Understanding chromaesthesia by strengthening auditory-visual-emotional associations

O'Toole, Patrick; Glowinski, Donald; Mancini, Maurizio

How to cite

O'TOOLE, Patrick, GLOWINSKI, Donald, MANCINI, Maurizio. Understanding chromaesthesia by strengthening auditory-visual-emotional associations. In: 8th International Conference on Affective Computing and Intelligent Interaction (ACII). Cambridge (United Kingdom). [s.l.] : IEEE, 2019. doi: 10.1109/ACII.2019.8925465

This publication URL: https://archive-ouverte.unige.ch/unige:150360

Publication DOI: 10.1109/ACII.2019.8925465

2019 8th International Conference on Affective Computing and Intelligent Interaction (ACII)

Understanding Chromaesthesia by Strengthening Auditory-Visual-Emotional Associations

Patrick O'Toole
Digital Arts & Humanities
University College Cork
Cork, Ireland
patrick.otoole@umail.ucc.ie

Donald Glowinski
Swiss Center for Affective Sciences
University of Geneva
Geneva, Switzerland
donald.glowinski@unige.ch

Maurizio Mancini
School of Computer Science and IT
University College Cork
Cork, Ireland
m.mancini@cs.ucc.ie

***Abstract*—Can cross-modal associations between notes and colours and between notes and emotions be strengthened by using an ad-hoc designed computer program? In this paper we present an experiment that we conducted to see (H1) if participants' associations between the auditory and visual senses could be strengthened through immersion in a multi-sensory program and (H2) if there was any correlation between auditory-visual and the auditory-emotion associations. In our experiment, participants were asked to use the SoundStrokes program, an application that translates notes played on an analog music instrument (i.e., a guitar) into coloured graphical shapes (i.e., rectangles). After several training sessions with the program, participants were asked to associate single music notes to colours and emotions. Applications of our work may vary from entertainment, to enrich in a systematic manner the user emotional experience in, for example, videogames or immersive experiences, to digital health, in which relatively simple tools can be developed, for example, to reduce anxiety through music.**

***Index Terms*—chromeasthesia, cross-modal association, emotion, sound, colour**

I. Introduction

This paper investigates the area of cross-modal associations between the auditory and visual modalities and the role emotion plays in these sense modalities. The research questions this paper seeks to provide an answer are:

1) Can cross-modal associations be strengthened through immersion using a theory connecting sound to colour?
2) Does emotion emitted from colour correspond to emotion emitted from sound?

Synaesthesia, particularly chromaesthesia, and its relationship with cross-modal associations is also investigated to keep a better understanding on the topic. Synaesthesia is defined as an individual experiencing sensation in an expected sensory modality but also involuntarily experiencing a sensation in another sensory modality [1]. In chromaesthesia, the above description is experienced between the auditory and visual modalities. Synaesthesia is a rare condition that affects between 2 - 4% of the population [2], [3], with chromaesthesia, roughly occurring in only 0.2% of the population [3].

While this paper's main focus is the investigation into the possibility of strengthening auditory-visual associations and the role of emotion in the general population (can single musical notes elicit a strong emotional response?), Ward et al. [4] see the study of synaesthesia, and in particular chromaesthesia, as important to inform theories on normal cognition and that it might be present in us all from a young age. That is, while understanding can be gained from synaesthesia, it is important to understand how non-synaesthetes associate different sensory modalities and, as we will show later, maybe the concept of synaesthete vs. non-synaesthete is the wrong way to refer chromaesthesia/auditory-visual associations.

Interest in synaesthesia spanned mainly the fields of Neuroscience, Psychology and Art, receiving a lot of attention during the 19th century with many artists interested in sensory fusion [1]. Art and creativity have been shown to be a popular outlet for synaesthetes. Campen [5] highlights a correlation between artistic people and synaesthesia, i.e., the University of Arizona conducted an interview with 358 fine art students at three universities and found 23% of them to have synaesthesia. Two artists that stood out as revolutionary for the use of synaesthetic perception in their art were Wassily Kandinsky and Alexander Scriabin. The aforementioned artists theorised about sound-colour associations for most of their life, creating many pieces of work as well as Scaribin's "circle of fifths" theory and Kandinsky's "aesthetic" theory [6].

