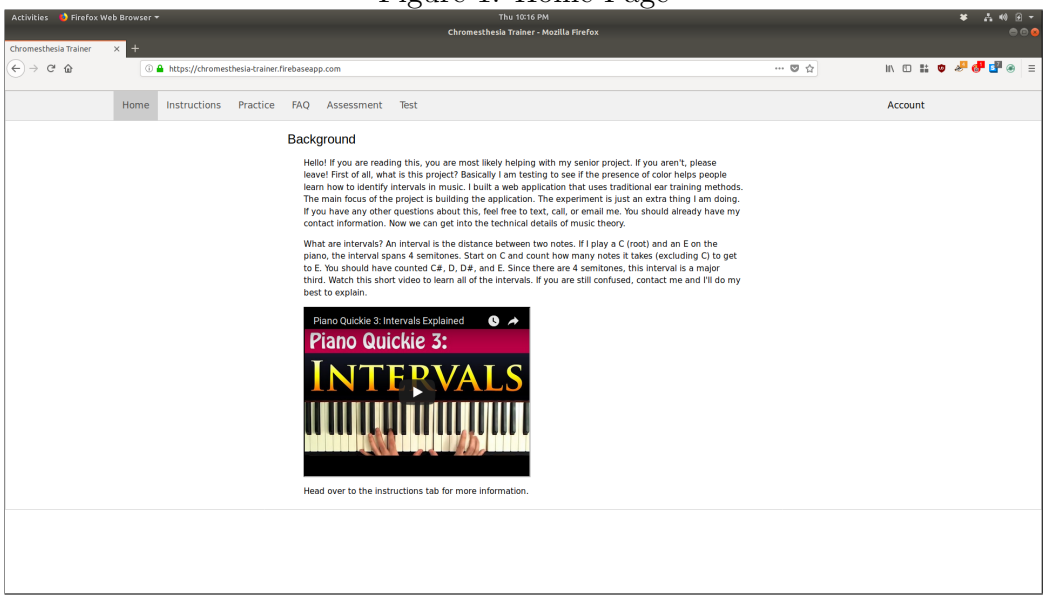
- sign up - register an account
- log in - login to an existing account
- log out - logout of the current account
- check status - see if a user is logged into an account

I included the *check status* button so users can verify that they are logged in and their data would be stored properly. The Account tab is vital for the experiment side of the project but not the functionality of the application.

2.2 Home Page

On the Home Page, users can find information about the purpose of the website. This also includes an explanation of intervals in regards to music theory. I also included a video to help those who need a visual explanation for intervals. The Home Page is a good place to start if you know nothing about music theory.

Figure 1: Home Page



2.3 Instructions

The instructions tab was created to inform the participants step by step of their daily tasks. These include the following:

1. Visit the practice tab. Familiarize yourself with the different intervals. You can ignore the root for now.

2. Read the FAQ. I've listed a few things that helped me. If you have suggestions to help other users, send me an email and I'll add them!

3. Take the assessment quiz. Do this after you are familiar with the intervals. Test yourself for 30 minutes. Do this once at the beginning of the experiment. Note that when you answer a question correctly, the application automatically proceeds to the next question.

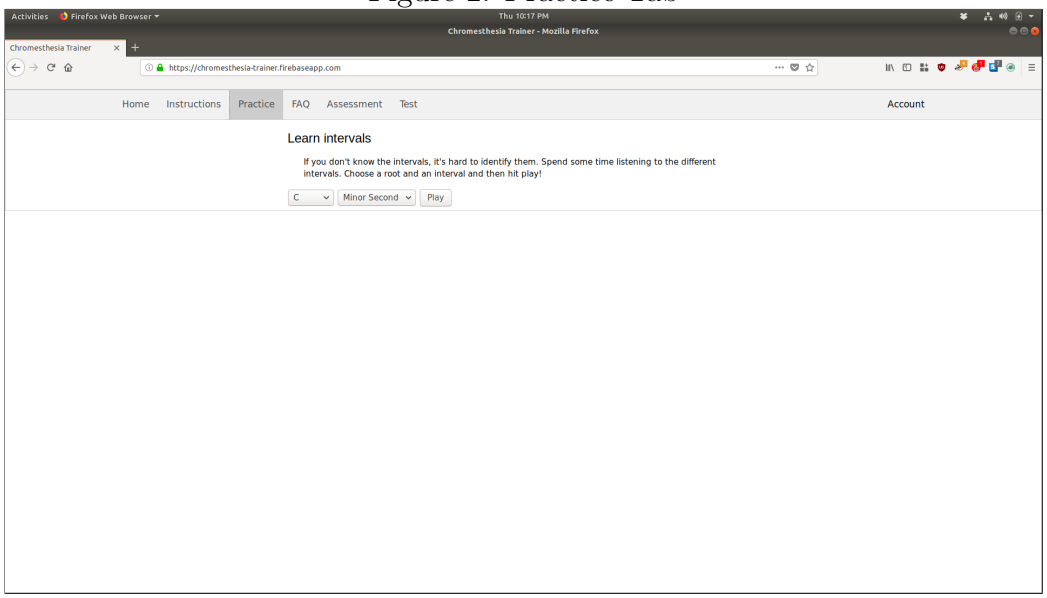
4. Take the quiz (daily). Make sure to test yourself for 10-15 minutes per day. If you don't think you'll remember to take the test, set an alarm to remind yourself. If you're feeling motivated you can take the test multiple times per day but try to keep each session 10-15 minutes.

