Utilizing Principles of Synesthesia to Develop Perfect Pitch

MUCS2020 Perfect Pitch (2): Report

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ABSTRACT

Synesthesia is a rare condition in which simulation of one sense evokes the experience of another. Research has shown that synesthesia can have a beneficial effect on memory, and that in general teaching methods involving the activation of multiple senses can enhance recall. We utilized this approach in our project by attempting to develop perfect pitch, the ability to identify notes and pitches without reference or assistance, through mimicking the experience of synesthesia. To accomplish this, we created a pair of glasses mounted with a light and interfacing with an app that allows the user to listen to tones while viewing corresponding colors. While far from perfect, users were able to correctly identify pitches with at least some level of accuracy for up to a week after using the device.

INTRODUCTION

Both perfect pitch and synesthesia are very rare conditions, with synesthesia only appearing in four percent of the general population and perfect pitch in less than two [1, 2]. In the musician community, perfect pitch is a highly sought after ability. To be able to recognize and identify notes without a reference such as sheet music is incredibly beneficial for improvisation, composition, and even just learning new music. There is some evidence that perfect pitch has both genetic and learned components, as it can run in families and is more common when musical training is begun at a young age [2]. Our project was designed to try to develop a method for learning perfect pitch by utilizing principles of synesthesia.

The human brain processes information from each of the five senses as part of a whole, not as separate streams of data [10]. Sometimes combining multiple senses while learning can help with later recall. Enhanced memory is one of the benefits of having synesthesia, which we took advantage of while designing our project [9]. If you've ever been told to wear a certain perfume or cologne while studying, then again during an exam to help jog your memory, that advice is operating on the same principle. While prior studies have not found a proven way for synesthesia to be truly induced in a subject, they have been successful in creating long-lasting associations (Rothen). For our project, we decided to associate different tones with corresponding colors to help boost memory and hopefully allow our participants to develop perfect pitch.

To achieve this objective, we decided to design a wearable device in the form of a pair of glasses. An LED is attached to the glasses and remotely controlled by an app we developed. The app allows users to play different notes as the glasses light up, as well as quiz themselves on their note recognition. The device was designed so that users could wear the glasses while going about their day-to-day lives, passively learning to recognize notes rather than actively studying them. We ran two studies, an initial pilot study with the members of our team and a final user study at the end of the project. The pilot study was very successful in teaching us to recognize two notes. The user study was somewhat less successful, but did have some upsides as well as some complicating circumstances that will be discussed later in this report. Overall, our approach was promising as a method for developing perfect pitch.

BACKGROUND

Interest in researching and discussing synesthesia has been increasing in recent years. For many, the idea of having senses that interact with each other in such a way is fascinating. Despite this growing body of research, however, we still don't know much about the actual causes of the condition. There have been documented cases in which synesthesia occured in response to drugs, sensory deprivation or brain damage, but it appears to be largely hereditary [1]. The condition is congenital, and there have been marked structural and neural differences discovered between synesthetes and non-synesthetes [9]. There has been some progress made in understanding the genetic basis of synesthesia, but it's still unclear whether there is some sort of evolutionary benefit to it or if it is simply a side effect of some other trait [1].

Synesthesia manifests itself in many different ways, and even people with the same type of synesthesia can have different experiences in response to the same stimuli [9]. Some people see colors when listening to music. Others can feel letters or taste sounds. Despite these differences, there does seem to be somewhat of a learned aspect to the condition. Researchers have theorized that while the condition itself is biological, the way it manifests depends on the perception, culture and experiences of the subject. For example, synesthetes who played with colorful letter blocks as children may later experience those same colors when reading (Rothen). This learned component of synesthesia has inspired research in trying to induce the condition in hopes of being able to share some of the benefits, such as enhanced creativity and memory.