II. Background

A. Synaesthesia: Classification, Categories and Types

Different fields have investigated synaesthesia in an attempt to establish a firm hypothesis on how and why synaesthesia appears in a small number of the population. With the large number of synaesthetic associations and the different situations it can arise from, it is tough to postulate one theory for synaesthesia.

Hill [7] describes Baron-Cohen and Harrison's theory of 4 primary classifications for synaesthesia: Developmental (develops in early childhood and is vivid, automatic, involuntary and unlearned), Metaphorical (linguistic expression of one sensory experience in terms of a differing experience), Acquired (revealed after injuries or physiological conditions), and Drug induced (temporary effects that wear off).

As stated, chromaesthesia is one of many categories of synaesthesia. There are over 60 known categories of synaesthesia, including odor-colour, taste-colour, sound-tactile, sound-colour, and grapheme-colour which is the most common category.

Synaesthesia can be perceived as either one of two types. Associators can be described as experiencing colours in "the minds eye" or "knowing the colour" when a different sensory module is stimulated. Projectors, on the other hand, describe seeing colours which are often projected outside the body and into external space [2]. It has been shown that the brain reacts differently in associators when stimulated, than that of projectors. A study has found projectors to have structural differences in other brain regions than those classified as associators [8]. This led them to suggest that experiencing internal versus external concurrents differs in terms of underlying neural substrates [8]. With these different neural mechanisms, colour memory is possibly crucial to associator synaesthetes [8].

If colour memory is crucial to associator types and, with cross-modal correspondence in non-synaesthetes and how they associate colour with other sensory stimuli (see also Section II-B), it could be suggested that everyone has the potential to be synaesthetic and that the question of, "do you have synaesthesia?" could be the wrong question. Campen [5] views this question as being too straightforward. She tested 223 fine art students, some of which were synaesthetes and some who were not, so she expected to view two peaks in her graph. However, she found a more gradual distribution of synaesthesia scores between 0 - 100% with no clear line between synaesthetic and non-synaesthetic scores. This led her to change the question above to the more fitting "How strong is your synaesthesia?".

B. Cross-Modal Correspondence

While a lot of understanding can be gained from synaesthesia, it is important to understand the links between how synaesthetes and non-synaesthetes use cross-modal correspondence when associating different senses, that can build a strong narrative around the question of "How strong is your synaesthesia?".

Many different theories can be found on colour and how it connects to our senses, emotions and has importance in chromaesthetic perception. There have been numerous studies undertaken in sound and areas related to chromaesthesia. They shown that high sounds can be associated with brighter colours, while low sounds are associated with darker colours [2], [4], [9]. Studies have also found other low-level associations between timbre-saturation, loudness-brightens and pitch-size [10]. While this paper will deal with mostly low-level associations, it briefly points out some high-level associations in sound. Studies show that the major mode can be associated with brighter colours and minor mode with darker colours, showing that melodies (or a collection of notes) can influence associations [11]. The colour theories researched in this paper, relating to sound are those of Isaac Newton [12], of composer Scaribin [6], whose theory was based on chromaesthesia and spent a lot of time researching the connection between sound and colour, and the one mathematically connecting light and sound frequencies [13], [14].

C. Emotions

This paper also seeks to provide indications about connections between emotion-colour and sound-emotions. Plutchik's wheel of emotions [15] is a theory based on the complementary colour wheel, where opposite colours in the wheel are connected. In his wheel of emotion, the four main emotional opposites: happy/sad, anger/fear, distrust/trust and surprise/anticipate sit across from each other on the wheel. These emotions are connected to certain colours and the eight outer segments are blends of closely situated colours and emotional words ("joy" & "trust" = "love", "yellow" & "light green" = "wedge of lime"). Plutchik's wheel of emotion is shown as a way to understand emotion-colour connections, with Hevner's model used for sound-emotion connections [16].

