

Simulating Chromesthesia through Augmented Reality

*An immersive program delving into synesthetic
neurological deficits and their impact on
catalyzing research for medical advancements*

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Table of Contents

I.	Abstract.....	Page 2
	a. Project purposes	
	b. Procedural outline	
II.	Background/ Introduction.....	3
	a. What is chromesthesia?	
	b. Scientific debates	
	i. Psychological vs. Neurological?	
	c. Expanding on theories	
III.	Problem Statement.....	4
	a. Real world applications	
	b. Chromesthete advantages	
	c. Call to Action	
IV.	Competing Designs.....	5
	a. Videos compared to AR	
	b. Benefits of AR	
V.	Risk/ Safety Precautions.....	6
VI.	Materials.....	6
VII.	Method.....	7
	a. Planning process	
	b. Creating the app	
	i. Algorithms/ scripts	
	c. Deciding factors to focus on	
	d. Importance of key signature and color	
	i. Relevance to chromesthesia	
VIII.	Data.....	8
	a. Parts of the app	
	b. Song selections	
	i. Genre	
	ii. BPM	
	iii. Key signature	
	c. 3D object assignment	
	i. Tones	
	ii. Colors	
IX.	Conclusion.....	8
	a. Error statements	
	b. Future ambitions	
	i. With program/ Generalities	
X.	Bibliography.....	10

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Abstract

The goal of this project was to convey both the restrictions and benefits of chromesthesia in real time, in a way that maximized the opportunity for an immersive experience. Upon witnessing a project in eighth grade about visual and auditory synesthesia, the multi-faceted topic of synesthesia has enamored me- this combined with my augmented reality (AR) project from last year prompted me to code an app that provides insight on this neurological condition. In creating this app, I used Unity as my primary platform because of its simplicity and susceptibility to AR/VR projects. After coding a live camera script in C#, I used algorithms from Unity assets to track three components and assign each to a shape: bass tones, mid tones, and high tones. The shape that those tones were assigned to were then each assigned a hexadecimal value based on the song to show how key signature affects the colors that chromesthetes see. Using this universal algorithm, I could apply any song I wanted- as long as I changed to colors to accurately represent its key signature. Since this project is unorthodox in its structure and purpose, which is to ultimately use AR to garner empathy and stimulate research for lesser known neurological disorders, the only tangible and/or quantitative data was taking into account BPM and how the positions of the 3D shapes fluctuated in the program. With the use of the program and more AR apps like my colorblind simulator from last year, I hope to raise awareness and catalyze research for abnormal conditions and how they can be used to aid in creations of solutions for more serious medical disorders.

Background

Chromesthesia is a form of synesthesia that is triggered by sounds, most notably, music. This synesthesia causes recipients to see different colors, patterns, and textures based on the noise they're hearing ("Hearing in colour – Synesthesia and musical composition."). The topic of synesthesia does not present with many concrete causes, but there have been speculations of it being a gene that tampers cross wiring between the audio and visual parts of the brain, as well as it being more psychological ("Synesthesia Research."). The *neonatal synesthesia theory* outlines the more neurological idea that synesthesia was developed early in life- newborns are said to have some synesthetic experiences due to an abundance of neural connections, and some scientists believe their brain simply never developed from that ("Synesthesia Research."). However, psychological synesthesia enthusiasts believe chromesthetes could attribute their vivid blue sights when they hear a piano piece because possibly their favorite piano book as a child was blue (Anderson). This kind of trained synesthesia is not a popular theory among scientists, however, largely due to the fact that synesthesia has been proven to be linked to autism- suggesting a more irrevocable neurological aspect to it (Anderson). While only 7.2% of typical people experience synesthesia, over 18% of autistic individuals experience it in one way or another (Anderson). This is a blanket statistic, including many types of synesthesia beyond chromesthesia. Along with psychological versus neurological debates on synesthesia, there are also disputes over whether synesthetes have completely different structured brains or just stronger connections between brain areas ("Synesthesia Research."). A completely different structured brain would mean that synesthete brain areas were rearranged to be closer to one another, meaning information for one area could possibly trigger another area based on close vicinity ("Synesthesia Research."). If this theory was accurate, that would mean chromesthetes

had audio and visual areas very close together, while audio-tactile synesthetes would have touch and audio areas close to another. Those attributing synesthesia to high levels of neuron connections would suspect synesthetes to have a hyperactive parietal lobe- the part of the brain that is responsible for binding brain areas together and thus triggering synesthetic reactions ("Synesthesia Research."). This lack of concrete knowledge surrounding synesthete origins/ neurological structure can be blamed in part to the fact that most people didn't believe synesthesia was real until the late 19th century ("Synesthesia Research."). Along with that long lasting misconception, it remains not exactly a priority on scientific agendas- its research is growing, but not enough to fully understand its origins or ramifications on succeeding generations.