Neural research has shown that the human brain uses complementary information from each of the five senses to facilitate our perception and behavior [10]. Even parts of the brain that we thought were dedicated to a single sense have recently been shown to facilitate complex interactions between the senses [10]. This interaction may be why synesthesia has beneficial effects on memory. The more senses that are part of an experience, the more cues the brain has to recall it. Different pitches can enhance visual cortex excitability and multisensory experiences have been shown to help people distinguish between different objects [5, 11]. All this has helped motivate the research aimed at teaching synesthesia. So far, there is no evidence that synesthesia can be induced in a subject, but researchers were successful in creating long-lasting associations. For example, participants who were trained to associate colors with letters were not capable of actually seeing the color when shown a corresponding letter, but they were still able to identify the associated color with high levels of accuracy (Rothen). These learned associations are not true synesthesia. However, they may have some of the associated memory benefits, which we took advantage of for our project.

Similarly to synesthesia, perfect or absolute pitch is a rare cognitive ability with some hereditary and some learned components. It tends to run in families, and has been shown to vary depending on environmental and genetic factors [2]. In contrast to synesthesia, however, perfect pitch does appear to have more of an ability to be learned. While in the general population the prevalence of perfect pitch is less than two percent, estimates for musicians have put the ability at as high as fifteen percent [2]. While this could be a simple case of people with more musical ability going into that field, research has shown that the age at which one starts musical training has a great deal of impact on whether or not they have perfect pitch, with those starting at a very young age benefiting [2]. There has been some research done on how visual cues can impact pitch recognition, as well as how sounds interact with vision centers in the brain [5]. It's been shown that visual cues can help improve perceptions of differences in pitch, which was very promising for our use of color to help with recognition of different tones [12].

Since our project focuses on helping people develop perfect pitch through color associations, the type of synesthesia we were most interested in was sound-color synesthesia. Interestingly, despite the previously discussed differences in how people experience synesthesia, there seems to be a fairly universal association between different types of sounds and colors that is mediated by emotion. Regardless of how much people actually like certain types of music, a 2016 study found that faster music in a major key was associated with warmer, more saturated colors than slower music in a minor key [7]. This was strongly correlated with the emotions participants associated with the colors and sounds. For example, the color red was seen as angry and associated with faster music [7]. These music-color-emotion associations don't necessarily correspond with the experiences of actual sound-color synesthetes, but they may be useful for future attempts at imitating the condition.

For our project we chose to create a wearable device. Wearable technology is very useful for ubicomp research due to its ease of use and minimal impact on the wearer's day-to-day life. Some of the prior research that has been done that was relevant to our project included the development of wireless interfaces for wearables and hidden LEDs in eyewear designs [6, 8]. While we didn't have time to redesign our glasses to hide the LED, we did implement wireless control in the second version of our prototype. We also gained useful information from the MISSIVE and Google Glass projects [3, 4]. Research on Google Glass brought up many important issues such as size, weight, battery life, and heat buildup, all of which were important during the development of both Google Glass and our own project [4]. MISSIVE is a recently developed multi-sensory haptic device. Although we focused on visual rather than haptic cues, MISSIVE's success in using passive learning techniques for communicating through an alternative sensory modality was very helpful in providing inspiration for our project [3]. Despite our limited time and resources, we did our best to take into account prior research and design decisions to create the most effective and easy-to-use wearable we could.

user more freedom of movement. We had hoped that the low energy aspect of BLE would lend itself to improving