Emotions play a role in every human action, it has been shown that enhancement of emotional perception is significant in, not just conscious, but also subconscious conditions [17]. This shows that we can be oblivious to the fact that every decision we make is informed in some way by emotion and shows the importance of considering emotion in any research on human perception.

Cytowic [1] states that our species evolution was not just brought about by our large frontal lobes that would benefit logical and more computational abilities, but developed along with the limbic system and hippocampus. The limbic system decides questions of salience and relevance and how we act on information, it is the place where all information passes through before being redistributed to the cortex for analysis, the gateway to perception [1]. With this thought, it would be hard to investigate sound-colour associations without investigating how emotion plays a role.

Palmer et al. [11] conducted tests showing that sound-colour associations were highly consistent with the emotional mediation hypothesis (i.e., when people listen to music, they have emotional responses and pick colors with similar emotional content). Tawny & Schloss [18] show similar results when testing connections between sound, colour and emotion, where subjects perceived music in major scale and at a faster tempo to be lighter in colour and be happier, and the opposite for music in the minor scale.

Hevner [19] created a model where emotive language is split into groups, with each group containing similar emotional expressions. Participants were given musical excerpts to listen to with different tempo, rhythm, keys and asked to provide their emotional response. The study found out strong connections between emotional responses and music keys, with major keys eliciting mainly happier emotions while minor keys being perceived more sad.

Compared to the works described above, our experiment focuses on lower-level associations between single notes (instead of musical excerpts) and emotional states.

III. Experiment

We now present our study aiming at confirming or rejecting the following hypotheses:

- **H1** - participants' associations between the auditory and visual senses are strengthened through immersion in our program `SoundStrokes`;
- **H2** - there is correlation between auditory-visual and auditory-emotion associations.

A. Participants'

18 people agreed to take part in the study, that was conducted in accordance with the Declaration of Helsinki. The study was approved by the competent local Ethics Committee The test took 7 people with minimal musical experience and 11 people who were proficient musically. Out of the 18 participants', 16 declared themselves as right-handed and 2 as left-handed. Everyone was asked to state their age group, with 9 people declaring that they were between 26 - 35, 4 people within the 18 - 25 group, 5 people between 36 - 45.

B. Pre-testing

Before commencing the experiment, participants were emailed a brief explanation and instructions to take a preliminary online test for synaesthesia called `The Synesthesia Battery`[1].

This is a website that allows people to take online tests for various forms of synaesthesia, to check if they are synaesthetic. The participants' were instructed to choose only the "music pitch to colour" synaesthesia test as that would correlate with the rest of our experiment. The test took roughly 5 mins and comprised of the participant listening to 12 different notes, 3 times, and to choose a colour on the RGB scale that they represent with that note. At the end, a score was given, with the score for synaesthetes expected to be below 1.0 and for non-syntesthetes to be around the 2.0 mark. Out of the 18 participants', no one scored below 1.0, so no one could be classed as being a synaesthete. However there was a range of different scores, with the lowest being 1.2 and the highest being 2.8 that gives strength to Campen's [5] idea that there is not clear line between synaesthetic and non-synaesthetic abilities. The average score of all participants' was 2.03, which is classed as non-synaesthetes who use memory or free association.

C. Apparatus

The `SoundStrokes` program was run using `Processing` on a MacBook Pro 13", which used an external screen to display the program. With the `SoundStrokes` program being displayed on the external monitor, the MacBook Pro 13" screen was used to conduct the cross-modal association tests. `Logic Pro X` was set up to output the sound from the guitar, connected to the audio interface, to the headphones. The audio interface used was an `Audient iD14`, which managed the input of the guitar and brought the signal into the `SoundStrokes` program to extract the correct frequency of notes. It was also used to output the sound from `Logic Pro X` and from the sound files in the survey to the headphones. An iPad was used to make the colour choices using an app called `Color Picker`. A '72 Fender Telecaster electric guitar was chosen as the musical instrument to emit sound in this experiment.