5. After the experiment is over, take the assessment test again!

2.4 Practice

The Practice tab enables people to learn the intervals without being timed or having information logged. I chose two drop down menus because listing out all combinations would require 144 total buttons. Here the users can set the root and the type of interval they would like to hear.

Figure 2: Practice Tab



2.5 Frequently Asked Questions

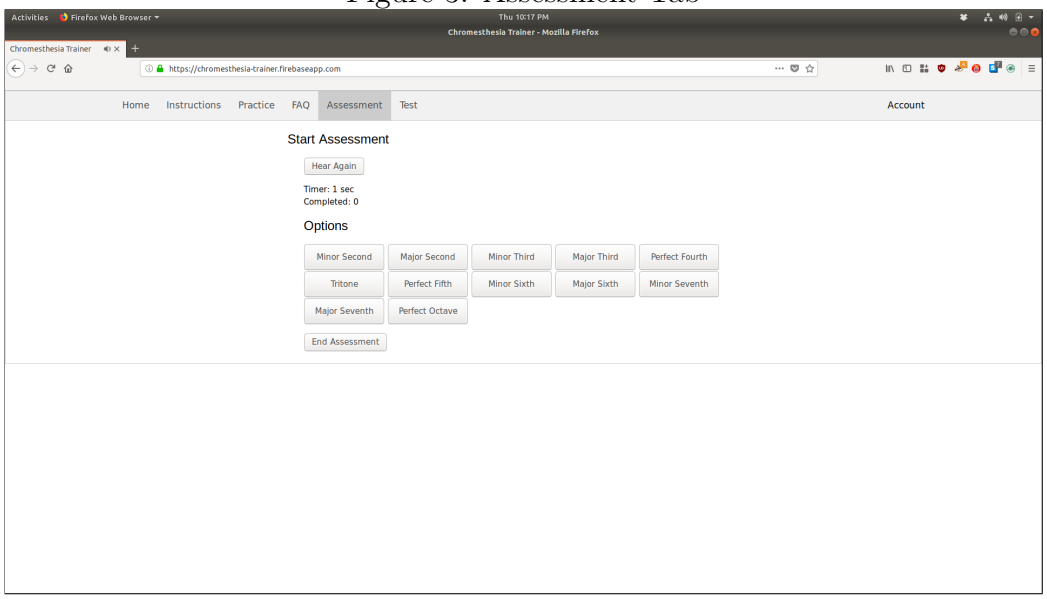
Participants can visit the Frequently Asked Questions tab to learn tricks that I personally use to identify intervals. A useful resource on this page is a link to a web page that lists common songs that contain each interval.

2.6 Assessment

The assessment is taken at the very beginning and later at end of the experiment. The assessment consists of playing the user two pitches and the user responding. This process is repeated until the user selects "End Assessment". The main form of validation to see if the user improved is based on their starting score and end score. When the user first visits this page it

is blank with only one button labeled *Start Assessment*. After starting the assessment, the page should look like Figure 3.