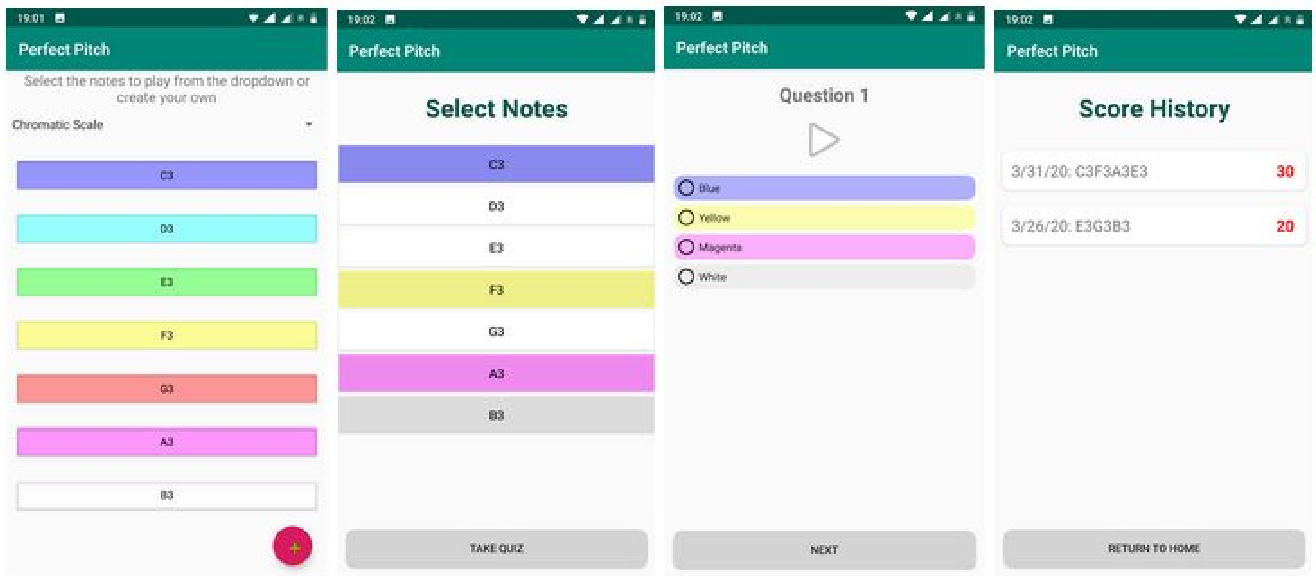

Figure 2. The various User Interfaces of the application

PROTOTYPE AND APPLICATION DESIGN

Wearable Prototype

Our final wearable prototype consisted of an RGB LED, some resistors, an Adafruit esp32 feather, a battery to power the feather, and a plastic glasses frame with the lenses removed. The Adafruit feather has Bluetooth Low Energy (BLE) capability which we used to communicate with our Android application. We took advantage of the fact that the feather is compatible with Arduino libraries and developed the feather code using the Arduino IDE. The feather was set up to receive data from the BLE connection and then drive the LED based on that data. When deciding what information to send to the feather our main question was how to keep track of the proper timing to synchronize the LED with the notes being played. We ultimately decided to minimize the number of places we were performing timing calculations. Instead of having the feather drive the LED for a specified amount of time, the feather would change the LED when it received a command to change. The timing portion of the program was then handled in the application, the wearable only turned the led on with a specific color or turned it off.

With regards to our proposal, the hardware portion of our prototype was able to overcome some aspects of the initially predicted challenges. The device itself was reasonably light and comfortable to wear. The feather allowed us to make the device wireless, which allowed the the battery life of the wearable, but we encountered a few issues with the battery that we used. It needed to be charged more frequently towards the end of testing, and one of the connected wires broke.

Android Application

The main motivation behind the Android application was to provide users with an easy to use interface that they could use to configure their glasses and connect to them. We discussed a list of features that we could add to the application such as the ability to play a pattern of notes/chords/songs and the ability to customize which note goes with which color. In the end, due to time constraints, we decided to restrict our feature list to allow the users to create their own pattern of notes with a pre-configured note to color mapping and the ability to quiz themselves on a selection of notes. Connection to the device was done using Bluetooth Low Energy(BLE) interface provided by the Android OS. Our glasses have their own “Bluetooth Name” and the application searches for the device and when connected to it, starts a service in Android. This service plays a tone according to the user’s playlist and relays the current color associated with that tone to be displayed on the glasses’ LED every 2 seconds by writing to the “bluetooth characteristic” of the glasses. The creation of a service allows our app to keep running even if the user uses some other application or moves our application to the background.