[1]https://www.synesthete.org/

D. Sound and Colour Stimuli

The sound stimuli used for the experiment came from two sources: the guitar, providing sound feedback to the participants' while they use the `SoundStrokes` program, and sound files previously created in `Logic Pro X` using the same guitar, where each note was recorded to a mono track with each note lasting 6 seconds. The same guitar was used to help promote reliable answers because, with instruments having different timbres, the same note can cause different associations, which could skew the results of the test [4]. The guitar signal was also sent to the `SoundStrokes` program which read the default sound input and calculated the frequency of the signal.

The colour stimuli used for the experiment also came from two sources: the colours produced from the `SoundStrokes` program and the colours to associate with a certain sound. In both cases, the colours were the same 12 colours: Blue, Blue-Indigo, Indigo, Indigo-Red, Red, Red-Orange, Orange, Orange-Yellow, Yellow, Yellow-Green, Green, Green-Blue. Within the `SoundStrokes` program, these colours were assigned to certain frequencies using RGB format and when that frequency was triggered by the note played on the guitar, it drew a rectangle to the canvas in the colour associated with the note. This outputted a form of geometric abstraction influenced by Concrete or De Stijl styles of art [20]. For the colour image used in the `Color Picker` App in testing, an image was created by drawing boxes and using the fill tool and the RGB scale to fill each box with the colours congruent in the program.

E. Procedure

Figure 1 shows one of the participants' performing the experiment.

Each Participant was involved in a one-on-one experimental session with the experimenter lasting 60-70 minutes and consisting of 4 stages, once the pre-test (see Section III-B) was taken. Each session stage involved 1 training and 1 test phase.

At the beginning of the session, participants were given an information sheet outlining what the research being carried out was and a breakdown of how the experiment session will be run with an approximate running time and information regarding opting out of their data being used. Everyone gave consent to take part in the test. Participants also took an online hearing test[2], which lasted roughly 5 minutes. Results of the hearing test showed that no one had any hearing problems that would affect their ability to make informed decision during the session.

Before beginning the experiment, participants were instructed on how the `SoundStrokes` program works and

[2]https://www.beltonehearingtest.com

Fig. 1. One of the participants being tested and the setup for the testing stage.

were given a feel for the guitar and, for people unfamiliar with playing it, a basic instruction on how to play basic notes. Participants' were also instructed by the experimenter that only the first 12 notes would give output to the display and to focus on the first 12 frets of the Low E string. They were also told to concentrate on the display in relation to what note they play on the guitar but no rigid instruction on how to play the guitar was given. It is our opinion that this learn-by-playing approach promotes more engagement.

During the experiment, participants had to perform 3 sound-colour (s-c) and 1 sound-emotion (s-e) association stages, each one preceded by a training phase lasting 5 minutes. So, the entire procedure was the following: training 1, s-c test 1, training 2, s-c test 2, training 3, s-c test 3, training 4, s-e test.

The three s-c stages were identical, except the first one which was preceded by a questionnaire on the participants' musical experience, age group and left/right hand inclination. The 12 questions on sound-colour associations were present in all the three s-c stages. Each question contained a link to a sound file containing one musical note played on the guitar, ranging from E0 to D#0. So, each participant had to listen to 12 different notes, whose order was randomised during each stage of the experiment. An iPad using the `Color Picker` app displayed 12 colour choices the participant could choose from upon hearing a sound stimuli. When choosing a colour it gave a numerical value that the participant could then input into the answer field for each question. They could listen to the sound stimuli as many times as they wished but once they had moved to the next question they could not go back.