Figure 3: Assessment Tab



2.6.1 User Input

- Hear Again - play the interval sound clip again
- Intervals - lets the user choose an interval until they choose the correct one
- End Assessment - exit the assessment

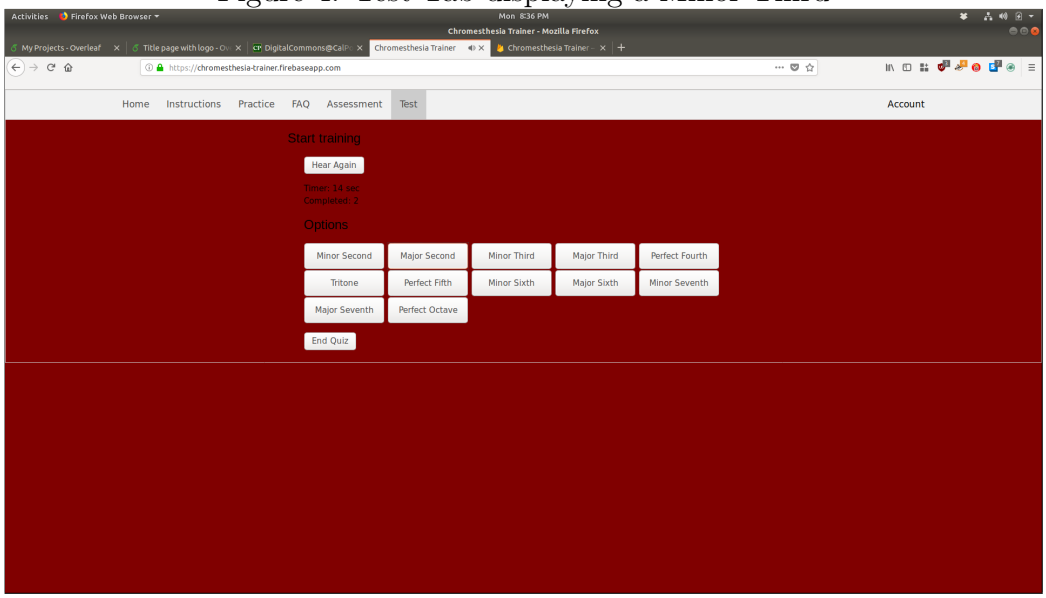
2.6.2 Information Displayed

- Timer - how much time has passed since the start of the assessment. This allows the user can keep track of how long they have been in the assessment.
- Completed - how many questions have been answered correctly. This number increases even if you had multiple guesses on a question.

2.7 Test

Users use this tab for daily testing. The information displayed as well as the button layout mimics the assessment tab. The sole difference here is users in the experimental group are shown colors while the interval sound clip is being played. Refer to Table 1 to see how the intervals are mapped to colors.

Figure 4: Test Tab displaying a Minor Third



2.7.1 Color Code

The colors were chosen from a color blind friendly palette to ensure that each color is distinct.

Table 1: Intervals with matching colors

Interval	**Color**	**Hex Value**	**Web Color**
Minor Second	Black	#00000	
Major Second	Red	#FF0000	
Minor Third	Maroon	#800000	
Major Third	Yellow	#FFFF00	
Perfect Fourth	Olivetone	#707030	
Tritone	Green	#00EE00	
Perfect Fifth	Islamic Green	#009000	
Minor Sixth	Cyan	#00EEEE	
Major Sixth	Persian Green	#00A0A0	
Minor Seventh	Blue	#0000FF	
Major Seventh	Magenta	#FF00FF	
Perfect Octave	Dark Magenta	#900090	

3 Background

3.1 Front End

The website was designed with pure HTML and CSS. All classes and modifications were made by following on-line tutorials. Functionality was implemented by using JavaScript. Since this was my first project in web development, I wanted to avoid using external libraries to keep the learning curve relatively low.

3.1.1 JavaScript Functions

The functionality lies in four tabs; Practice, Assessment, Test, and Account. Most of the functions are bound to buttons.

3.2 Back End

The back end is handled by Firebase. Using Firebase allowed for simple integration. Firebase was used to implement account authentication, database management, storing the sound files, and web hosting. The audio clips that are played back to the user were hand created. There are a total of 144 clips that are stored with Firebase.

3.3 User Data

All information from the user is stored in the Firebase database. Each user is stored based on their UID which is a unique code assigned to the user when they register an account.

- email - to easily match a UID to a user. This is mainly included for readability on my end.
- is_color - when users are first authenticated they are randomly assigned a number. 0 indicates no color (the control group) while 1 indicates color (experimental group)
- list of assessments
- list of tests

3.4 Assessment and Test

The assessments and tests follow the same format.