We allow the users to customize their own playlist by adding notes or re-ordering them. At the moment, we are also restricted to just the notes in the C major scale. This playlist is saved in the device's local storage.

The quiz function allows the user's to see how well they are learning the note to color association. They can select the notes that they want to test themselves on and a list of random questions is generated for them asking them to recognize the color that goes with the note. Their final score reflects how many of these questions they got right. We store the results of every quiz that the user takes so they can track their progress to see how well they're learning over time.

Pilot and User Study

We conducted a pilot study among ourselves and a user study with outside participants to test our hypothesis of passive learning through synaesthesia and get feedback on the usability of our application and the glasses.

In the pilot study, we decided to run 4 sessions on each one of us, 2 sessions a day spaced out by at least 6 hours. Each session corresponded to us wearing the glasses for 30 minutes while working on some task (working on an assignment, coding) and a repeating pattern of notes played in the background. The pattern was C3-G3 with each note being played for 2 seconds. We chose these two notes because G is the fifth note in C's chromatic scale and thus, easily distinguishable. C3 was mapped to blue and G3 was mapped to red and the glasses would display this color on the LED while the corresponding note was played. After the 4 sessions were over, we took two tests. One immediately after the completion of the last session and one 24 hours after. These tests consisted of 6 questions, ordered randomly. Each question asked us to associate a note to a color. We tested ourselves on 3 notes, C3, E3 and G3 and the options for colors were Red, Green and "None of the above". We selected E3 as the third note because it is almost equidistant to C3 and G3. Each of us scored 100% on both the tests and were quite confident in associating the note to the color that we saw.

Due to the situation at the time of conducting this experiment (social distancing guidelines due to a pandemic), we had some difficulty in recruiting participants for our user study. The participants were all Georgia Tech graduate students between the ages of 23 to 28. In this study too, we decided to run with 4 sessions, 2 on each day, spaced out by at least 6 hours. We increased the pattern of notes that we were training on to 3 ,C3-F3-G3 with the colors being blue, yellow and red respectively. We decided to add F3 to the pattern because it is a note close to G3 and would help us in seeing how granular people's note discerning skills could be. The number of tests were increased to 3; one immediately following the last session, one 24 hours later and one a week after the last session. The number of notes we tested the participants on were also increased to 5. These notes were B3, C3, E3, F3 and G3. We included E3 because it is only one semitone away from F3 and B3 because it is well separated from the rest of the group, thus helping us note how much the participants could discern between notes that were close and notes that were well separated.

RESULTS

The participants filled out a survey upon completion of their last session, one 24 hours after and one a week after the last session. We gathered feedback on the quality and the comfort of the device. Participants found the device easy to use and comfortable, with the quantitative details represented in Fig. 3. Some participants who wore glasses already had trouble with adding on another pair of glasses on top. Charging the device was also reported as a problem. To work around this problem, we envision the device without the glasses which could be snapped on to any frame. The LED on the glasses were clearly visible to all participants and the selection of tones that played were also generally pleasant to listen to. The participants found the application easy to use and straightforward with additional features of time tracking to be easily able to track the number and duration of sessions that the user completes and

#	Field	Minimum	Maximum	Mean	Std Deviation	Variance
1	Comfort of the Glasses	4.00	5.00	4.33	0.47	0.22
2	Usability of the App	4.00	5.00	4.67	0.47	0.22
3	Pleasantness of the Sound	3.00	5.00	4.50	0.76	0.58

