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An Examination of Musical Pitch/Color Correspondence in Music, Arts, And Non-arts Students and Adults

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AN EXAMINATION OF MUSICAL PITCH/COLOR CORRESPONDENCE IN MUSIC, ARTS, AND NON-ARTS STUDENTS AND ADULTS

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ABSTRACT

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Chromesthesia is the involuntary combination of a visual color response to a musical stimulus. Previous research has associated the presence of absolute pitch with color responses to musical pitch; however, recent studies indicated that color associations were also made amongst those who did not possess absolute pitch. Eighty-four participants to various extent and of varying ages representing backgrounds in music and in arts (as well as those with neither background) took part in a series of experiments to determine if a color/music pitch connection was prevalent in their responses. Additionally, participants were tested individually regarding the presence of consistent visual color associations when applied to musical pitch as well as the presence of consistent musical pitch associations when applied to visual color. The results of this research indicated that while these color associations were not wholly universal, there were certain systemic similarities for many of these colors and musical pitches. The application of these similarities might prove successful in any number of diverse musical settings.

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Especially to my mom Sandy who was not able to see me through to this moment, I love you, and I dedicate this degree and this work to your memory. Thank you for instilling in me the wonderful gift of music. It changed my life in countless ways, and I was so grateful to get to share so many years of that gift with you! I'm here because you believed in me.

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INTRODUCTION

Statement of the Problem

It was the beginning of my sophomore year of college at Oberlin Conservatory when I made the acquaintance of an excellent freshman organist. As we started discussing music on one particular afternoon, he revealed to me that he had perfect pitch. I was in awe of “those” people who were born with this special gift. After expressing this sentiment, I discovered something quite unexpected: a reply that included the statement “Oh, I wasn’t born with perfect pitch. I learned it by hearing the pitches as colors.” I asked many questions that day, and felt reasonably content with the responses I received, but I never quite got over the shock of that initial statement. Fast forward 20 or so years from that experience, with the idea of this pitch/color connection still implanted in my head, when I discovered by chance on a Sunday afternoon that my daughter not only possessed perfect pitch but also heard these pitches in brilliant and well-defined colors. At once, all of those previous feelings and excitement about the topic were reinvigorated in me and I knew this topic needed my attention. In a sense, color and music pitch connection had once again spoken to me as it had decades earlier and the continuation of a previous journey began with fresh eyes.

Synesthesia is the presence of one sensory experience while participating in another different sensory experience. Common examples include experiencing color sensations while reading letters and words that do not on the surface inherently express those colors or experiencing sensations of pain while merely watching the pain-producing scenario but not actually physically going through it. One of the most common forms of synesthesia involves the perception of colors when sounds or pitches are heard. This form of synesthesia is referred to as chromesthesia. While the print journal *PLoS Biology* and various books and online sites such as the *Nautilus Journal* and synesthesiatest.org documented chromesthesia typically at a 1 out of 3,000 people occurrence (Hellier, 2017), the American Psychological Association considered the number closer to 1 in 2,000 (Carpenter, 2001). However, the number is just an estimate as some sources contend that elements of chromesthesia likely exist in far greater numbers than are reported (Admin, 2018). The Synesthesia Project, a combined project between researchers from Boston University and the Vision and Cognition Laboratory (2008), estimated that those possessing chromesthesia are sometimes unaware others do not possess this same ability and are reluctant to mention it. This means many more people are likely experiencing this phenomenon, consciously or subconsciously, than researchers are aware. It may also mean that many more people who are experiencing some aspect of chromesthesia are non-reporters of the phenomenon and thus have no understanding of what possibilities the presence of this special ability can unlock.

As a high school music theory teacher, I have seen this chromesthesia ability demonstrated by a handful of students who connect color and musical pitch, and their work and musicianship are outstanding. I postulated that if other students could harness a similar ability, they too might be able to demonstrate considerable mastery in some of the finer tasks of this course as well as practically applying the abilities to other performance-based music situations. The benefits of an implementation of such a system might prepare students to apply elements of color hearing to pitch to increase critical hearing and processing in many music performance and theoretical constructs. Previous research has either developed color/musical pitch techniques and not implemented them or provided participants with researcher-generated color assignments that do not allow participants to share how they are individually hearing and processing visual color and musical pitch (Keelan, 2015; Kuo & Chuang, 2013). If chromesthesia or elements of chromesthesia are frequent occurrences for many in the population, harnessing this skill could serve to help students truly connect color to musical pitch in a powerful and exciting way. While not limited to the musical world, the artist Kandinsky (Jacobsen & Wolsdorff, 2007) suggested a color correspondence but with shapes instead of pitch. Exploring this possible color correspondence might open up additional perspectives on a color and music correspondence. This research served to explore those possible color connections while attempting to determine if, on some level, those associations were to any degree universal or at the very least systematic across participants in the study.

Purpose of the Study

The purpose of this research was to determine the existence and/or prevalence of correspondence between colors and musical pitch. If natural correspondences exist among colors and shapes, they might also exist to some degree among colors and musical pitch. This research sought to explore those correspondences first for their existence and then identify any universal similarities between demographics or patterns amongst either participants or specific correspondences.

Definition of Terms

The following terms are used often. Please note how they are defined for use in this study. Definitions are paraphrased from the Oxford Handbook of Synesthesia (Simner & Hubbard, 2013).

Chromesthesia: The very specific form of synesthesia that results in a color and pitch connection.

Chromesthete or **chromesthetic:** A person who experiences some form of chromesthesia.

Correspondence: A linked connection between two experiences.

Cross-modal: Any experience that differs from the intended experience.

Synesthesia: The experience of a sensory reaction in a different modality than the one that is intended given a stimulus.

Synesthete or **synesthetic:** A person experiencing this type of cross modal reaction.

Adding the term *universal* meant some phenomenon occurred in the same way for everyone. Additionally, much of the research in this field occurred in England; thus, the alternative spellings for synesthesia and chromesthesia were occasionally used when citing materials in publications derived from research in this geographical area and in other areas where this spelling was adopted and common.

Procedures

An online survey began the research process. Each participant spent roughly 15 minutes completing the survey; the results, which included basic demographic information as well as narrative responses to questions about various elements of correspondence, established baseline impressions for both data and that participant. Once the initial survey was completed, participants completed two additional experiments at their leisure and on their own time frame. These two experiments sought to explore correspondences among pitch and color, resulting in both response data and narrative explorations of pitch and color. The results allowed for a greater understanding of the relationship of cross-modal associations in the processing of pitch. The statistical methods used to process the data are included specifically in the methodology section but included measures of central tendency, chi-square testing, RGB sum of squares averaging, and the creation of color models based on data frequencies. Each of the specific statistical methods served as ways of understanding the relationships of colors and musical pitch.

Significance of the Study

This research sought to analyze participant responses to pitch and color stimuli to determine if there were underlying correspondences between colors and shapes as well as underlying correspondences between colors and musical pitch. To date, participants have not participated in experiments where their individual experiences with color and pitch were used to map sight and sound. This research could prove valuable to many interconnected music disciplines as well as disciplines outside of music. A universal or systemic correspondence among color and pitch, this could be particularly helpful for many aspects of musical training, specifically tuning, balance, blend, hearing, and other color-related concerns that lead to successful pitch acquisition. Beyond the scope of universality, these correspondences might be helpful in training in music theory by improving audiation as well as aural skills tasks (such as melodic and harmonic dictation), improving intonation and pitch in performance-based ensembles (by providing color-driven approaches to centering pitch and hearing), and furthering perfect and relative pitch acquisition and understanding (through pairing color with actual pitch). The research might also shed light on the application of additional ways of hearing (and thus "seeing") that could be beneficial to musical training in general as well as determine whether these color connections, if present, held any systematic patterns.

CHAPTER II

REVIEW OF LITERATURE

History of Synesthesia

The purpose of this research was to determine the existence and/or prevalence of correspondence between colors and musical pitch. Attempts to define synesthesia and synesthesia-like processes have had an interesting and often colorful history throughout the past many years. Although interest in the subject dates back 2000 years (Polzella et al., 1982), until recently, the lack of scientific research might have led to misunderstandings about the nature of the phenomenon. The terms abnormal, metaphoric, and schizophrenic (now discredited) entered into scientific thought at various points during the early history of synesthesia research (Ione & Tyler, 2004). The ability to experience one sensory perception while simultaneously experiencing another completely unrelated sensory perception has intrigued and perplexed researchers since the first documented case of synesthesia in 1812 (Jewanski et al., 2011; Sachs, 1812). Early on, such events were seen as abnormal or to some degree the by-product of drugs and/or medication (Ellis, 1898). Contemporary explanations for the ability vary from heredity (Brang & Ramachandran, 2011) to social conditioning (Witthoft & Winawer, 2013). Some visual artists even began postulating underlying universal processes that govern synesthetic experience (Kandinsky, 2007). As a result, a few researchers found the history of synesthesia research humorously entertaining because of these conflicting theories and oftentimes speculative origins (Cuddy, 1985). However, American researchers Lawrence E. Marks and Richard Cytowic as well as British researchers Jeffrey Gray and Simon Baron-Cohen made investigation into synesthesia their life's work. As more is written about and discovered with regard to synesthesia, these studies are becoming more plentiful.

Definition of Synesthesia

From the earliest attempts to qualify and quantify it, synesthesia has been described as a union of the senses (Mills et al., 2003) and a phenomenon of perception (Block, 1983). It has also been identified as a rare condition of involuntarily evoking a sensory sensation by a different sensory stimulus (Specht, 2012). Synesthesia has also been explained as a condition in which perceptual experiences are elicited by stimuli not normally associated with such an experience (Ward, Tsakanikos et al., 2006). Specht (2012) went further to describe a possessor of synesthesia (known as a synesthete) as someone who "perceives two joint and concurrent perceptions, where only one is caused by a real external stimulus, while the other is an internally-evoked synesthetic experience without any direct external cause" (p. 15). The *Oxford Handbook on Synesthesia* (Simner & Hubbard, 2013) also made a case for intra-sensory synesthetic experiences (i.e., a stimulus producing an effect in the same modality) in addition to the more common cross-modal associations such as projection synesthesia in which colors are linked to certain letters, numbers, or words or chromesthesia in which color is linked to some form of sound.

Nature Versus Nurture of Synesthesia

Initial misunderstandings of the biological roots of synesthesia complicated the identification of the source of synesthesia further. Arguments for a theory of inherited synesthesia (Simner, 2012) were juxtaposed against arguments maintaining it was a distinctive event with no common origin from possessor to possessor (Deroy & Spence, 2013). While some evidence pointed to the hereditary nature of synesthesia (Gregersen et al., 2013), many relatives of synesthetes did not experience the same synesthetic experiences as their family members did

(Specht, 2012). A fair amount of speculation still exists on the origins of synesthesia; thus, despite continued research, the frequent conclusion and concession by researchers is the origin of synesthesia is still unknown (Specht, 2012).

In a 2004 study, Rich et al. found that over a third of synesthetes in their sample had at least one biological relative with synesthesia and the overwhelming majority of these relatives were female. The remaining 64% of participants either did not know if they had a synesthetic relative (13%) or confirmed they had no biological relatives with synesthesia (51%), which continued to further complicate the understanding of synesthesia. Their data also indicated that synesthesia in humans occurs in 1 in 1,150 females (0.087%) and 1 in 7,150 males (0.014%). Other research findings on synesthesia prevalence indicated it could be as high as 14% of men and 31% of women (Block, 1983). Researchers indicated the actual prevalence was likely somewhere closer to 4% of the population (Rogowska, 2011; Specht, 2012), although individuals likely underreported because they did not understand this phenomenon was unique to them.

Changing Understandings of Synesthesia Over Time

Synesthesia manifests itself in many different forms and has been explained through many different theories. The advancements in research methodology have taken the study of synesthesia from a speculative research topic to a more scientific and psychological one. The first research theories on synesthesia were compiled and explored in 1933 by Otto Ortmann. He listed eight theories (see Table 1) prevalent at the time, providing defense of some aspects and criticism of others.