- date - what day they took the assessment/test
- list of questions
- time (in seconds) - total time spent on assessment/test

3.4.1 Questions

- guesses - how many wrong answers
- interval - which interval is being tested
- root - the root of the interval
- time (in seconds) - total time spent on this question

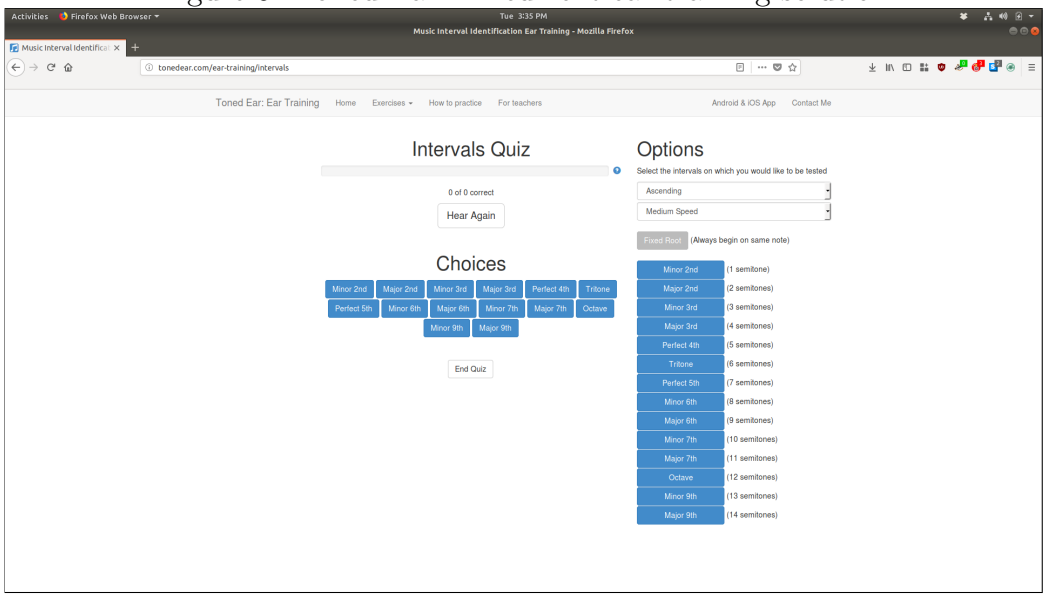
Refer to Figure 10 in *Implementation* for a visual representation of Users, Assessments, Tests, and Questions.

4 Design

4.1 Graphical User Interface

The main design took influence from different web pages. Users are typically familiar with the navigation bar on the top as well as the tab functionality. The button layout took inspiration from Toned Ear, a popular ear training tool.

Figure 5: Toned Ear - A current ear training solution



4.2 User Input

The main form of user input is point and click. Another solution that I have seen for this type of input is binding keys on the keyboard to the buttons on the screen. This idea was scrapped because it would increase the cognitive load of the user if they had to learn an addition mapping (keyboard keys to interval). Instead they are able to completely focus their attention on listening and identifying the intervals.