Problem Statement

The aim for this app is to accurately simulate a facet of chromesthesia, with the ultimate goal of prompting research for neurological conditions. Synesthesia is one of many disorders not seen as a priority in the world of science, however it provides important insight into unique brain wiring- insight that could possibly be used to solve other, more pressing conditions. For example, synesthesia is known to exhibit signs of increased density of gray/ white matter in certain brain parts ("Synesthesia Research."). Gray matter, simplified, is involved in paralysis and muscle weakness, as well as in using motor skills and interpreting sensory information ("What's the Matter?"). White matter is instrumental in sending nerve signals, allowing ability to move, and provoking reflexive reactions ("What's the Matter?"). If scientists researched more heavily on why synesthetic individuals produced such excessive amounts of white and gray matter, it would open up medical possibilities pertaining to injuries caused by white/gray matter damage. After harm inflicted on said matter, like spinal cord injury or intracerebral hemorrhage,

it typically takes longer in adults than children to reproduce all the white/ gray matter necessary for optimal health (Villines). Knowing exactly why synesthetes were born/ evolved to have this advantage would be unparalleled in terms of aiding the maladies brought upon by white/ gray matter damage. Because synesthesia is fairly irrelevant due to it being seen as an advantage rather than a hindrance, researchers don't prioritize it- that is why I want to spread awareness through this AR program. Not only is it valuable in terms of empathizing with chromesthetes, it would implore the user to think more inquisitively on the subject. This type of deeper reflection provoked by a harmless program could then possibly trigger a more focused research on its origins, seeing as though right now the basics of synesthesia are not yet solidified. Knowledge is power, and through AR I intend to educate as many people as possible on non topical conditions so that they may use that power to solve related medical diseases.

Competing Designs

There are multiple videos online that simulate chromesthesia, but usually on a blank background or on a preprogrammed video ("How a Person With Color Synesthesia Perceives Music."). My app differs from these in multiple ways. For one, the algorithm and assets I used are completely susceptible to any song. All I need to do is put a song's .mp3 file into the program, and the viewer can see the simulated chromesthesia with that song. This personalized effect is much more memorable than watching a video with a song you may not know well enough to fully understand how the rhythms, BPM, dynamics, and tempo affect the visuals depicted on the screen. Another way my program is different is that in addition to being AR, it renders in real time. This means the viewer is able to walk around and notice their surroundings with the chromesthesia, just like a chromesthete would. This extra level enhances user empathy and understanding for the condition, as well as takes out the imagination users are forced to use

when just looking at it on their computer. There are multiple paintings, computer graphics, descriptions, and videos online on this topic, but they all lack to personalization and immersion of this AR program.

Risk/ Safety Precautions

Despite the project being fairly tame, I made sure to be cautious in testing the program. To avoid nausea and dizziness, I made sure to always be seated while testing, and I never kept it on for the duration of all 6 song *consecutively*. I made sure to notice the temperature of the phone to verify that it didn't overheat from excessive use. Just to be extremely careful, I kept all liquids far from my computer and phone. Lastly, I made sure the phone was secured in the goggles before putting it on to avoid the phone dropping and possibly shattering.

Materials

- Samsung Galaxy S5
- Windows computer
- Google Cardboard goggles
- Unity 5.6.4 (programming module)
- Microsoft Visual Studio (for coding C# scripts)
- Headphones

Method

The creation of this program was difficult because of how many possibilities there were. I already knew I wanted to simulate chromesthesia on a real time camera with binocular rendering, but I never really thought out what aspect of it I would focus on, which was the first error. After

coding the live camera script and importing it into Unity, it took me about a week to construct the program using the Visualizer Studio asset- and from there, I spent an entire day familiarizing myself with the controls and GameObject triggers ("Visualizer Studio."). The biggest problem with not having a set facet to focus on was that I was overwhelmed with the possibilities and tried doing too many things at once. Eventually I realized that I would need to focus on one part of the music and build the program around that.