Table 1

Ortmann's Eight Theories of Synesthesia

Theory	Description
Association	Synesthesia as chance association.
Degeneracy	Synesthesia as an evolutionary holdover.
Compensation	Synesthesia as a better developed sense replacing a defective one.
Psychoanalytic	Synesthesia as a result of sex experiences of childhood.
Vibration	Synesthesia as solar spectrum wave frequencies similar to those of the tonal octave.
Emotional-Tone	Synesthesia as awakening of pleasant color images from pleasant tones and vice versa.
Sensation-Form	Synesthesia as simultaneous effect of transtensity (in this case, pitch), intensity (degree) and protensity (duration).
Sensory-Reflex	Synesthesia as causing a sensation as a reflex action.

Ortmann's (1933) research contrasted starkly with Aleksandra Rogowska's (2011) research (78 years later) identifying 11 kinds of synesthesia (see Table 2). It is from the artistic category of Rogowska's research that the concept of chromesthesia is derived.

Table 2

Rogowska's Identification of Synesthesia

Theory	Description
Constitutional or Developmental	Synesthesia present in early childhood and doesn't change
Acquired or Post-accidental	Synesthesia that occurs in adulthood from brain changes from accidents or disease
Phantom	Synesthesia as pain in amputated parts of the body
Mirror-Touch	Synesthesia as experience of self-sensations while watching others being touched
Artificial or Synthetic Virtual	Synesthesia as a result of sensory stimulation as a part of the creation of visual illusions
Post-Hypnotic	Synesthesia as the product of suggestion under hypnosis
Narcotic	Synesthesia as result of psychoactive substances, e.g., LSD, mescaline,psilocybine
Neonatal	Synesthesia during the first four months of life that tapers off
Weak	Synesthesia as popular cross-modal matching
Artistic	Synesthesia in strong relationship with art

What is Chromesthesia?

Chromesthesia is one of the most prevalent synesthetic experiences (Mills et al., 2003; Specht, 2012) with 18.5% of synesthetes (of the reported 4% of those in the total population who have self-identified as possessors of some form of synesthesia) reporting hearing colored-musical sounds (Ward, Huckstep et al., 2006). Chromesthesia is a form of synesthesia in which tone elicits a color in addition to its musical pitch (Block, 1983). Additional research suggested "color- hearing" refers to a tonal stimulus accompanied by color vision, which is a typical example of synesthesia between vision and audiation (Hoshino, 1996). The term audiation was coined by noted music educator, researcher, and theorist Dr. Edwin E. Gordon (2012) to describe the process as the musical equivalent of thinking in language. The association between sounds and colors is not automatic (Mompeán-Guillamón, 2012); however, such sound and visual connections do exist among synesthetes and non-synesthetes (Moos et al., 2014). While the backgrounds of possessors of chromesthesia vary (just as they do in the understanding of the larger synesthesia population), there are some commonalities related to the phenomenon.

Cases of chromesthesia share some common features, often including absolute pitch ability (Block, 1983). While possession of absolute pitch is not a prerequisite for chromesthesia, the two are frequently found in the same possessor. Block's research sought to identify whether college music majors with absolute pitch would have a more consistent tone-color response over time than college music majors who possessed only relative pitch. The research involved 22 college music majors (10 who possessed absolute pitch and 12 who possessed a good relative pitch sense). The study included the use of a full chromatic octave of pitches from C_4 to B_4 and involved measuring the variability of degrees of pitch/color identification on a 51 hued color wheel over five trials administered once per week over five consecutive weeks. The results of this experiment indicated those absolute pitch possessors were more consistent than their relative pitch counterparts in their tone-color responses over time. Block's conclusions indicated that focused encouragement (whatever that encouragement might look like) from a younger age would produce a greater probability of chromesthetic experience.

The two elements of "tone height" (roughly equivalent to frequency) and "tonal chroma" (the sound color of each particular musical note) have been cited in assisting the production of absolute pitch (Korpell, 1965). Korpell recruited 23 volunteers, all college students, to test this theory. He found tonal chroma occurred in the ear of the perceiver rather than in the overtone-structure. Pitches in his research were subjected to pitch alteration through recording devices, yet were still identifiable. The non-linear response of the ear is the mechanism by which tonal chroma (and thus pitch) are identified. Additional research by Sergeant (1969) also supported Korpell as it was possible there was extra sensitivity in the absolute pitch possessor to the "clang" or "chroma" of a musical note. Later studies however, especially those of Collier and Hubbard (2004), indicated that tone chroma, based more on the overtone amplitudes rather than on the sense of an individual pitch, might be the catalyst for chromesthesia.

History of Chromesthesia

Because it produces vivid color and music relationships to the possessor, chromesthesia has a long history of science-oriented exploration, perhaps even longer than the broader subject of synesthesia. As such, chromesthesia research is not a new branch of scientific research. Interest in music-color connections inspired Pythagoras to assign specific colors to specific notes around the sixth century BCE (Ione & Tyler, 2004). Sir Isaac Newton created a color theory of red, orange, yellow, green, blue, indigo, and violet for the pitches C, D, E, F, G, A, and B (Kuo & Chuang, 2013). Dr. Sachs (1812) documented the first report of synesthesia and chromesthesia in 1812 (Ione & Tyler, 2004).

Cross-Modal Possibilities of Chromesthesia

As with synesthesia, the understanding of the origins of chromesthesia vary considerably. Evidence suggested chromesthesia might be present in everyone from a young age, prompting some researchers to suggest the development of a neonatal pruning theory. This theory stated that everyone is born with chromesthethically-wired brain function but most lose the ability over time (Ward, Huckstep et al., 2006). Some, however, retain this ability through genetics or training (Ward, Tsakanikos et al., 2006). In addition to heredity and training, some instances of chromesthesia have also been attributed to the effects of cross-modal associations (Rogers, 1987). In such cases, connections have produced sensations across mediums even if the connection was unintentional. For example, associations of toy xylophones with colored bars and piano or organ methods associated pitches with colors, potentially further these cross-modal associations.

Nature Versus Nurture of Chromesthesia

The notion of "nature versus nurture" seen in synesthesia research also found its way into research into chromesthesia. Carroll and Greenberg (1961) were convinced of some greater connection of chromesthesia to heredity, stating "these associations, when independently and formally reported on two occasions, were so consistent and (in general) similar as to suggest the operation of an underlying mechanism" (p. 48). The age-old nature versus nurture debate was evident in the findings of one study that stated if chromesthesia is learned, it could vary as a function of musical experience, but if it is unaffected by musical experience, neuropsychological indicators could suggest a physiological basis (Polzella et al., 1982). In addition to heredity, evidence also suggested that synesthesia and chromesthesia function as responses to the challenges involved in learning to recognize, discriminate, and understand the relationships between the elements being processed (Watson et al., 2014).

Facilitation of Creativity of Synesthesia and Chromesthesia

Synesthesia (and by extension, chromesthesia) might facilitate the expression of creativity (Rothen & Meier, 2010). Synesthetes and chromesthetes are, therefore, more common in the world of creative art, according to Rothen and Meier (2010), as synesthesia and art (in which chromesthesia is one of the most common forms) are consistently linked to each other.

Studies of art students frequently revealed this connection. In a study of 358 fine arts students, 23% indicated such a synesthetic or chromesthetic connection (Domino, 1989).

Researchers suggested the results of synesthesia and chromesthesia studies should be interpreted with caution. Most research involving the identification of synesthesia and/or chromesthesia could be conflicted because participants self-report. Tests of genuineness were frequently used to confirm subjects were not making up connections or imagining connections they did not personally experience (Gregersen et al., 2013). However, the research findings were only reliable if the participants were completely honest. This contrasted with, as an example, absolute pitch ability in which the phenotype was readily testable.

Color/Music Experiments in Art, Music, and Science

Because of the high prevalence of chromesthesia in the arts, many outstanding possessors took to their chosen art discipline to write and experiment in color-music connections. Visual artists such as painter Paul Klee and writer Georges Vantongerloo sought to explore chromesthetic connections in their work (Evers & Van Gerven, 2012). Composers such as Alexander Scriabin, Jean Sibelius, Oliver Messiaen, and György Ligeti similarly applied color concepts in many of their musical compositions (Beek, 2018). Artists were not alone in color-music exploration; indeed, revered scientists such as Sir Issac Newton, Johannes Kepler, and Hermann von Helmholtz all experimented, wrote about, and explored links between color and music (Lubar, 2004). While also interested in color/music relationships, some artists were building associations between colors and shapes or form and exploring those artistically.

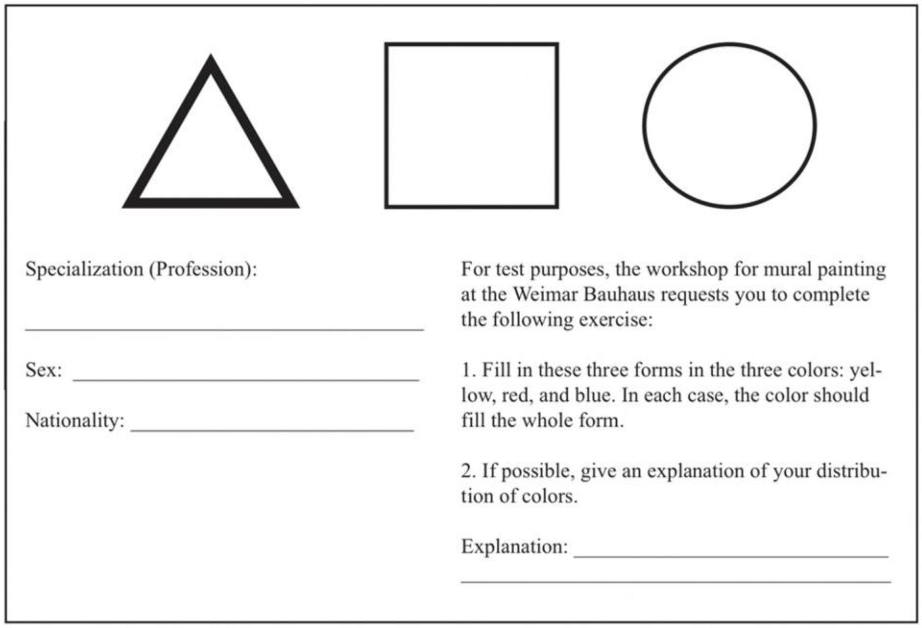
Kandinsky and Correspondence Theory

Wassily Kandinsky (1866-1944) was a Russian painter who was also a self-professed synesthete, possessing multiple forms of synesthesia throughout his life (Makin & Wuerger, 2013). In addition to being an artist, Kandinsky was a theorist who derived profound spiritual meaning from aesthetic experiences. In his 1910 book *Concerning the Spiritual in Art*, Kandinsky discussed the relationship of colors, music, and emotions and the use of this knowledge in producing paintings (Barbiere et al., 2007). Looking for a theoretical justification of abstract art, he created an aesthetic theory to describe not only his perceptions of visual art but also his sense of an *innerer Klang* or “internal sound” (Sheppard, 1975), which lent itself to musical application.

Kandinsky (as cited in Jacobsen, 2002) described four characteristics that make up *innerer Klang*: (a) being mystical in nature, (b) deriving from objects, (c) originating in the psyche of the artist, and (d) implying that art is a self-reflexive arising from its own materials (words in poetry, color in painting, or sound in music). In 1923, Kandinsky took the *Klang* theory further, creating what has become known as correspondence theory: the systematic explanation of color and form associations. He suggested the fundamental correspondence of basic colors and forms was mediated by the inherent relationships of colors and angles (Jacobsen, 2002). Three simple shapes (triangle, circle, and square) were said to elicit three specific colors (yellow, red, and blue, respectively) based on angles in each figure as they corresponded respectively to the visible color (Chen et al., 2015). A copy of the questionnaire administered by Kandinsky is seen in Figure 1.

Figure 1

Kandinsky's Color Questionnaire


Specialization (Profession): ______________________

Sex: ______________________

Nationality: ______________________

For test purposes, the workshop for mural painting at the Weimar Bauhaus requests you to complete the following exercise:

1. Fill in these three forms in the three colors: yellow, red, and blue. In each case, the color should fill the whole form.