At the end of the third s-c stage, participants could train with the program for 5 additional minutes and, after that, they took the final sound-emotion association test. Participants' were guided to take the s-e association survey, where they were given 4 basic emotional responses (joy, anger, sadness and fear) to choose from after listening to the sound stimuli. If the exact emotion that they felt was not available, they were asked to choose the emotion from the available ones that was closest to it. Once the 12 questions were answered, participants were invited to express any overall feedback or insights they had on the entire session.

F. Data Handling

Google Forms was used to gather participants' answers from each sound-colour and sound-emotion test which was connected to a Google Sheet which housed all the data. A script was run on all the sound-colour answers to present the data in a visual way, helping to compare colours between answers and participants.

G. Analysis

For the sound-colour tests, we converted participants' colour choices to integer scores. Since the use of two circular constructs with a colour wheel and musical note system were researched, a similar approach for scores was ideal to rate which sound-colour associations are more congruent than others. If a participant chose the expected sound-colour association (i.e., the one that was used by the `SoundStrokes` program), they would score a zero; if they chose the furthest option in respect to the correct association, they would score a six. So, the higher the score, the more the association is incorrect, and vice-versa. This is because they could only be six spaces away in either direction to the correct option. The scores for each question in a sound-colour test were added together for each participant to give a total score for that test, which could be then compared with the other two test phases to look for a trend. Once the data was ready for analysis, Page's trend test [21] was chosen to check for significant trends in the data.

For the sound-emotion test, each emotional word was coded to a number, with Sadness = 0, Anger = 1, Joy = 2, and Fear = 3 (following the colour order in the Plutchik's wheel of emotions [15]). To analyse the association of emotions to sound, the Intraclass Correlation Coefficient (ICC) statistical test was used to measure the agreement between participants choices. Additionally the `Tableau` and `Voyant` software was used to do some extra visual analysis on the datasets and to visually represent the best and worst colour-notes scores, and word clouds for emotions chosen.

H. Results

1) Sound-colour association tests: Page's trend test run on all participants showed that no significant result was present. While the test showed an overall improvement between the 3 s-c tests (mean difference of 0.1 between tests 1 & 2; mean difference of 0.36 between tests 2 & 3), there was not enough improvement to find a significant trend between them. To evaluate socio-demographic aspects we conducted separate

TABLE I
RESULTS FROM PAGE'S TREND TEST ON THE DIFFERENT GROUPS FOR THE SOUND-COLOR (S-C) ASSOCIATION TEST

Groups	**Participants'**	**L Score**
All Groups	18	224.5
Musical	11	142.5*
Non-Musical	7	82
Age: 36-45	5	66.5*
Age: 26-35	9	112.5
Age: 18-25	4	45.5

* A significant trend was found ($p < .05$)

checks for musical experience and age groups. The Page's trend test was run again on age groups: the 18-25 and the 26-35 groups did not exhibit any significant trend, while the 36-45 age group produced significance (see Table I). Next, a Page's trend test on the 11 musical and the 7 non-musical participants' was run. While the non-musical participants did not exhibit any significant trend, the musical participants did (see again Table I).

2) Sound-emotion association test: We evaluated the participants inter-agreement for the sound-emotion test by computing the Intraclass Correlation Coefficient (ICC), which was $.639[.239 - .884]$. This value is considered as acceptable and may show a relative good agreement between participants in evaluating the emotional correlates for each listened note. As for the possible socio-demographic aspects, musical experience and age did not give significant results showing that such emotional interpretation of notes is potentially valid beyond the variety of participants peculiarities. These results will need further confirmation by testing a higher number of participants.

I. Discussion

1) H1 - Sound-colour association: The results described in Section III-H1 suggest that **H1** can be accepted, that is, is appears to be possible to strengthen cross-modal associations through immersive use of the ad-hoc designed `SoundStrokes` program, at least for some participants groups. While the overall results accepted the null hypothesis, results from two subgroups (musical & 36-45 age group) rejected it and showed significant improvements between the 3 test phases after time immersed in the program. To dissect why these two groups were able to strengthen their sound-colour associations, it can be argued that older people had more years to build cross-modal associations and to better develop sensory input processing. The musical groups results might be easier to explain, as they already have experience and a stronger musical ear, they might not be familiar with the guitar but would have a better reference point to start from than the non-musical participants.