I ended up choosing the tones of the song to analyze. I set up three 3D GameObjects (sphere, cube, cylinder) and assigned each a tone to track. The sphere would pulse when it detected a bass tone in the song, and the cube and cylinder would do the same for high and medium, respectively. The reaction time was set to the minimal amount so the objects would pulse as soon as their assigned tone happened in the song, with the illusion of it being immediate and without any buffering time. After completing the grunt work of the project, I moved on to choosing songs. I decided to pick one from each major genre of music, barring rap due to school friendly restrictions, and I made sure each song was a different key. This was vital because chromesthetes are said to associate different colors to different keys and I wanted to have as diverse of a color scheme as possible ("Hearing in colour – Synesthesia and musical composition.")(Palmer). Each 3D object was then given a hexadecimal value corresponding with its key, and I was able to trigger a constant stream of particle explosions (with the correct colors) to add pizzazz to the program.

Data

SONG TITLE	ARTIST	SONG GENRE	KEY SIGNATURE	COLORS	BPM
<i>Bye Bye Bye</i>	NSYNC	Pop	A \flat Major	Yellow, Red	173 BPM
<i>Movin' Out</i>	Billy Joel	Classic Rock	D Minor	Yellow, Purple	134 BPM

<i>All to Myself</i>	Dan + Shay	Country	D \flat Major	Purple, Blue	95 BPM
<i>Last Nite</i>	The Strokes	Indie	C Major	White, Red	104 BPM
<i>Brandenburg Concerto No.2</i>	Bach	Classical	E Major	White, Green, Yellow, Red	97 BPM
<i>Best Part</i>	Daniel Caesar, H.E.R	R&B	G Major	Orange, Green	75 BPM

Color (Hexadecimal Value)

SONG GENRE	CYLINDER (Mid)	SPHERE (Bass)	CUBE (High)
Pop	FF1912	FFC90A	7F0D09
Classic Rock	FF5BE8	FFC90A	7F2D74
Country	1921FF	DB55E5	719AFF
Indie	E51710	FFFFFF	7F0D09
Classical	49FF32	FFF700	E51310
R&B	5AFF33	FF6105	2D7F1A

Conclusion

The effort to create the chromesthesia program was successful in that I was able to track the three tones of the song as accurately as possible. Each song, despite having the same shapes in the same position, was able to be a unique experience because of the colors designated based on key signature. The lack of testing a tangible hypothesis rendered me without results/ data to analyze, but the algorithm worked as expected and I was able to glimpse into the world of chromesthesia- which was the overarching goal of the entire experiment. The program's ability

to encourage change in the field of neurological research cannot be measured, but I will keep advocating for increased visibility of lesser known conditions both with and without this app.

The errors while creating this app were frequent and often those of impactful caliber. I already discussed the issue of wanting to do too much at once in the methods section, and that particular error set me back immensely. In order to capture the essence of chromesthesia to the best of my abilities, I had watched countless videos depicting it as perceiving 10 different shapes and colors at once, and coding such a feat would've been extremely difficult. I had first attempted to code individual data sheets per song rather than a universal algorithm because I wanted all those shapes and colors bombarding the user, but after realizing the complexity and tediousness of that magnitude of code, I reverted back to an asset that could be applied to every song. Since I am self taught in the language of C# and in the interface of Unity, it was challenging getting the shapes to appear large enough for the viewer to see until I realized that changing the z position was much more beneficial than changing the scale of the objects. My knowledge from my science fair project last year was extremely useful, but there was still a significant amount of trial and error involved in getting the app to work just how I wanted. Another issue was the reaction time of the shapes. Because this algorithm triggers the shapes to pulse in real time as the song is playing, I had trouble making the reaction time short enough that the shapes were in sync with the music; Unity already has buffering issues with VR and I didn't want to exacerbate that. Despite the fact that I made the reaction time as short as possible, there's still a brief moment before the trigger, making the shapes and song look slightly unsynchronized.

In the future, I would like to possibly expand and take other musical factors, such as pitch or tempo, into account to make the program more true to chromesthesia. Whether that be through tedious but accurate data sheets made specifically for each song or through a complex

but accessible algorithm that can be applied to any song, I plan on finding ways to help execute this condition to the best of my abilities. In a broader sense, I want to continue making empathy centered programs like this one and my project last year. I want to push scientists to delve deeper into the world of smaller conditions that perhaps aren't a global priority, and see how the understanding of that condition could help other, more damaging infirmities. I would also like to strive to make programs like this to reduce ignorance in our nation. With accessible and entertaining VR/AR apps, users tend to glean empathy and knowledge on subjects without even realizing it. And since apps are so easy to download and spread, empathy centered apps can help foster a more educated and tolerant demographic, which is vital because of the sheer amount of people affected by uncommon neurological anomalies. They deserve to be surrounded by those who are more susceptible to understand what they must live with as well as those who are working to further solidify causes and long term effects of such conditions.

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