2. If possible, give an explanation of your distribution of colors.

Explanation: ______________________

Connecting Kandinsky's Correspondence Theory to Music

An important but often neglected aspect in the understanding of music is the concept of tone-color, which itself is a chromesthetic term used to describe specific qualities of music pitches. Previous understanding of music has not considered this aspect (Cogan, 1975). Tone-color connects the visual arts to music. Kandinsky's original correspondence theory, while perhaps effective for color and shape at the time, has since lost some of its meaning based on previously mentioned associations of colors and angles. Similarly, perhaps a universal color/pitch correspondence exists but is lost in present-day musical associations. Correspondence theory could reflect Kandinsky's intuition into some sub-clinical, quasi-synesthetic pairings. Like the Bouba-Kiki effect (a mapping between speech sounds and the visual shape of objects first observed by Wolfgang Köhler in 1929), these pairings could be near-universal (Makin & Wuerger, 2013). If this same correspondence theory existed universally with color and musical pitch, such a relationship could be explored in a high school music theory class to increase aural recognition of musical patterns and activities, improve audiation and inner hearing, and lead to better performance on those music theory tasks in which aural perception is crucial for musical processing including, but not limited to, increased absolute and relative pitch ability, improved hearing and singing, and better overall and comprehensive musicianship.

Experiments in Music Correspondence and Color

Within the last 50 years, many researchers began to explore music correspondence with color in greater detail, using aspects of both as central components to their research and experiments. These studies helped to pave the way toward new ways of thinking about how these two elements are connected in participants' musical experiences.

To begin testing a universal theory of music and color, Kuo and Chuang (2013) devised a simple system of music notation for two single line melodies using the color wheel created by Johannes Itten, Kandinsky's colleague at the Bauhaus. Conceptually, the researchers wanted to pair frequency-based synesthesia of color and music and do so through a color music notation system. The end goal was to have beginning music students read and play music more quickly, accurately, and confidently. The idea for such a connection was derived from the 1992 Mary Bassano book, *Healing with Music and Color – A Beginner's Guide*. The researchers' guiding observation was that "people psychologically produce a certain specific color or a set of colors when they hear a single note or a piece of melody" (Kuo & Chuang, 2013, p. 397).

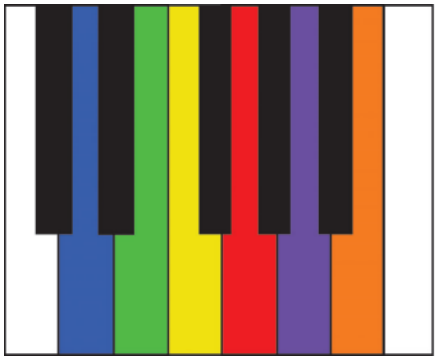
Incorporating Newton's color theories to create a novel color music notation system based on the Itten color wheel, with colors corresponding to the pitches of a chromatic scale, the researchers' intent was to assist elementary students in learning a piece of music visually (Kuo & Chuang, 2013). Kuo and Chuang (2013) discussed the history of music notation, casting their assessment into three distinct histories: early, conventional, and modern music notation stages. Each major step of progress on the history is documented from 1800 B.C. (a simple style with no writing at first) to and through the mid-19th century advancements that produced the common numbered musical notation (where the Arabic numerals 1 through 7 represent the established solfege system of labeling pitches as Do through Ti or Si and small written points identify the change of octave (known as the Galin-Paris-Chevé notation system).

This history of notation was followed by both an exploration of the history of color music notation as well as color reproduction technology. Throughout, the notion of a chromesthetic connection between pitch and color "…the process of reading and hearing music can be linked by the synesthesia of coloring and hearing" (Kuo & Chuang, 2013, p. 397) is continually highlighted. The color theory of Newton, which links visible frequencies of red, orange, yellow, green, blue, indigo, and violet with aural frequencies of pitches C, D, E, F, G, A, and B is presented. Kuo and Chuang (2013) began by examining the music reading problems (including pitch, duration, intensity, range, and symbol identification) experience of 58 students aged 15-20. After documenting many of the issues these participants experienced, the researchers then created a colored notation system that spoke to pitch, duration, range, and intensity without reference to lines, accidentals, clefs, key signatures, or numbers of any kind. Most interestingly, while listing the many benefits of this proposed color system, the extent of the research was just that: the creation of the system to fill a perceived need. No experiment was involved beyond the creation of the colored notation system. Their approach pointed toward an inevitable music-color correspondence but this was not tested with the participants for whom the system was created. The research that went into their creation of such a colored notation system suggested there was an applied support for using color association experiences in music classes.

Researcher Chris Keelan (2015) went further in his work than Kuo and Chuang by attempting a chromesthetic connection of pitch and color in undergraduate aural skills training. Mr. Keelan's research sought to explore "possible effects, pedagogical applications, and benefits of pairing color with certain musical elements in undergraduate aural skills courses" (p. 11). In particular, he suggested early in his literature review that "although many of us do not have synesthesia, this does not mean a 'learned synesthesia' cannot be utilized to build memorable associations between two senses" (p. 11). Similar to other studies, the research began with a brief overview of synesthesia followed by a history of color musical notation ideas and systems. The research group consisted of 35 music students from the University of Nebraska-Lincoln who were in various places in their undergraduate degrees with the range representing freshmen in their first semester of theory through seniors who had finished their entire music theory sequence. The participants were divided into two groups (labeled "A" and "B") to facilitate two experiment topics: single line melodic dictation (Group "A") and multiple line harmonic dictation (Group "B"). Keelan created his color system for his experiments based on Western cultural uses of color. He progressed through his reasoning behind each color choice based on traditional real-world color uses. Keelan's color/pitch pairing, as seen in Figure 2, had an immediate limitation.

Figure 2

Keelan's Pitch/Color Pairing



While the specific color scheme, chosen for its particular Western associations might have some intrinsic merit (C-white, D-blue, E-green, F-yellow, G-red, A-purple, and B-orange), the most immediate limitation was it ignored any and all chromatic pitches outside of C major. In fact, the experiments that followed all occurred within the confines of the key of C major for these melody and harmony tasks. This left almost as many chromatic notes unaccounted for and without visuals as there were diatonic pitches in the experiments. Instructions for each of the three experiment sets were given. In the first set (tests IA and IB), participants were told they would see a series of colors while hearing a series of notes (Group A, melodic dictation task) or they would see a series of colors while hearing a series of chords (Group B, harmonic dictation task). In the second set (tests IIA and IIB), participants were told they would only see colors (both Group A and Group B). In the third and final set, participants would hear only isolated solfege (Group A) or chords (Group B). All experiments required participants to initially complete one of three broad activities: (a) hear pitch (or chords) while viewing color, (b) see only color, or (c) hear only pitch (or chords) followed by a memory recall task. During each experimental set, 10 possible levels existed for participants to progress through with the first level starting at three stimuli with three possible points and each subsequent level adding one stimulus as well as one point up to a maximum of 10 levels. Thus, progressing through all 10 levels in an experimental set would result in 75 cumulative points. While results through analysis of variance for the Group A tasks indicated no change given confidence levels, the Group B results using that same analysis of variance approached significance, meaning there was some positive benefit academically to associating color with pitch as it aligned with chords and chordal progressions. In his discussion of results, Keelan (2015) suggested two specific ideas of particular interest:

1. By using the twelve-color wheel, a scale could be laid over it and the interval patterns between the colors and notes would stay consistent. (p. 78)
2. In a harmonic dictation setting, a color pairing based upon function and the similar emotional analogies would utilize many associative elements color may have to offer. (p. 79)

Incorporating these two suggestions could create a scenario in which musical pitch and corresponding half-steps within the musical scale are governed by a stationary color system with blending colors responsible for composite sounds such as intervals, triads, or chords. Keelan's (2015) suggestions for future study lent themselves to some (though not all) components of the present research into musical pitch and color correspondence. The choice of which colors to use for such research came about through the linguistics book written by Berlin and Kay (1969).

Anthropologist Brent Berlin and linguist Paul Kay (1969) collaborated on the popular and even controversial book *Basic Color Terms: Their Universality and Evolution*, which had as its premise that far from being a random collection of terms across many different languages, color terms were basic to all languages with the development of each language producing a similar list of terms based on the complexity of the individual language. The researchers also put forth the notion that semantic universals exist in the domain of color vocabulary (Berlin & Kay, 1969). Drawing upon 98 languages from either written or spoken samples from natives, Berlin and Kay noticed a consistent trend as it related to color terms and stages of language development. Their research created seven principles all languages, depending on their stages, follow. These rules are summarized in Table 3.

Table 3

Berlin and Kay Color Term Rules

If the Language Contains…	Basic Color Term That Is Added
3 terms for color	Red
4 terms for color	Either green or yellow (but not both)
5 terms for color	Both green and yellow
6 terms for color	Blue
7 terms for color	Brown
8 or more terms for color	Purple, pink, orange, grey or some combination

Note. All languages contained terms for white and black.

Beyond these 11 terms, Berlin and Kay (1969) found Russian and some Slavic languages had specific basic color terms for two varieties of blue—both a lighter and darker version. While the lighter blue was not a separate color term for all such speakers, it was for many. In these languages, and possibly beyond, the term “blue” might constitute both an 11th and 12th basic color term. Berlin and Kay’s initial hypothesis that *“color categorization is not random and the foci of basic color terms are similar in all languages”*[emphasis by the authors] was confirmed through their research (p. 10). If these sequential terms are fundamental to all cultures, then this research, while not music related, provided a basis for organizing the 12 chromatic pitches around 12 fundamental color descriptors.

In a study on sound-color synesthetic associations, Mompeán-Guillamón (2012) tested for evidence of synesthetic sound symbolism in the general population as well as testing the psychological reinforcement of such a system if it existed. While not expressly a color/pitch study (in the musical sense), the research involved color, sounds, and phonetics. Fifty-seven undergraduate students at the University of Murcia in Spain took part in the experimental research. Necessary background information data including consent forms, demographic information and responses to diagnostic questions were collected prior to the start of the experiments. Diagnostic information included age and gender responses. Diagnostic questions included responses to right/left-handedness assessments, the identification of known auditory problems, and the presence of Daltonism, a color-blindness condition in which greens, yellows, and reds are confused (which is the most common occurrence in those with color-blindness). A color-blindness test followed to verify the self-reporting of Daltonism in the diagnostic questions. If participants passed this initial assessment, they were then able to begin the first experiment proper.

In the first experiment, participants were presented with 32 vowel sounds (eight sounds each heard four different times) and asked to identify which specific color of 12 color options seemed most appropriate to the sound (Mompeán-Guillamón, 2012). Each instance of vowel sound was accompanied by the color selection screen but with the colors in different orders so as to not cause participants to choose colors based on their placement on the screen. It is important to note that the choice of colors for this particular experiment was derived from the previous referenced basic color terms book by Brent Berlin and Paul Kay (1969). Notably, Mompeán-Guillamón (2012) made use of all 11 of these main colors. Berlin and Kay suggested that in Slavic countries, the word for blue is divided into light and dark hues as part of their basic color terms, which produces two identifiers for one of these—hence a collection of 12 possible terms. Mompeán-Guillamón only allowed a darker blue as part of the color palette plus the addition of a 12th square participants could select if none of the other color choices present matched, in their assessment, the color they felt most represented the vowel sound they were hearing.

Mompeán-Guillamón's (2012) findings showed that participants consistently and significantly associated seven of the eight vowel sounds with a single color and the eighth vowel sound was associated with two colors. The researcher's analysis was these color/vowel connections were correlated at a better than chance degree, meaning there might be some degree of universality to the color mapping of these vowel sounds across participants.

Researchers concluded that further understanding of color associations to music might produce valuable insights—insights that could be used in forming new instructional strategies, music series books, and multimedia teaching aids (Cutietta & Haggerty, 1987).

Conclusions

A clear connection between color and pitch has been studied and verified through research. While various chromesthetic connections have been explored in this research, these experiments were limited in their execution. True, many researchers have devised color/pitch systems for implementation in the classroom but they do not go so far as to test the implementation of those systems. When there is implementation, the researchers in each case developed a system of predetermined color patterns (either as part of a scale or associated with chords) on which participants were tested. In none of these experiments did the researchers allow the participants to govern the creation of a color system for pitch. If there were natural and universal color terms that applied to all languages and significant color responses to familiar sounds, there was also likely to be such a connection with color and pitch.