Figure 2 shows the total scores for each sound-colour associations across the 3 tests, the lower the score the stronger association. This shows that improvement was made in 7 out of 12 associations between the first two tests and 8 out of 12 associations between the second and third tests. The strongest

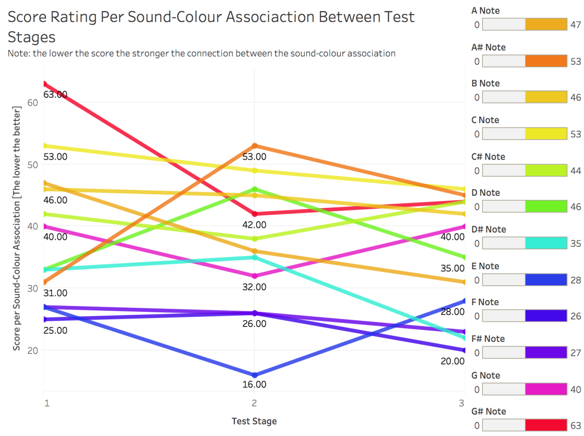

Fig. 2. Ranging from test 1 - 3, this visualisation shows the total score from all participants' for each sound-colour association

overall associations were the three lowest notes followed by the highest note. Most participants' were able to closer associate the dark colour group with low notes, and light blue with high notes, as it is highlighted in previous research works on sound-colour associations [2], [4], [9]–[11]. Associations with red, orange and yellow, that are in the middle, produced the worst scores. Participants could identify with more ease the colours associated at either end of the spectrum, with the lowest-darkest and the highest-brightest association scoring well across all participants.

One interesting insight received from a participant after the session was that they did not agree with some of the associations in the test. While this participant did not emerge from the pre-test as having synaesthesia, they did score strongly towards the synaesthetic spectrum. They believed that the "red note should have been a dark brown" and that "the green colour was wrong for the note that was played, I think it should have been more of a blue-grey colour. I think maybe a rose colour would have suited the green". These observations lead us to think that the question "How strong is your synaesthesia?" (see Section II-A) could be a way to view associations between the senses, especially for chromaesthesia [5]. Another participant expressed that, when associating colours in the test, they not only used the musical note but also the position of where the musical note was on the neck to make an informed choice. It is impossible to get a perfect agreement between two sense modalities because of the many senses used when interacting with the surrounding environment and while there are primary, secondary and tertiary senses, everyone takes in different amounts of information from each sense which shapes how they perceive what they see, touch, feel, smell and hear [22].

2) H2 - Sound-emotion association: Figure 3 aims to provide further insights on the sound-emotion test, which exhibited an acceptable agreement between participants as described in Section III-H2, suggesting that **H2** could be confirmed. The word clouds in the figure show which emotions were chosen the most, overall (above) and within each colour group

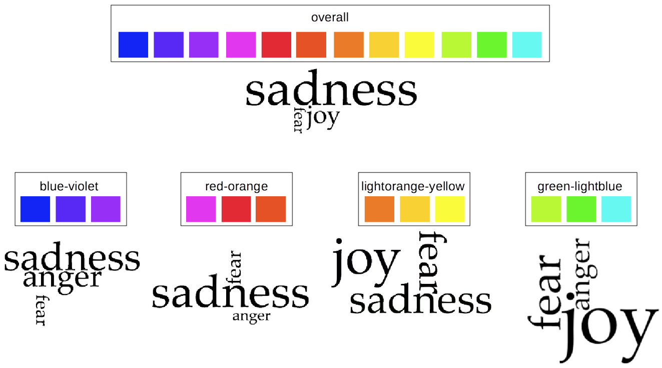

Fig. 3. Word cloud for all participants' emotional choices and broken down into sound-colour associations

(below). While participants could choose among 4 Plutchik's basic emotions (anger, sadness, joy, fear) the majority picked joy and sadness, as shown by the word clouds.