4.3 Feedback

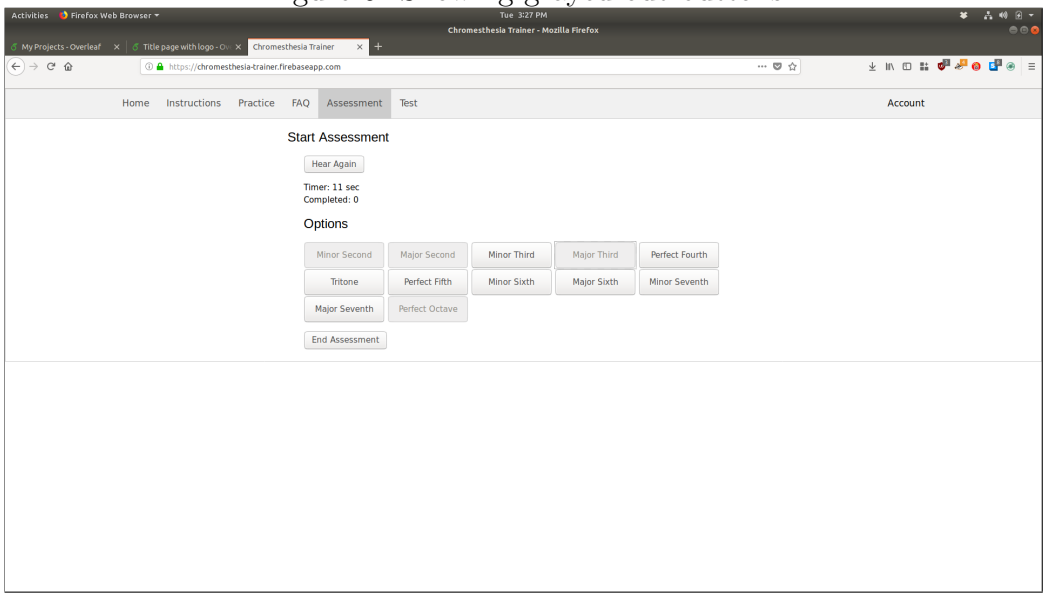
4.3.1 Answer Feedback

The main design decision I had to make for user feedback was in the Assessment and Test tabs. Current ear training applications notify the user when they correctly answer a question. This is done by either a pop up or by playing a specific sound to notify the user that they are correct. In order to keep the user in "flow", I decided against both of these. Pop ups are disliked by most users, especially when they are trying to focus on answering the questions correctly. I did not implement a sound to notify the user because I thought it might confuse the users since they are already trying to identify specific sounds. When a user correctly identifies an interval, the system simply moves on to the next question.

4.3.2 Incorrect Feedback

The other type of feedback deals with incorrect answers. Instead of letting the user click on a button that they already tried, the button gets grayed out to prohibit them from repetitively clicking the same button. After they correctly identify the interval, all buttons are enabled for the next question.

Figure 6: Showing grayed out buttons



5 Implementation

5.1 Playing Sound Clips

The sound clips were hand made and converted to a .wav file. The Practice, Assessment, and Test tab all use a similar format to play the sound clip.

Figure 7: Play Sound Clip Source Code

```
function play_sound_clip() {
    let root = getRoot();
    let interval = getInterval();

    // check if an interval is already playing
    if (current_playing != null) {

        // stop it if it is playing
        current_playing.pause();
    }

    // set the audio file
    current_playing = new Audio('res/audio/'.concat(root,
                                '/', interval, '.wav'));
    current_playing.play();
}
```

The main difference between Practice and Assessment/Test is the ability to choose which sound clip is played. In Practice, getRoot(); and getInterval(); fetch the options that the user inputed from the drop down menu. In Assessment and Test, the root and interval are randomly generated by using the Math.random() function.

5.2 Assessment and Test

The Assessment and Test tabs must also check if the user chose the correct interval. This function also keeps track of how long a user spent on each question.

Figure 8: Checking Interval Source Code

```
async function check_interval(interval) {
    if (interval === current_interval) { // user was correct
        question_end = Date.now();

        store info in Database

        // move on to next question
        questions_completed++;
        wrong_count = 0;
        question_start = Date.now();

        // enable all button that user got wrong
        enable_intervals();

        current_interval = intervals[uniform_random(0,
                                    intervals.length)];
        current_root = roots[uniform_random(0, roots.length)];

        current_audio = getAudioPath(current_root, current_interval);
        current_audio.play();

        if (is_color) { // change background if user is color
            await sleep(2000);
            setColor(colors[current_interval]);
        }
    } else { // user was incorrect
        wrong_count_q++;

        // disable the button they pressed
        disable_button(interval);
    }
}
```

5.3 Account

Users have four total actions they can perform related to their account. All actions are bounded to buttons.

5.3.1 Sign Up and Login

Signing up and logging in fetches the email and password from the text fields on the page. This information is passed through to Firebase to see if the account already exists. If there is no account linked to the email, an account will get created and stored. If there is an account, the password is checked to see if it matches. If this is a new user, they will be assigned a group; experimental or control. Finally the user is logged in automatically.

5.3.2 Log Out

This will log the user out if they are currently logged in. A check is performed (similar to check status) to see if the user is logged in.

5.3.3 Check Status

The *Check Status* button allows the user to see if they are currently logged into an account. If they are logged in, a window will alert them displaying the email that is tied to the current account.

Figure 9: Check Status Source Code

```
function check_login() {
    if (firebase.auth().currentUser) {
        window.alert('You are logged in as '
                    + firebase.auth().currentUser.email);
    }
    else {
        window.alert('You are not logged in');
    }
}
```

5.4 Database Structure

Figure 10: JSON Layout

```
chromesthesia-trainer
{
    users: {
      UID-0: {
          email: user-test@test.com,
          is_color: 0,

          assessment0: {
              date: 2018-06-02_12:11:43,
              question1: {
                  guesses: 4,
                  interval: major_sixth,
                  root: Gb,
                  time: 8.74
              },
              ...
              questionN: {...},
              time: 913.7
          },
          ...
          assessmentN: {...},

          test1: {...},
          ...
          testN: {...}
      },

      UID-1: {...},
      ...
      UID-n: {...}
    }
}
```

6 Analysis and Verification

6.1 Issues

Unfortunately most participants were not consistent with their usage. Out of the twenty participants, about four or five of them consistently used the application.