Research Questions

Allowing participants to be directly involved in the creation of a color/pitch system would be of great benefit to individual participants to connect color to their inner ear. Having a consistent and distinct color system to match the number of available musical pitches for participants was crucial in creating such a system. Thus, the current goal of this research was to test for any color/pitch correspondences across participants from multiple diverse backgrounds. Determining if such correspondences, if present, were consistent was important to determine if they might be applied either universally or, if not universally, systematically in how participants processed pitch and color. The following research questions guided this study:

Q1 Do previous experiments in color/shape correspondence also suggest a correspondence, universal or otherwise, between color and musical pitch?

Q2 Are consistent visual color associations present when participants apply colors to musical pitch they hear?

Q3 Are consistent musical pitch associations present when participants apply musical pitch labels to color they see?

CHAPTER III

METHOD

The purpose of this research was to determine the existence and/or prevalence of correspondence between colors and musical pitch. This study was divided into several different activities and included a participant survey on perceived color/shape and color/music correspondence, a color/musical pitch correspondence experiment, and a musical pitch/color correspondence experiment. All experiments were designed to be administered virtually and completed in a one-step process by the participant.

Participants could also choose to execute these experiments over many steps if they desired. The survey sought to gather information including demographics of participants as well as multiple choice and free-response components. The two research experiments that followed were themselves mixed-methods research opportunities in which qualitative responses to pitch with color (in the first experiment) and qualitative responses to color with pitch (in the second experiment) were processed as narrative (written, visual, and auditory) responses but also quantitatively processed for consistency in response output.

Survey Method

Participants

The study targeted participants in two primary groups: high school students of varying ages involved with music and/or art and adults of any age with or without a musical background. Some participants were known to the researcher and recruited to participate; others were recruited through opportunity sampling or by participant word-of-mouth. For high school participants, arts students from the target high school were invited to participate. These students attended classes in a school district of 30,000 students in Fort Collins, Colorado, a mid-sized Western city with a population between 160,000 and 175,000. The students were recruited by direct contact with teachers at the target school as well as individual instructors in both arts areas, to solicit participation. Personal visits by the researcher were made to all potential sampling classes. A brief description of the general idea of the research was given to all students in these classes. Most student participants in the study received recruitment materials directly from the researcher. For additional participants not covered under one of the descriptors above (this applied to recent high school graduates as well as freshmen and sophomore college or university students), contact was made directly with the participant to both recruit and solicit participation. Adult participants were sent materials directly or delivered to them personally. Once confirmation was received from an adult or student regarding their desire to participate in the study (this typically was the return of a consent form by the participant), a follow-up email was drafted to confirm more details of the survey including dates of the administration window and other important deadline information. Copies of all consent forms as well as recruitment materials are provided in Appendices A and B.

There were 84 participants in the initial survey portion of this research comprised of high-school aged and older students as well as adults. All but a few participants were residents of northern and southern Colorado (primarily Fort Collins, Loveland, and Colorado Springs). Most of the students in the study attended Fossil Ridge High School in Fort Collins where they were involved in the school’s music (band, choir, orchestra, and music production and technology classes) and arts (general art classes, two-dimensional drawing, three-dimensional drawing, pottery, photography, and advanced placement [AP] studio art) programs. Adult participants were recruited from musician populations in Fort Collins, Colorado and Colorado Springs, Colorado.

Following these presentations, students were offered one of two consent form packets available during these visits. Students over 18 years of age received the general consent form. Students under 18 years of age received two forms: a minor assent form as well as parental consent form. During these informational visits to classes, over 90 individuals expressed an interest in participating in this research and asked for their respective consent forms. Students were under no obligation, by taking a consent form, to participate in the research study.

Student participants, for the most part, were enrolled in grades 9-12 and involved in visual art and music classes offered at their respective schools. Students enrolled in more than one arts class were only allowed the opportunity to participate in the project once. Study participation was not limited to students in high school. Recruitment procedures and research methodology were in compliance with and had been approved by the University of Northern Colorado’s Institutional Review Board (IRB) as well as the school district in which the research took place. Under no circumstance was participation in the survey required, no additional benefits (academic or otherwise) were offered to students taking the survey either from the researcher or the high school teacher of record, and no penalties (either academic or otherwise) were inflicted on students choosing not to take part in the survey. A copy of the Institutional Review Board approval letter is found in Appendix C. Additionally, a copy of the school district permission letter is provided in Appendix D.

It was my hope that by including students from all music and art backgrounds, the data would reflect a broader representation of the total school-aged population and therefore be more relevant in terms of identifying the level of synesthesia or chromesthesia in the population as a whole. This might prove helpful in transferring the experimental results to a broader population. Adult participants were selected via inquiry emails sent out via local arts organizations as well as general inquiries emailed to local organizations known to the researcher. All adult participants who wanted to be involved in the study were allowed with no cap size on their participation. This adult population consisted of participants both known and unknown personally to the researcher. Recent high school graduates and college/university students, for the purpose of this research, were classified into the "adult" demographic category. Some of these adult subjects worked in arts-related fields but many did not.

Materials

A survey consisting of 29 questions was created using Google Forms. After a short series of questions regarding the subject's demographics, participants were asked questions regarding their understanding of Kandinsky's work, the possibility of color/shape correspondence, specific color/shape questions, and then their opinion on the possibilities of color/music correspondence. Care was taken to craft questions that were specific enough to address the intended research questions but broad enough not to force participants into pre-conceived responses or notions. Questions included a variety of formats: simple yes/no questions, multiple-choice, and free response. Questions followed a natural and logical progression from one topic to the next. All questions required a response before the next question was posed. The survey questions are contained in Appendix E.

Administration

Hard copies of all consent documents (one for participants of age, two for all minor participants) were required before any participant was allowed to access this initial survey. Once in the survey proper, all participants encountered a survey question asking them to acknowledge they had read and understood the previous consent documents.

A weblink to the survey was sent by email to each participant who agreed to be part of the research and for whom consent forms had been received. The link was the same for all participants regardless of their age or background in the arts. Surveys were only available in electronic form and designed to be completed virtually and at the convenience of individual participants. To guarantee a higher return rate, the survey could be completed on any device with internet access: desktop computers, laptop computers, mobile devices, smartphones, or tablets. Participants could progress through the 29 questions at a comfortable pace. The entire survey was projected to take 15 minutes or less time to complete. Participants could opt out of completing the survey up to the very last question by simply closing the internet browser tab in which it was open. However, once the final question was submitted, their participation in the survey was officially recorded.

Procedures

No participant could access the survey without the weblink and no weblink was sent without first having the required consent forms in hand. E-mail addresses were collected through the survey to facilitate subsequent participation in additional studies. The survey consisted of a battery of multiple choice and short answer questions as well as baseline questions for demographic purposes. Participants were allowed only one submission of the survey form; however, anyone could take a survey multiple times provided they had the survey link. Any duplicate responses were removed. The survey data were collected through Google Forms as responses were completed and the data were available on both the individual and collective level.

Participants for subsequent research experiments were identified through their email addresses in response to the survey. Subjects for this later research included, potentially, all participants in this survey.

Description of Analysis

This initial survey returned a wealth of data ranging from binary choice response options to more qualitative responses and many response types in-between. Therefore, the survey data were processed in multiple ways. Questions 1-12 were overall more demographic in nature and, thus, were processed using simple central tendency measures (mean, median, mode, etc.) and respondent percent analysis.

Questions 13-15 focused on color/shape correspondence and required participants to freely respond to color choice of Kandinsky shapes (triangle, circle, and square). Since there was an expected value on each of these responses (given the Kandinsky original experiment data), a chi-square test was employed to determine the deviation of the participant responses from the expected values as well as the statistical significance of the associations participants made in comparison with those established previously by Kandinsky.

Questions 16-18 represented the same task as questions 13-15 except in this case, participants were given only three color choices for each shape with those choices corresponding to Kandinsky's original colors for those three shapes. At this juncture, there were multiple data points to analyze and included participant color to the Kandinsky original as well as participant color from questions 13-15 compared with participant responses to questions 16-18. Here similarities between responses were noted and once again the chi-square test was employed to determine deviation of participant responses from expected values (especially as it related to comparison to the Kandinsky original colors).

Questions 19-24 posed a new and fascinating opportunity to not only compare responses to Kandinsky's original color orientation but also to have a direct comparison between the three colors and three shapes as both non-moving and moving colors for each participant (questions

16-18 against questions 19-24). Various descriptive statistics were used to determine trends and patterns in these responses. The remaining questions in the survey were of a nature that did not allow for statistical analysis.

Color/Musical Pitch Correspondence
Experiment #1

As a baseline for determining if there existed a universal or systematic color/music correspondence, participants assigned pitches they heard to colors presented to them. This experiment and the one that followed it served as prototypes for anticipated additional studies beyond the scope of the present study and aimed to answer the second research question.

Participants

Participants for this study comprised 62 high-school aged and older students as well as adults who had all participated in the initial survey. There was no opportunity to determine the reasons why the 22 additional participants in the survey did not go on to complete this first correspondence experiment. In each of the two experiments that followed, the presence of absolute pitch and/or self-reported possession of chromesthesia was not a determining or negating factor in their participation for this research.

Materials

This research experiment was built upon the work of Brent Berlin and Paul Kay (1969) in *Basic Color Terms: Their Universality and Evolution*. In this largely linguistics-oriented work, the authors determined that as languages evolved, so did the terms for specific colors. Their research indicated that the most sophisticated languages universally possess tangible terms for 11 different basic colors (with some languages possessing 12 basic color terms with the addition of specific basic terms for light blue and dark blue). By extension through previous experiments in chromesthesia, these basic color terms could map to the pitches of the chromatic scale, which contains 12 distinct pitches or data points. In previous research experiments in music, pitch color was often determined by the researcher of the experiment. The current experiment allowed the opportunity for participants to determine their own color hearing with these 12 basic color terms translated into visual colors from which they could choose. The 12 documented colors of Berlin and Kay (1969) used as the basis of this experiment can be seen in Figure 3. Participants in this study were presented with color representations in each of the Berlin and Kay colors for this activity.

Figure 3

Berlin and Kay Colors

White	Green	Dark Blue	Pink
Black	Yellow	Brown	Orange
Red	Light Blue	Purple	Grey

Pitch stimuli for use in this experiment were generated using the Finale Music Notation software program. Each pitch of the chromatic scale was generated from C4 to B4. Musically, a pitch with minimal sound decay was desired for each color-matching instance. This allowed participants to hear a pitch without decay in the sound over an extended period of time. A pipe organ timbre was chosen for this quality. This experiment required two separate files to complete. A link to a Google form was presented for participants to follow. Initially, an audio file for participants to play was sent along with the form link for participants. However, shortly after sending this out, it was discovered the outgoing email server was not allowing the attachment to be viewed properly by participants. This was subsequently corrected to utilize the same audio file as a Google drive link participants could click. This proved effective and without technical difficulty from the outgoing email server and so was used in place of the previous audio file version. All other aspects of the experiment remained unchanged from the original planned and described procedures. Each pitch was presented as part of its own question for which participants selected as a response the color they felt most represented the pitch they heard. Participants were able to repeat each pitch as often as they liked before selecting their choice of color. Once they submitted their choice for a sound, the next question was presented to them. Each question followed the same procedure. The color panel was presented as a visual in the same manner for each question so as to not cause any participant to select a color based merely on its location in the question responses. Throughout this experiment, and in all experiments involving sound, the international standard of pitch, in which A=440 Hz, was preserved.