The Figure shows a basic correspondence between our findings and the colour-emotion choices in Plutchik's theory, with joy being the most chosen emotion in the orange-yellow group and sadness being the most chosen one in the blue-violet group. It also shows that, for the green-light blue group, joy is the most chosen emotion and sadness is the most chosen one in the red-orange group. Participants' found it hard to make emotional connections to single notes, with one participant pointing out that the note from a previous question affected how they chose the emotion for the current one, with ascending notes being perceived as happy and descending ones more somber. However, a connection between our findings and Plutchik's theory appears possible. As mentioned in Section II-C, emotional decisions can be made subconsciously, which could play a part in the disconnect between the positive results shown here and participants' comments on struggling to make an emotional connection [17].

The above speculations are in line with previous research works on music-emotion associations [11]. Compared to them, we aimed to show that people could consistently associate single notes (instead of chords, or melodies [19]) to emotional states, after some cross-modal training on sound-colour correspondence. We hypothesise that, by strengthening sound-colour associations, and by taking into account previous findings about the associations between colour and emotion, participants have also strengthen their ability to perform sound-emotion associations.

IV. Conclusion

In this paper we present an experiment exploiting an immersive program to strengthen cross-modal auditory-visual-emotional associations. Results show that, at least for some participants groups, some of these associations (e.g., the auditory-visual one) have been improved while other ones (e.g., the auditory-emotional one) will require further investigation, even if results are encouraging.

A. Limitations

Being present during each phase of the experiment, we noted a few factors that could have affected the outcome. The time constraints and the amount of work needed to test a single participant (a single long session of roughly 60-70 minutes) were probably not ideal, as a perceptual study is highly demanding in terms of focus and concentration for the participant. We noticed, on a few occasions, participants copying and pasting their previous colour choice to the next one or making quick and unfocused choices. With the immersive interaction using the `SoundStrokes` program and an instrument like the guitar, there is a degree of freedom to how the instrument is played. This is important to keep the interest of the participant high and give them a licence to express themselves, to favour deeper connection between stimuli. However, with this approach, even under guidance that only the first octave range will be drawn to the canvas, and connections are between single notes and colours, there were participants' that either strummed chords, played outside of the range, scratched the strings or made weird noises.

B. Future work

To continue and extend our investigation on chromaestesia and cross-modal association, it will be important to be able to spread out the test into different sessions. Each session would test the participants once after they use the program, with more time allowed for immersion in the `SoundStrokes` program. Testing participants over longer periods of time and with more than 3 training sessions would also strengthen the argument that the sound-colour associations being tested will remain. By spending more time and resources in future improved experiments, a control group taking the test in the same time-frame, showing no improvement could also help to exclude the test-retest effect. Another aspect that might be explored in future experiments is changing the instrument and to adopt, e.g., a piano. While even the non-musical participants' were able to play notes on the guitar, they did not always play clear notes and had to look down sometimes to the fretboard to hit a string.

C. Applications

The potential of the setup exploited in the experiment is to enable a user to develop their own associations, and to test whether such associations are consistent over time. The work presented in the paper shows that it should be possible, for example, to develop simple portable apps that could be used to train and test user's "sound-colour-emotion profile" over various time-spans (e.g., 1 week, 1 month). The app could also provide insights about the external factors that could have contributed to the profile variability. The user's profile could be exploited, for example, in entertainment, to enrich the user's emotional experience in videogames or immersive application, or in digital health, to develop simple tools to, for example, reduce anxiety through music [23].

REFERENCES

[1] R. E. Cytowic, *The man who tasted shapes*. Cambridge, Mass: MIT Press, 2003. OCLC: 937348414.

[2] C. Curwen, "Music-colour synaesthesia: Concept, context and qualia," *Consciousness and Cognition*, vol. 61, pp. 94–106, May 2018.