Figure 3. Feedback on the comfort and usability of the device and application

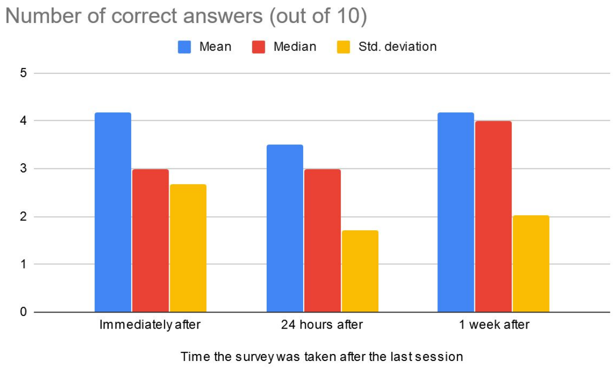

Figure 4. Mean, Median and Standard Deviation for the number of correct answers to the questions

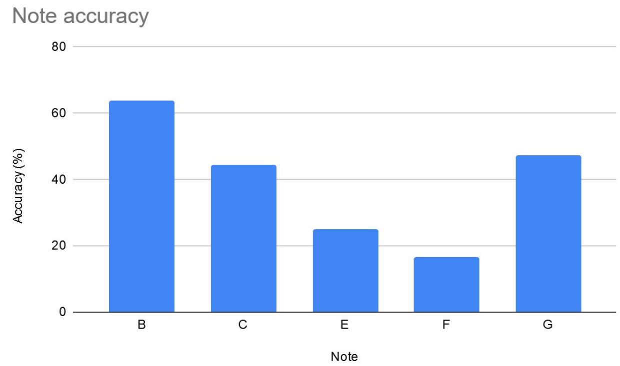

Figure 5. Accuracy of correct color association for individual notes

tune playing to be able to train on a simple tune being requested.

We also tested the participants' ability to recognize notes that they had trained on. Five questions were posed to each participant, on each iteration of the survey. Each question had a playable note and asked the participants to recognize the color that they think should go with that note. After the participants finished those 5 notes, they would be given an option to go back and listen to those notes again and change any answers if they want to. Overall, the participants reported an accuracy of about 39.44%, i.e they were able to associate the color to the note about 4 out of 10 times which is slightly better than chance. However, this metric was skewed by one participant who had very high accuracy on all three tests (83.33%). The median correct answers for each round of the survey were 3 for the tests conducted immediately after and 24 hours after the last session and 4 for the test conducted a week after the last session. Surprisingly, there wasn't much difference in the number of notes participants were able to recognize immediately after the session and one week after the last session.

We broke the data further to see how participants fared on each note and if there were certain notes that the participants struggled with. We found that all participants reported high note to color association for B (63.89%), C(44.44%) and G (47.22%) notes and struggled with E (25%) and F (16.67%). This could possibly indicate better association with certain colors (C - Blue, F - Yellow and G - Red), an artifact of the pattern that we used to train the participants, possibly forming a certain scale that makes C and G easy to recognize or it could be a statistical anomaly. High recognition of B can be explained by the large tonal distance between B and the rest of the notes. This large distance made it easier for the participants to correctly identify B as an outlier. More studies would be needed to confirm why this anomaly exists for E and F. While filling out the answers to these questions, participants reported recalling the colors associated with the sound but not experiencing seeing the colors. Our findings were consistent with earlier findings of not being able to induce synaesthesia in an experiment of short duration.

CONCLUSION AND REFLECTION

In the end, we were able to achieve most of our objectives. We created a wearable prototype and application which had slightly less functionality than our proposed version due to external factors and the move to a distance learning format. The results from our initial pilot study and later user study suggest that the device may successfully improve the ability to identify tones, but requires more research to be certain. Our participants reported that they remembered the color associated with the tone but did not see it, meaning that we did not induce synesthesia but there was still an association made between color and tone. The overall design and development of our prototype went smoothly for a small team with varying schedules. We could have definitely used more practice designing a user study that would have produced more definitive results, but the study that we carried out was a good experience. If we were to continue our work after this semester ends, it could potentially improve the learning experience of musicians everywhere. Future studies could have longer running participants to investigate whether the color/tone association is just a short term association or if it will last for a long period of time, add chords and simple songs to the app, and seek feedback from actual musicians in order to best help our target demographic.

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