Procedures

As with other experiments, participants could move into this experiment immediately and progress through it at their own convenience. All responses were recorded individually. Because of its virtual nature, this experiment was preceded by a written explanation of procedures contained alongside the links for participants. Each participant was asked, in turn, to match one of the colored representations to each of the 12 pitches produced. Each pitch was recorded in such a way to provide sound for five seconds followed by silence for 10 seconds. This timing was embedded within the audio for each musical pitch. Participants could repeat the playing as many times as they wished prior to making a color selection. However, once a color selection was made, participants were moved onto the next question. During this 10 second silence (or longer should the participants decide not to replay a given pitch), participants were asked to audiate the pitch they just heard in a comfortable octave. Since this experiment was conducted virtually, any method of audiation was acceptable and could include singing or humming. Following this audiation activity, each participant was asked to select a colored representation they thought visually matched the sound they heard. Each of the above referenced colors was always visible for each question as each participant completed every question in the experiment. Proceeding in this manner allowed participants a degree of freedom when selecting colors rather than being forced into selecting only from the remaining colors, which could produce less validity as the experiment went on. To account for random selection of colors, participants were informed within the written introductory explanation that some pitches would be sounded again later in the experiment. This ensured participants had multiple opportunities and attempts at matching pitches and colors. Participants were similarly informed that not all pitches (and thus colors) in the testing session would be repeated. Any participant who applied a different color than previously assigned in the experiment had that response noted accordingly.

In all cases, participants completed each pitch/color matching series in sequence. The arrangement of pitches was unknown to participants. For each question, the participant's color choice was recorded in the given form. For ease of notation, each color representation was assigned a number by the researcher. After the color selection for each question was made, the color was converted to its corresponding number by the researcher and also recorded as the participant's response for each question. This was to facilitate additional data analysis. The numbers were converted back into their appropriate color for purposes of further analysis defined below. The pitches were presented in such a way as to include the full chromatic pitch possibilities with an additional sounding of all pitches contained within C major. The pitch "C" in this experiment was sounded three times. A copy of the specific pitches used and the order of their presentation can be seen here in Figure 4.

Figure 4

Presentation Order of Musical Pitches for Experiment #1

C	F	B	G#/Ab	E
F	C#/Db	G	D	G
E	A	D	B	A
A#/Bb	F#/Gb	C	D#/Eb	C

Note. Pitches were presented from top to bottom of each column from left to right.

Description of Analysis

This experiment produced single color choices for each of the sounding pitches. As such, a search for consistency was of the highest interest. All color data were processed through multiple chi-square tests that measured the deviation of participant sample responses from expectation. Testing included overall color selection, individual color selection per pitch trial, and combined testing for multiple trials when applicable. It was also helpful to determine the statistical significance of those associations in comparison with those established between the same sound and other colors. This also allowed for analysis of possibly smaller participation numbers and insured that any real differences in the research conditions were detected.

Data gathered from these multiple trials were helpful in determining correspondence connections among all pitches within the chromatic scale. Analysis was performed to examine relationships between two groups of variables (color and pitch), allowing for measurement of each single variable against the strength of the other variables. Further, to illustrate a precise color/pitch mapping for this participant group, the total RGB colors selected were averaged using a technique involving summing the squares, finding the mean of those summed squares, then returning its square root. This technique returned colors more accurate to colors selection than the mere traditional central tendency measure of summing and dividing by the number of participants (the traditional “arriving at the mean”).

Color/Musical Pitch Correspondence
Experiment #2

Continuing the exploration of the existence of a universal or systematic color/music correspondence, participants were asked to complete one additional experiment that inverted the concept of the previous color/pitch correspondence experiment #1. In this experiment, participants were asked to generate a musical pitch for a color presented to them. This experiment and the one that preceded it aimed to answer the third research question and served as prototypes for anticipated additional studies beyond the scope of the present study.

Participants

Participants for this study comprised 58 high-school aged and older students as well as adults who had all participated in the study’s survey and color/musical pitch experiment #1. There was no opportunity to determine the reasons why the four additional participants in the previous experiment did not go on to complete this second correspondence experiment. Again in this experiment, the presence of absolute pitch was not a determining or negating factor in participant selection. Additionally, if participants had self-reported as possessors of chromesthesia, this similarly was not a negating factor in their participation for this research.

Materials

The colors employed in the previous research activity were again used in this current research setting. The Berlin and Kay (1969) color terms (and colors) seen in color/musical pitch experiment #1 were recreated using their exact RGB numbers. Because of its virtual nature, this experiment was also preceded by a written explanation of procedures contained alongside the links for participants. In an effort to keep the platforms consistent throughout all three phases of the research, all possibilities to keep the Google format were considered for consistency for all participants. While Google forms did not include an audio capture function, many browser add-on extensions allowed for this functionality. This was particularly important as the original concept of this experiment required participants to sing or hum responses through the form interface, which were then to be recorded directly into the submission form and processed for pitch.

The extension Mote was selected as it presented the most function with the least amount of potential technology issues. The extension needed to be added on to an Internet browser of the participant's choice. A link to the download and instructions were provided to all participants along with the Google form link. The addition of the Mote add-on allowed participants to record their audio responses directly into the form for each question. The opportunity also existed for participants to indicate, in writing on the form, their selected pitch response (this was particularly helpful for participants with perfect pitch or those who sang and referenced their pitches to some instrument prior to providing a response).

For the processing of pitch, it was determined the use of sophisticated software, such as Praat, was unnecessary. Instead, the application Zen Tuner was used to identify all pitches provided as audio responses. The only limitation to this approach was all sounding enharmonic pitches were displayed as sharps through the Zen Tuner. While this labeling was practical to many pitches, it also presented challenges in identifying pitches how they would most commonly be referred. To facilitate identifying responses across all pitches and in documenting those pitch responses, pitches labeled C# or Db were identified as C#. Pitches labeled D# or Eb were labeled as Eb. Pitches labeled F# or Gb were identified as F#. Pitches labeled G# or Ab were identified as Ab. Pitches labeled A# or Bb were identified as Bb. This was held consistent throughout the experiment. When analysis was completed on this data, all pitches were represented by both of their enharmonic equivalents.

Procedures

Each participant was tested individually through virtual submission of their experiment responses. Participants were shown a single visual representation of a color before being asked to sing or hum the pitch that came to mind when seeing that particular color without reference to specific pitch names. Once again, the colors presented were one of the twelve colors from the Berlin and Kay (1969) chart. In each case, the color prompted the participant's responses. Each colored visual representation was posted until a pitch response was recorded and verified recorded with the participant. As with color/musical pitch experiment #1, 20 stimuli were presented one at a time in an order unknown to the participants. Eight of these twelve colors were presented twice. Because black was a testing color in the experiment, it could not be used to interleaf responses with the other visuals for this experiment as was originally intended. Thus, after each question was asked and then submitted, a rainbow visual was presented before the next color visual appeared (see Figure 5).

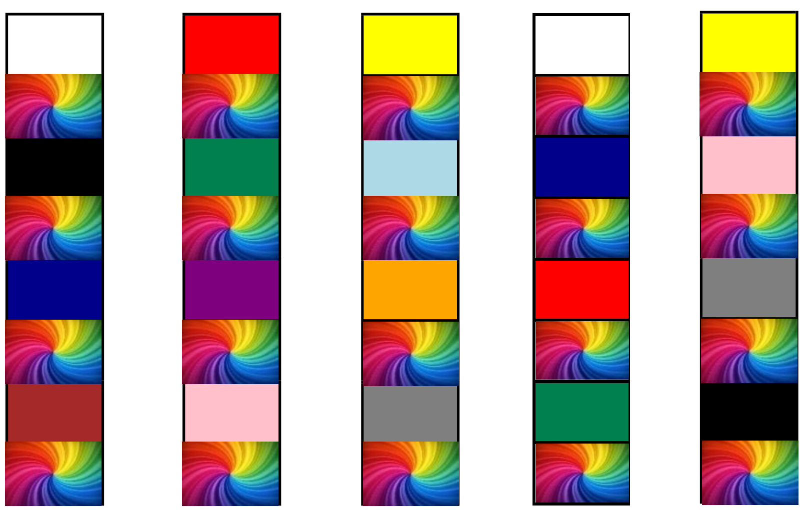
Figure 5

Rainbow Visual Interleaf Screens

Wide discrepancies in pitch for any participant were noted. In all cases, participants supplied one specific sung pitch for each viewed color. The arrangement of colors appeared random to participants. For each question, once a response was made, the note was recorded by the participant into the submission form. Again, for ease of documentation, each pitch was recorded without processing the specific name of the pitch for the participant. The sung pitches were converted into specific pitch names for further analysis using the previously mentioned Zen Tuner, which identified and labeled pitch samples as musical note names. A copy of the specific color slides that were used and the order of their presentation can be seen in Figure 6.

Figure 6

Presentation Order of Colors for Experiment #2



Note. Colors were presented from top to bottom of each column from left to right.

Description of Analysis

This experiment produced single pitch choices for each of the presented colors. As such, a search for consistency was the highest interest. To that end, all pitch data were processed through a chi-square test that measured the deviation of participant sample responses from expectation. It was also helpful to determine statistical significance of those associations in comparison with those established between the same color and other sounds. These chi-square tests, similar to the ones conducted for the previous experiment, allowed for examination of the entire set of pitch responses collectively, each individual color trial with corresponding pitch, and combined multiple trials for colors that had more than one research trial. This allowed for analysis of possibly smaller participation numbers and insured that any real differences in the research conditions were detected. Descriptive analysis allowed examination of each color trial factored over its pitch responses. Further, to illustrate a precise pitch/color mapping for this participant group, the total RGB colors selected after accounting for individual pitches were averaged (in the same fashion as experiment #1) using a technique involving summing the squares, finding the mean of those summed squares, then returning its square root. This technique returned colors more accurately to color selection than the mere tradition central tendency measure of summing and dividing by the number of participants (the traditional "arriving at the mean").

Summary of Experiments

After all of the data for these three research activities were received and processed, some fascinating response trends began to emerge. Participants shared rich narrative responses for their thoughts on correspondences with color and with pitch. Freely chosen colors for color responses in many instances mirrored expected responses. Participant responses to pitch produced a color map of sound while their responses to color produced some consistencies in pitch over the duration of the experiment. While further study would always be necessary to further analyze any color and music pitch relationships, the current data set produced some expected and unexpected results.

CHAPTER IV

RESULTS

Q1 Do previous experiments in color/shape correspondence also suggest a correspondence, universal or otherwise, between color and musical pitch?

Seeking to answer this question, an initial survey was conducted asking for responses to a variety of demographic as well as color- and shape-related questions.

Q2 Are participants able to assign colors to heard musical pitches to determine if there is a universal color and musical correspondence?

Q3 Are consistent musical pitch associations present when participants apply musical pitch labels to color they see?

Additionally, in seeking to answer the questions above, participants were tested first on perceived color responses to pitch and then on perceived pitch responses to color.

Data collected for each of these research activities produced both quantitative and qualitative results as well as data items that could be manipulated into quantitative results from initial qualitative sources. While there was some attrition between each experiment, the data collected points to significant trends, though not universality, in participant connections to pitch and color (and color and pitch). Many response trends came through during the research and produced not only a clear and consistent picture of how specific sounds and specific colors were perceived by participants but also audio and visual representations of some of those concepts. Particular focus in the data analysis was placed upon discovering if relationships between variables were of a chance nature or not. In all matters, this was the first exploration of these concepts and this research established connections for research studies in the future.

Survey Results

Participation was solicited from school populations as well as adult populations to gather feedback and perception regarding a previous Kandinsky (2007) color-shape correspondence experiment. Eighty-four participants took part in this survey with 52.4% identifying as either a music student, an art student, or both a music and art student and 47.6% identifying as an adult participant with a gender delineation of 63.1% female, 33.3% male, and 3.6% preferring not to answer this demographic question. Grade level participation was evenly split amongst four high school grade levels (48.8% overall) with 51.2% of participants indicating they were either out of high school or an adult. The principally surveyed high school represented 46.6% of all responses with participants in other high schools or out of high school accounting for 53.6% of all responses. When asked about their familiarity with the work of visual artist Wassily Kandinsky, 59% of participants indicated no familiarity with a relatively even split among participants answering in the affirmative or unsure (13.3% and 15.7%, respectively). The following table summarizes these demographic findings.