Additionally, I would have liked to extend the experiment to nine weeks to mirror the previous study. When the project was completed, I only had four weeks to test it before the quarter ended.

Both of these issues have prevented a definite conclusion on whether the presence of colors helps improve the users ability to recognize relative pitch.

6.2 Results

With the data that I did have, most users in the experimental group did fine on the tests but poorly on the assessment. I believe that the users were relying on the colors as a crutch instead of actually identifying the interval correctly. Since the experimental group had this crutch, their test scores were better than the control. Over the course of experiment users in both groups did not improve significantly in their ability to identify intervals.

7 Future Work

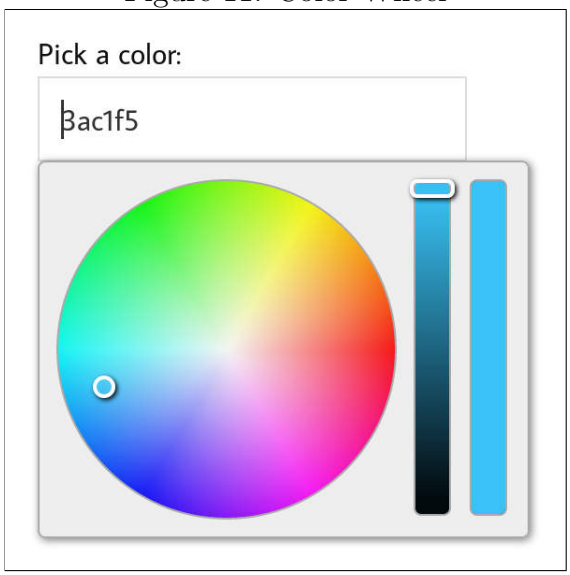
7.1 Dedicated Study

I would definitely like to test this application again in the future. My conclusions are based off of data from inconsistent usage, so repeating the experiment with a dedicated group of participants would be beneficial. I would also like to have a type of rating system where the users could rate their musical background. This information could also be useful for the experiment.

7.2 User Customization

One thing that users suggested was being able to set their own colors for the experiment. User customization could lead to more users feeling attached to the experiment. Allowing users to set there own colors could also improve the results since certain colors mean different things. Perhaps users did not agree with me assigning a calm green to the harsh sound of a tritone. The implementation side of this would not be difficult to implement but designing a proper interface might pose a challenge. Most color picker interfaces are implement with sliders and other advanced features as seen below.

Figure 11: Color Wheel



7.3 Analytical Tools

Some users requested the ability to see their data. I think this would be helpful to include so users could see their progress over time. Users would also be able to recognize trends in their usage, like if they consistently identify minor sixths incorrectly. This would also allow users to focus on their weak points. The easiest way to represent this data is by listing out the intervals and displaying the percentage of how often they correctly identify an interval.

7.4 Perfect Pitch

Another useful tool for musicians is having perfect pitch. Testing this application with perfect pitch rather than relative pitch would be fairly simple to implement. The only functionality that would need to be changed is the button layout and the sound files.

7.5 Libraries

On the implementation side, I would like to use a couple different tools. Since I was working with pure HTML/CSS, the web page is not very responsive. If someone is viewing the page from a mobile device or if their window is not full screened, the information is not correctly displayed. I believe using Bootstrap would allow for easy and dynamic front end design.

Additionally, I had to manually play each interval. There is a MIDI library for JavaScript that could be used to create sound clips dynamically. Using this would also allow for intervals to be played in different octaves. Overall it would introduce more variation in sound clips for the user.

8 Conclusion

This is a project I have been wanting to do for a while. I have always had an interest in music and this project allowed me to combine my passion of music with programming. I started this project with no experience in web development but now I feel comfortable working with HTML/CSS and JavaScript.

References

[1] Bor, Daniel, et al. *Adults Can Be Trained to Acquire Synesthetic Experiences* Nature News, Nature Publishing Group, 18 Nov. 2014, www.nature.com/articles/srep07089