[3] F. R. Farina, K. J. Mitchell, and R. A. P. Roche, "Synaesthesia lost and found: two cases of person- and music-colour synaesthesia," *European Journal of Neuroscience*, vol. 45, pp. 472–477, Feb. 2017.

[4] J. Ward, B. Huckstep, and E. Tsakanikos, "Sound-Colour Synaesthesia: to What Extent Does it Use Cross-Modal Mechanisms Common to us All?," *Cortex*, vol. 42, no. 2, pp. 264–280, 2006.

[5] C. v. Campen, *The hidden sense: synesthesia in art and science*. Cambridge, Mass.: MIT Press, 2010. OCLC: 906956300.

[6] M. D. Rucsanda, "Synaesthesia and artistic experimentation in alexandr scriabin's works.," *Bulletin of the Transilvania University of Brasov, Series VIII: Performing Arts*, vol. 10, no. 2, pp. 95 – 104, 2017.

[7] L. C. Hill, *Synesthetic Music Experience Communicator*. PhD thesis, Digital Repository, Iowa State University, 2006.

[8] A. B. Janik McErlean and M. J. Banissy, "Color Processing in Synesthesia: What Synesthesia Can and Cannot Tell Us About Mechanisms of Color Processing," *Topics in Cognitive Science*, vol. 9, pp. 215–227, Jan. 2017.

[9] A. I. Goller, L. J. Otten, and J. Ward, "Seeing Sounds and Hearing Colors: An Event-related Potential Study of AuditoryVisual Synesthesia," *Journal of Cognitive Neuroscience*, vol. 21, pp. 1869–1881, Oct. 2009.

[10] C. Spence, "Crossmodal correspondences: A tutorial review," *Attention, Perception, & Psychophysics*, vol. 73, pp. 971–995, May 2011.

[11] S. E. Palmer, K. B. Schloss, Z. Xu, and L. R. Prado-Leon, "Music-color associations are mediated by emotion," *Proceedings of the National Academy of Sciences*, vol. 110, pp. 8836–8841, May 2013.

[12] M. Greated, "The nature of sound and vision in relation to colour," *Optics & Laser Technology*, vol. 43, pp. 337–347, Mar. 2011.

[13] N. A. Fiorenza, "Planetary Harmonics & Neuro-biological Resonances," Aug. 2008.

[14] C. Goss, "The Color of Sound - Pitch-to-Color Calculator," Feb. 2019.

[15] R. Plutchik, "The nature of emotions: Human emotions have deep evolutionary roots, a fact that may explain their complexity and provide tools for clinical practice," *American scientist*, vol. 89, no. 4, pp. 344–350, 2001.

[16] M. Hanada, "Correspondence analysis of color-emotion associations," *Color Research & Application*, vol. 43, pp. 224–237, Apr. 2018.

[17] N. Watanabe and M. Haruno, "Effects of subconscious and conscious emotions on human cue-reward association learning," *Scientific Reports*, vol. 5, July 2015.

[18] T. Tsang and K. B. Schloss, "Associations between color and music are mediated by emotion and influenced by tempo," *The Yale Review of Undergraduate Research in Psychology*, vol. 82, 2010.

[19] K. Hevner, "Experimental Studies of the Elements of Expression in Music," *The American Journal of Psychology*, vol. 48, p. 246, Apr. 1936.

[20] A. Dempsey, *Modern art*. Thames & Hudson, 2018. OCLC: 1062400444.

[21] E. B. Page, "Ordered hypotheses for multiple treatments: a significance test for linear ranks," *Journal of the American Statistical Association*, vol. 58, no. 301, pp. 216–230, 1963.

[22] G. Martino and L. E. Marks, "Cross-Modal Interaction between Vision and Touch: The Role of Synesthetic Correspondence," *Perception*, vol. 29, pp. 745–754, June 2000.

[23] J. Bradt, C. Dileo, and N. Potvin, "Music for stress and anxiety reduction in coronary heart disease patients," *Cochrane Database of Systematic Reviews*, no. 12, 2013.