Table 4

Sociodemographic Characteristics of Participants at Baseline

Characteristic	Research Participants	
	n	%
Classification		
Adults	40	47.6
Music Students	33	39.3
Both Music & Art	11	13.1
Gender		
Female	52	63.1
Male	28	33.3
Prefer not to say	3	3.6
Current Grade Level	1	1
9th	8	9.5
10th	10	11.9
11th	13	15.5
12th	10	11.9
Other	43	51.2
Familiar with Kandinsky		
Yes	11	13.3
No	59	71.1
Unsure	13	15.7

For participants who indicated some level of knowledge of Kandinsky's work, a rich narrative question followed giving the opportunity to provide any insight they knew or wanted to share. This question was only answered by the 11 participants who indicated "yes" to the previous question and included a similar pool of responses. These responses included "abstract artist," "Russian," "colorful," "colors and shapes," and "abstractionism" in varying degrees. Three responses, however, were very specific and worthy of note. One participant wrote, "I learned about him when I was in middle school. He was an abstract artist that had synesthesia and painted the spaces and colors that he saw when he heard certain music." Another participant responded, “I’ve [sic] read about his study of colors and shapes.” The third specific response included “He worked with color and it’s [sic] relationships outside of art.”

Two more baseline questions were asked prior to the free response question portion of the survey. When presented with the statement and question “Kandinsky believed certain shapes corresponded with colors. Do you believe this is true?”, 42 participants (exactly 50%) indicated yes with 42.9% responding with “maybe” and only 7.2% (representing six participants) indicating “no.” The subsequent question sought to gather opinion regarding music and color. When asked “Could a correspondence between color and music exist?”, 71 participants (84.5%) indicated “yes,” leaving 15.7% (or 13 participants) responding with “maybe.” Fascinatingly, no participants responded with “no,” meaning even the 7.2% of participants who did not believe there was a color/shape correspondence in the previous question at the very least considered a color/music correspondence a possibility if not likely. Table 5 summarizes these final two multiple choice response questions prior to the experimental questions.

Table 5

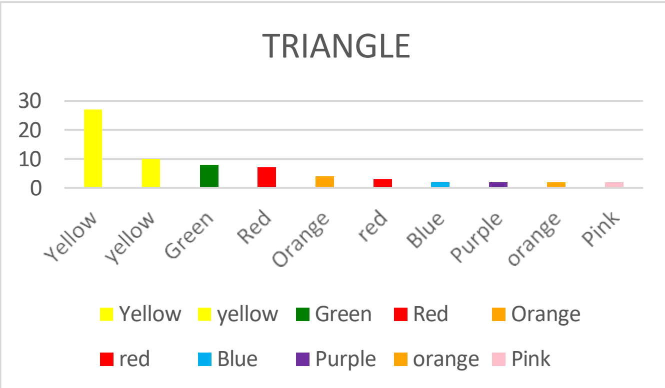
Responses to Correspondence-Specific Questions

Question	Research Participants	
	n	%
Color/Shape Correspondence Possibility?		
Yes	42	50.0
No	6	7.1
Maybe	36	42.9
Color/Music Correspondence Possibility?		
Yes	71	84.5
No	0	0
Maybe	13	15.5

The next three questions asked participants to process specific shapes and suggest a color for these shapes. The participants were presented with each shape followed by the prompt: "If you were to assign a color to this shape, which would you choose," followed by a free response section in which participants wrote down the color of their choice. It is extremely important to note that several conditions were avoided prior to asking these questions as well as during the questions themselves. At no point prior to these questions were any indications given to participants about which specific shapes they would need to work with. Participants were only given this instruction: "The following questions will ask you to make some assumptions regarding specific shapes and specific colors." Additionally, at no point prior to these questions was any indication given to participants regarding Kandinsky's suggested color/shape correspondences. Further, no shape or color indications were given during the asking of the questions. As a final important characteristic of this research, all opportunities for responses were free responses with no additional color information or suggestion provided for participants. Upon seeing a shape, each participant had an opportunity to indicate any color they wished of all the possible colors available on the color spectrum as well as colors participants themselves created as blends of existing colors (e.g., "Kermit the frog green" or "eggplant purple"). All colors were free choices. Upon seeing the visual of a triangle, participants were asked to assign a color to the shape. The results of this question are contained in Figure 7:

Figure 7

Participant Responses to Triangle Shape



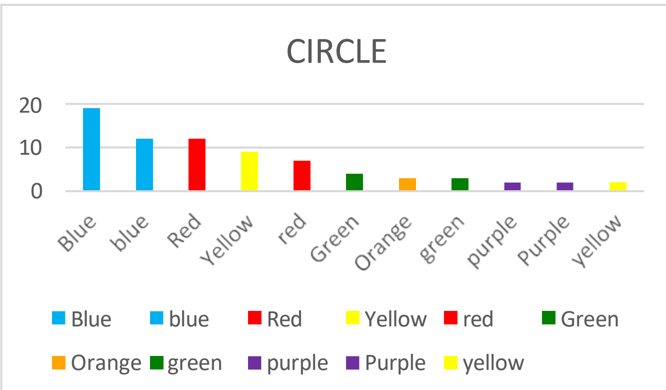
Note. Table taken directly as reported in Google to two instances of color choice.

Because of how responses were tabulated within a Google survey, capitalization affected the reporting in the graph. Use of the same word but one with capitalization and the other without resulted in two separate entries in the chart. To preserve the data exactly as reported by Google, the figures for each of these shapes were presented precisely how the data were returned. Compilations of data occurred after processing the visuals. In the above figure, “yellow” is represented as 11.9% of the responses. However, “Yellow” (note capitalization) is also represented by the initial high response bar of 32.1% as well as a single additional response containing yellow with a different spacing in the response, meaning that participant responses of the color “yellow,” regardless of capitalization or spacing, made up a total of 45.2% of the total responses. This represented both the largest single-color response of all responses for the triangle shape as well as the original shape/color correspondence suggested by Kandinsky (2007) in his original experiment. It should also be noted that perhaps a real-world association with the color of a triangle in relation to modern-day “Yield” might may have contributed to this response subconsciously for participants.

Next, participants were asked to evaluate their preferred color assumption for the circle shape. Responses to this question are found in Figure 8.

Figure 8

Participant Responses to Circle



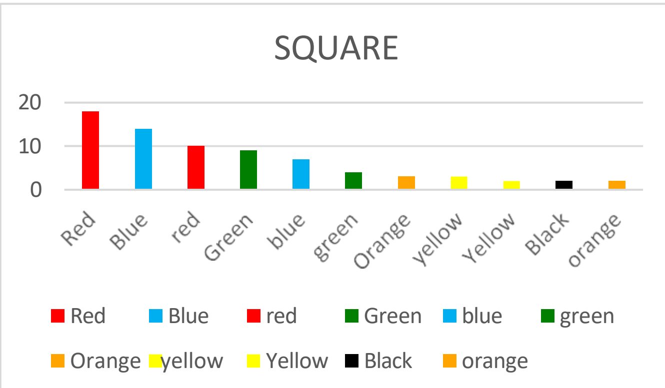
Note. Table taken directly as reported in Google to two instances of color choice.

Similar to capitalization issues encountered in the previous question, this question presented the same challenge of identifying similar colors, which the Google survey considered different responses because of their first letter. When the capitalization factor was processed for color responses for "circle," the color blue received 22.6% and 14.3% of all responses. The addition of "sky blue" in the same family resulted in the color blue appearing in 38.1% of all responses, once again representing both the largest single-color response of all responses for this shape as well as the original shape/color correspondence suggested by Kandinsky (2007) in his original experiment (an additional 1.2% response prevalence was possible if the reported participant color of "teal" was processed within the blue color family more than the green color family. In this accounting, it has not been processed in that fashion).

Participants were then asked to assess the final of Kandinsky's (2007) shapes: the square. Participant responses for color assumption to the square are provided in Figure 9.

Figure 9

Participant Responses to Square



Note. Table taken directly as reported in Google to two instances of color choice.

While participant responses seemed to be closer between the 14 responses for Blue on the graph and 18 for Red for color responses to the square, capitalization issues again added an additional 10 participant responses for "red," making the color red (regardless of capitalization) both the largest single color response of all responses for this shape (at 33.3% of the overall responses) as well as the original shape/color correspondence suggested by Kandinsky (2007) in his original experiment (again, an additional 1.2% red response could be obtained by taking the red/green color response of one participant as belonging to the red family. This seemed a particularly problematic leap given the difference in these apparent hues and so this has been avoided in the present color accounting).

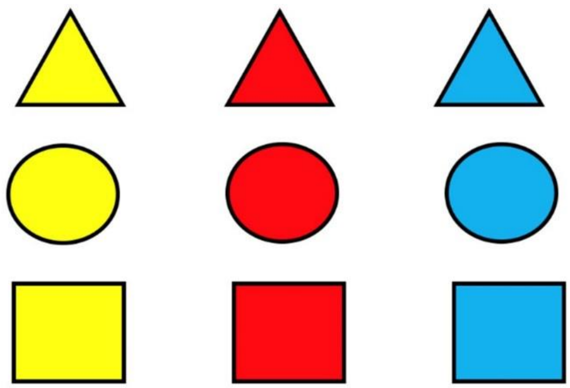
In all three shapes presented to participants in this first research assessment, each met both the standard of most popularly selected color as well as matching Kandinsky's (2007) proposed natural shape/color connections. More specific statistical research on the phenomenon presented in these first three questions proved difficult given the possibility of an unlimited number of color responses against the three expected values for each shape.

The next three questions in the survey asked for the same basic information as the previous three questions but in these cases, they limited the possible participant responses to just three colors: red, blue, and yellow (see Figure 10).

Figure 10

Presentation of Kandinsky Shapes and Colors

Shapes and Colors



Note. Each horizontal line was presented to participants in each question.

With only these three colors available as response options and the previous three participant question responses available, some combination of four research outcomes seemed likely: color distribution would mirror the previous three question color distributions, color distribution would favor a greater percentage of individual colors in accordance with Kandinsky's proposed color correspondences, color distribution would favor a lesser percentage of individual colors in opposition to Kandinsky's proposed color correspondences, or color distribution would fall equally amongst all three colors to all three shapes.

In the first of these three questions, participants were asked to consider the triangle shape and provide the color they thought most appropriate for the shape, imagining their color choice was solid and motionless. For this triangle, the color yellow was selected 67.9% with red selected by 19% of participants and blue by 13.1%. This color selection further supported Kandinsky's (2007) model as well as increased the response rate of the previous free-response question for triangle color preference by 22.7%. A concern at this point was the color response proportions might be within the realm of a natural distribution owing to mere chance. To compare the distribution of the color choice in this question among the three possible color choices presented to participants, a chi-square goodness-of-fit test was used. After verifying its assumptions (the sample was randomly drawn from the population, and each category contained more than five observations), the test was performed. A *p*-value less than 0.05 would indicate statistical significance. The chi-square goodness-of-fit test confirmed the proportions did differ by color and this was not by chance, $\chi^2 (2, N{=}84) = 45.50, p = .0001$. This difference was considered extremely statistically significant.

In the second question, participants were asked to consider the circle shape and provide the color they thought most appropriate for the shape, again imagining their color choice was solid and motionless. For this task, blue was selected by 51.2% of participants. Red was the second choice at 32.1% with yellow following at 16.7%. Again, the highest percentage color selected for this circle was consistent with both the most popularly selected color in the previous circle question and Kandinsky's (2007) proposed color suggestion. Additionally, this question produced a response that was 13.1% higher for the same most popular color as the previous circle question. A chi-square goodness-of-fit test on these responses also revealed the proportions differed by color and this was not by chance, χ^2 (2, *N*=84) = 15.07, *p* = .0005. This difference, too, was considered statistically significant.

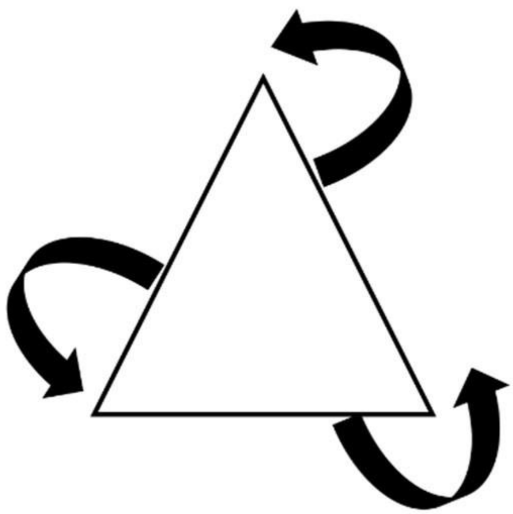
In the final question in this sequence, participants were asked to select the most appropriate color for the square shape given the same parameters as before. Red was selected by 40.6% of respondents, followed in popularity by blue (36.9%) and then yellow (15.5%). The selection of red as the most popular color mirrored the selection as most popular color in the previous circle question as well as that of Kandinsky's (2007) suggestion. This result, in much the same way as the previous two shape questions, increased the initial red circle data response, in this case by 14.3%. Once again, the chi-square goodness-of-fit test was employed to determine the level of chance these percentages demonstrated. In this case, as in both previous cases, the proportions did differ by color by more than chance, χ^2 (2, *N*=84) = 13.50, *p* = .0012. This difference was statistically significant (but less significant than results for yellow triangle and blue circle). These responses and tests revealed that while the color responses were not universal amongst all participants, they were prevalent in the majority of responses.

Throughout Kandinsky's (2007) work, he contended in many of his writings that there was a motion component to color and these specific shapes with their angles helped to mirror those motions. It seemed reasonable, then, to attempt to recreate his suggested motions within the static solid color structure. For this series of three questions, participants were given a set of instructions on the type of motion desired as well as a visual example and then asked to imagine this motion as they chose what they deemed to be the most appropriate color for each of the three shapes. The presentation order of the shapes and colors were the same and again colors were limited to the three possibilities as presented in the previous three questions.

For the triangle question, participants were asked to imagine a color in the shape moving in ex-centric motion (a motion characterized by rotation outward and counterclockwise). A picture, which can be found in Figure 11, accompanied this description.

Figure 11

Visual to Accompany Ex-Centric Motion for Triangle

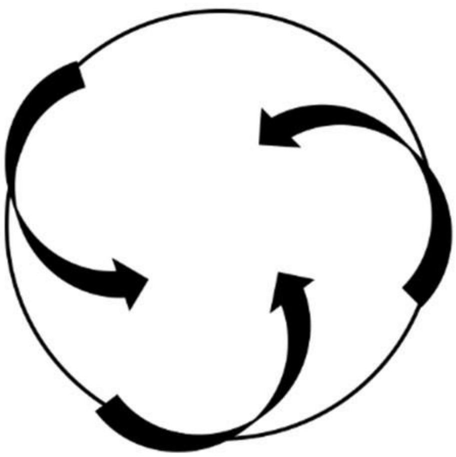


With this new motion component, the percentage responses for color were 41.7% red, 36.9% yellow, and 21.4% blue. This was the first response that diverged from the previous triangle experiment responses as well as the Kandinsky (2007) proposed color/shape connection. Turning to the chi-square test again might reveal whether this attribution of colors fell within a random variation of responses. When these data were subjected to the chi-square test, it was discovered that the proportions did not differ by color by more than chance, χ^2 (2, N=84) = 5.64, p = .06. Hence, the difference was not statistically significant. This result might be explained as being a random collection of color choices for this shape combined with its requested motion.

The second question in this set paired the circle shape with its concentric motion. For this question, participants were asked to imagine a color in the circle shape moving in concentric motion (a motion characterized by rotation inward and counterclockwise). A picture, which can be found below as Figure 12, accompanied this description.

Figure 12

Visual to Accompany Concentric Motion for Circle

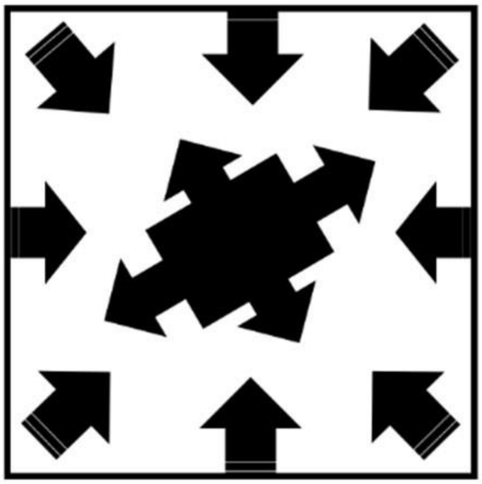


Adding the motion component to this circle question produced a favored participant response for blue (52.4%), then red (34.5%), followed by yellow (13.1%). This trial again supported the color selection on each previous circle question as well as Kandinsky's (2007) suggestion; thus, these data were also a good candidate for the chi-square test. The testing again indicated a result beyond the element of chance, χ^2 (2, N=84) = 19.50, p = .0001 and in the statistically significant range.

In the final question, the square was tested with its proposed intrinsic motion (a motion within the shape itself). A picture (see Figure 13) accompanied this description.

Figure 13

Visual to Accompany Intrinsic Motion for Square



Participants ranked their color choices with 47.6%, suggesting red was the most appropriate color for the square. This was distantly followed by 28.6% responses of blue and 23.8% of the responses with yellow. Use of chi-square again suggested a statistical significance greater than an expected color selection, χ^2 (2, N=84) = 8.00, p = .0183.

Three multiple-choice questions and one free-response question closed out this survey. In the first of these multiple-choice questions, participants were asked if they believed a color/musical pitch correspondence could be possible. Participants responding “yes” made up 77.4% of the data (65 participants) with 19% (16) indicating “maybe” as their response and the remaining 3.6% (3) indicating they were unsure. Again, it was interesting to note that of these 84 participants, none responded with “no” after having gone through the rest of the survey. Percentages of “yes” and “maybe” responses did differ from their original prior responses in the survey (responses of “yes” decreased 7.1% from the early survey question and responses of “maybe” increased 3.5% from the early survey question). However, it is important to note that the initial question asked participants if a correspondence between color and music could be possible. The current question asked if a correspondence between color and musical pitch was possible. The difference in wording, though unintentional and subtle, might be significant.

Following this question, participants were asked to explain their responses to the question in a free-form narrative format. All 84 participants responded to this question. Their responses included descriptions of colors and sounds sharing emotions, psychological connections between the two, as well as many beliefs that there could be a connection but nothing concrete to share. One participant wrote, “It's hard to explain. Music just has colors to it. The sound has colors.” The complete series of responses, too numerous to summarize fully or include here, are provided in Appendix F. Perhaps the most intriguing of these responses was from a high school participant who wrote, “Color and pitch are both perceptions. A person could correlate perceptions.”

Participants were then asked if they possessed perfect pitch. A majority of participants (69.9%) indicated they did not. When asked whether the participant heard music in color, the majority of responses (43.4%) were “no” although the categories of “yes”, “maybe”, and “unsure” made up the other 56.6% of responses. A summary of these final questions is found in Table 6.

Table 6

Sociodemographic Characteristics of Participants at Baseline

Characteristic	Research Participants	
	n	%
Possibility of color/musical pitch correspondence?		
Yes	65	77.4
No	0	0
Maybe	16	19.0
Unsure	3	3.6
Do you possess perfect pitch		
Yes	6	7.2
No	58	69.9
Maybe	14	16.9
Unsure	5	6.0
Do you hear music in color?		
Yes	19	22.9
No	36	43.4
Maybe	18	21.7
Unsure	10	12.0

Pitch/Color Experiment Results

Respondents who participated in the Google Survey were invited to continue their participation into the first of two experiments involving musical pitch and color. In this first experiment, participants were presented with 20 musical pitches and asked to select the color they deemed most appropriate from a list of 12 colors. These colors matched the first 12 colors identified in the basic color terms work of Berlin and Kay (1969; referenced previously; see Figure 3).

Although the opportunity to participate in this experiment was open to all respondents who participated in the initial survey, only 62 chose to participate in this second requested research activity. All of those participating had, however, completed the previous survey. The presentation order of the pitches was the same as in Chapter III (reference previously; see figure 4).

With the given number of participants and the number of audio trials (20), the resulting 1,240 color selections provided ample opportunity to analyze this data. The initial analysis was to organize each of the individual pitches to color responses into a visual matrix. After creation of the first matrix matching color name responses with their respective colors, additional matrices were constructed consisting of only color with no color words (see Figures 14 and 15, respectively).

Figure 14

Participant Color Responses with Words and Matching Colors

Pitch 1:	Pitch 2:	Pitch 3:	Pitch 4:	Pitch 5:	Pitch 6:	Pitch 7:	Pitch 8:	Pitch 9:	Pitch 10:	Pitch 11:	Pitch 12:	Pitch 13:	Pitch 14:	Pitch 15:	Pitch 16:	Pitch 17:	Pitch 18:	Pitch 19:	Pitch 20:
C	E	E	A#/Bb	E	C#/Db	A	F#/Gb	B	G	D	C	G#/Ab	D	B	D#/Eb	E	G	A	C
Black	Brown	Brown	Dark Blue	Brown	Black	Brown	Black	Brown	Black	Black	Black	Brown	Black	Black	Black	Black	Black	Brown	Black
Black	Brown	Brown	Dark Blue	Brown	Black	Dark Blue	Black	Dark Blue	Black	Black	Black	Brown	Black	Brown	Black	Black	Brown	Dark Blue	Black
Black	Brown	Brown	Dark Blue	Brown	Black	Green	Black	Dark Blue	Brown	Black	Black	Dark Blue	Black	Dark Blue	Black	Brown	Dark Blue	Green	Black
Black	Dark Blue	Brown	Green	Brown	Black	Green	Black	Green	Brown	Black	Black	Dark Blue	Black	Dark Blue	Black	Brown	Dark Blue	Green	Black
Brown	Dark Blue	Dark Blue	Green	Brown	Brown	Green	Brown	Green	Brown	Black	Black	Dark Blue	Black	Dark Blue	Black	Brown	Dark Blue	Green	Black
Brown	Dark Blue	Dark Blue	Green	Brown	Brown	Green	Brown	Green	Brown	Brown	Black	Dark Blue	Black	Dark Blue	Black	Dark Blue	Dark Blue	Grey	Black
Brown	Dark Blue	Dark Blue	Grey	Brown	Brown	Green	Brown	Green	Dark Blue	Brown	Black	Green	Black	Green	Black	Dark Blue	Green	Grey	Black
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Brown	Green	Green	Light Blue	Dark Blue	Brown	Light Blue	Dark Blue	Grey	Dark Blue	Brown	Brown	Green	Brown	Green	Brown	Green	Green	Light Blue	Brown
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Brown	Green	Green	Orange	Green	Dark Blue	Light Blue	Green	Orange	Green	Dark Blue	Brown	Light Blue	Dark Blue	Light Blue	Dark Blue	Light Blue	Light Blue	Light Blue	Brown
Brown	Green	Green	Orange	Green	Dark Blue	Light Blue	Green	Orange	Green	Dark Blue	Dark Blue	Light Blue	Dark Blue	Light Blue	Dark Blue	Light Blue	Light Blue	Orange	Brown
Dark Blue	Grey	Grey	Orange	Green	Dark Blue	Orange	Green	Orange	Grey	Dark Blue	Dark Blue	Orange	Dark Blue	Light Blue	Dark Blue	Light Blue	Light Blue	Orange	Brown
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Dark Blue	Grey	Grey	Orange	Green	Dark Blue	Orange	Green	Orange	Grey	Dark Blue	Dark Blue	Orange	Dark Blue	Light Blue	Dark Blue	Orange	Light Blue	Orange	Brown
Dark Blue	Light Blue	Grey	Orange	Green	Dark Blue	Orange	Grey	Pink	Grey	Dark Blue	Dark Blue	Orange	Dark Blue	Light Blue	Dark Blue	Orange	Light Blue	Orange	Brown
Dark Blue	Light Blue	Grey	Pink	Green	Dark Blue	Orange	Grey	Pink	Grey	Dark Blue	Dark Blue	Orange	Dark Blue	Orange	Green	Orange	Light Blue	Orange	Dark Blue
Dark Blue	Light Blue	Grey	Pink	Green	Dark Blue	Orange	Grey	Pink	Grey	Dark Blue	Dark Blue	Orange	Green	Orange	Green	Orange	Light Blue	Pink	Dark Blue
Dark Blue	Light Blue	Grey	Pink	Grey	Dark Blue	Orange	Grey	Pink	Grey	Dark Blue	Dark Blue	Orange	Green	Orange	Green	Orange	Orange	Pink	Dark Blue
Dark Blue	Light Blue	Grey	Pink	Grey	Green	Orange	Grey	Pink	Grey	Dark Blue	Dark Blue	Orange	Green	Pink	Grey	Orange	Orange	Pink	Dark Blue
Dark Blue	Light Blue	Grey	Pink	Grey	Grey	Orange	Grey	Pink	Light Blue	Dark Blue	Dark Blue	Pink	Green	Pink	Grey	Orange	Orange	Pink	Dark Blue
Green	Orange	Light Blue	Pink	Grey	Grey	Orange	Grey	Pink	Light Blue	Green	Green	Pink	Green	Pink	Grey	Orange	Orange	Pink	Dark Blue
Green	Orange	Light Blue	Pink	Grey	Grey	Pink	Grey	Pink	Light Blue	Green	Green	Pink	Green	Pink	Grey	Orange	Orange	Pink	Dark Blue
Green	Orange	Light Blue	Pink	Grey	Grey	Pink	Light Blue	Pink	Light Blue	Green	Green	Pink	Green	Pink	Grey	Orange	Orange	Pink	Green
Green	Orange	Light Blue	Pink	Grey	Grey	Pink	Light Blue	Pink	Orange	Green	Green	Pink	Green	Pink	Grey	Orange	Orange	Pink	Green
Green	Orange	Light Blue	Purple	Light Blue	Grey	Pink	Light Blue	Pink	Orange	Green	Grey	Pink	Green	Pink	Grey	Orange	Orange	Purple	Green
Green	Orange	Orange	Purple	Light Blue	Grey	Pink	Light Blue	Purple	Orange	Green	Grey	Pink	Green	Pink	Light Blue	Orange	Orange	Purple	Green
Green	Orange	Orange	Purple	Light Blue	Grey	Pink	Light Blue	Purple	Orange	Grey	Grey	Pink	Green	Pink	Light Blue	Orange	Orange	Red	Green
Grey	Orange	Orange	Red	Orange	Grey	Pink	Light Blue	Purple	Orange	Grey	Grey	Purple	Green	Pink	Light Blue	Orange	Pink	Red	Green
Grey	Orange	Orange	Red	Orange	Orange	Purple	Light Blue	Purple	Orange	Grey	Grey	Purple	Grey	Pink	Light Blue	Pink	Pink	Red	Green
Orange	Orange	Orange	Red	Orange	Orange	Purple	Light Blue	Red	Orange	Grey	Grey	Purple	Grey	Pink	Orange	Pink	Pink	Red	Grey
Orange	Pink	Orange	Red	Orange	Orange	Purple	Orange	Red	Pink	Grey	Orange	Purple	Grey	Pink	Orange	Pink	Pink	White	Grey
Orange	Pink	Orange	Red	Orange	Pink	Purple	Orange	Red	Pink	Grey	Orange	Red	Grey	Purple	Orange	Purple	Pink	White	Grey
Orange	Pink	Orange	White	Orange	Purple	Purple	Orange	White	Pink	Light Blue	Purple	Red	Orange	Red	Purple	Purple	Pink	White	Grey
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Purple	Pink	Orange	White	Pink	Purple	Red	Pink	White	Purple	Orange	Purple	Red	Orange	White	Purple	Purple	Purple	White	Orange
Purple	Pink	Orange	White	Pink	Purple	Red	Pink	White	Purple	Orange	Purple	Red	Orange	White	Purple	Purple	Red	White	Orange
Purple	Pink	Orange	White	Purple	Purple	Red	Pink	White	Purple	Orange	Purple	White	Orange	White	Purple	Purple	Red	White	Pink
Purple	Purple	Pink	White	Purple	Purple	Red	Purple	White	Red	Orange	Purple	White	Orange	White	Purple	Purple	Red	White	Purple
Purple	Purple	Pink	White	Purple	Purple	Red	Purple	White	Red	Purple	Purple	White	Orange	White	Purple	Red	Red	White	Purple
Purple	Purple	Purple	White	Purple	Purple	White	Purple	White	Red	Purple	Red	White	Orange	White	Purple	Red	Red	Yellow	Purple
Purple	Red	Purple	White	Purple	Purple	White	Purple	White	Red	Purple	Red	White	Purple	White	Purple	Red	White	Yellow	Purple
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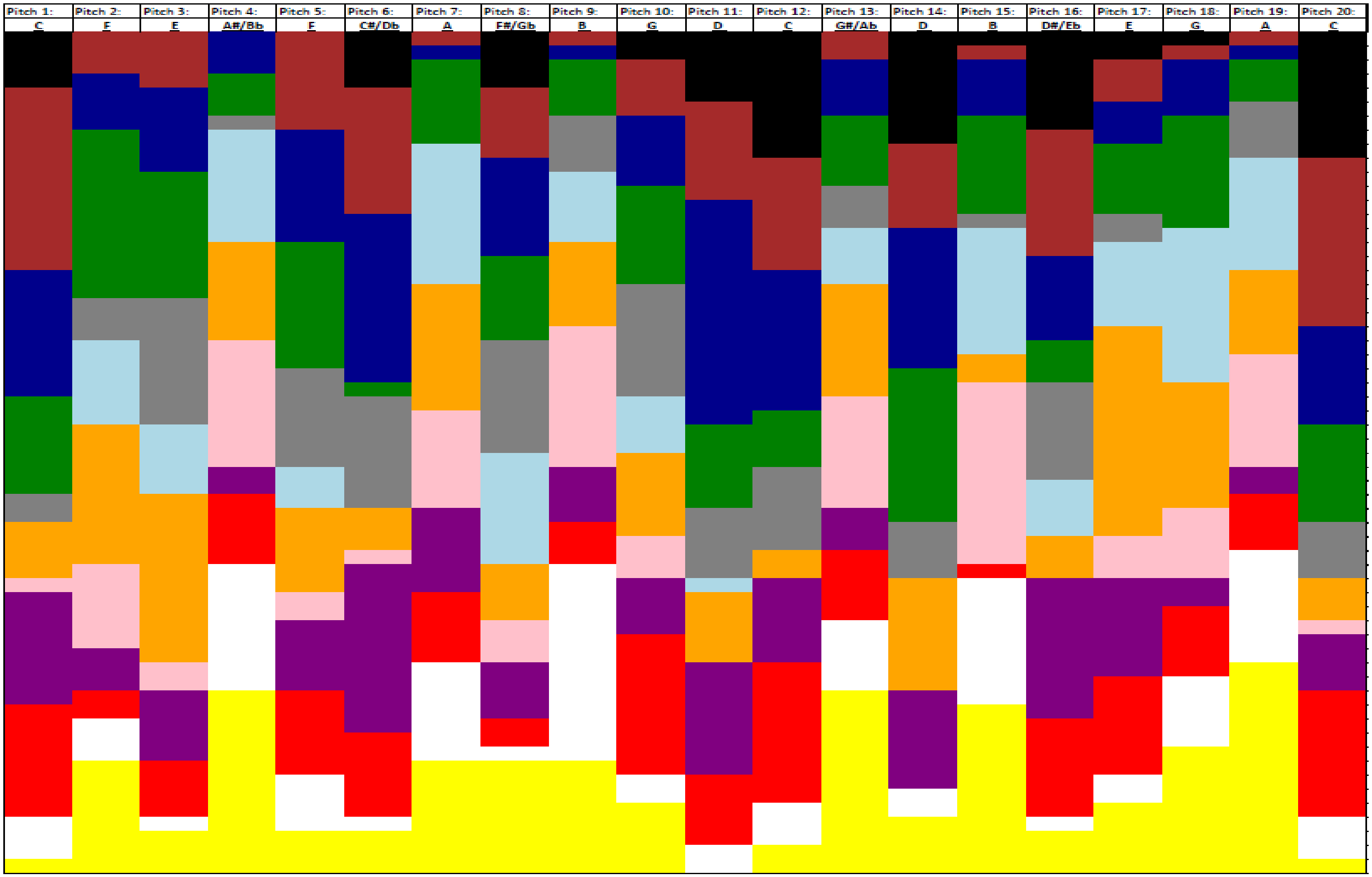
Red	White	Purple	Yellow	Red	Purple	White	Red	Yellow	Red	Purple	Red	Yellow	Purple	Yellow	Red	Red	White	Yellow	Red
Red	White	Red	Yellow	Red	Red	White	Red	Yellow	Red	Purple	Red	Yellow	Purple	Yellow	Red	Red	White	Yellow	Red
Red	Yellow	Red	Yellow	Red	Red	White	White	Yellow	Red	Purple	Red	Yellow	Purple	Yellow	Red	Red	Yellow	Yellow	Red
Red	Yellow	Red	Yellow	Red	Red	Yellow	Yellow	Yellow	Red	Red	Red	Yellow	Purple	Yellow	Red	White	Yellow	Yellow	Red
Red	Yellow	Red	Yellow	White	Red	Yellow	Yellow	Yellow	White	Red	Red	Yellow	Red	Yellow	Red	White	Yellow	Yellow	Red
Red	Yellow	Red	Yellow	White	Red	Yellow	Yellow	Yellow	White	Red	Red	Yellow	White	Yellow	Red	Yellow	Yellow	Yellow	Red
Red	Yellow	White	Yellow	White	Red	Yellow	Yellow	Yellow	Yellow	Red	White	Yellow	White	Yellow	White	Yellow	Yellow	Yellow	Red
White	Yellow	Yellow	Yellow	White	White	Yellow	Yellow	Yellow	Yellow	Red	White	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	White
White	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Red	White	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	White
White	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	White	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	White
Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	White	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow

Figure 15

Participant Color Responses with Only Matching Colors



A simple observation revealed, as expected, no one pitch was ever heard as entirely one color throughout the research. However, many pitches had prevalent color responses from participants. Some pitches included multiple trials, which in all cases repeated the initial color preferences from the original responses. The degree to which the color selection in the experiment resulted from chance was of interest in an activity such as this. Turning again to the Chi- square goodness-of-fit test, this researcher wanted to determine if the color selection deviated from the expected values and if so, if it was significant enough to warrant further consideration. The initial test took all of the 1,240 color responses into consideration over the 20 pitch trials. There was no opportunity for participants to select colors beyond the 12 listed nor were they able to select a response that consisted of no color. The order of the 12 colors remained in the same order throughout the experiment. Results for the test on 12 pitches over the duration of the entire experiment showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=1240) = 57.32, p < .0001. This difference was considered statistically significant, meaning the difference in the selection of these colors over the course of the experiment from what we would expect under normal circumstances could not be explained as an accident or normal. There was something at work behind the scenes in the entire experiment.

Having assessed the chi-square goodness-of-fit for the entire experiment, it was appropriate to test each individual pitch trial in the same manner to determine if the observed values differed from the expected values. Twenty individual chi-square goodness-of-fit tests were performed with one for each pitch trial. Results showed that almost all pitch trials demonstrated distributions of color responses that differed significantly statistically from chance. Three individual pitch trials showed no statistical significance, meaning the color selection might have been due to chance. In two of these three trials, a second trial on the same pitch returned a statistically significant result. The third pitch trial had no repetition in the testing. Detailed chi-square goodness-of-fit tests for these pitches are provided in Appendix G while Table 7 summarizes all the individual chi-square goodness-of-fit tests for these individual pitch trials.

It is worth noting the three trials that resulted in non-statistically significant tests (second trial F, only trial F#/Gb, and 1st trial G) all surrounded the mean Hertz central tendency measure of 366.59 Hz. This average Hertz equated roughly to a slightly flat F#, meaning the only measures of insignificance surrounded the mean by a half step on either side. These measures tested significantly in their other trials save for F#/Gb, which was only tested once in this experiment. Thus, the pitch farthest away from the pitch heard the most often (C) with the most consistent color responses was the one pitch that could not establish its own individual color. For the pitches that were sounded more than once, an additional chi-square goodness-of-fit test was conducted for each of those combined trials.

Six chi-square goodness-of-fit tests were performed with one for each combined pitch trial for pitches that had more than one playing. Results showed all pitch trials demonstrated distributions of color responses that differed significantly statistically from chance. Five tests measured pitches that were given two trials each. The note C was the only pitch that received three trials. Detailed chi-square goodness-of-fit tests for these combined pitch trial tests are provided along with their single trial results in Appendix G. Table 8 summarizes all the individual hi-square goodness-of-fit tests for these combined pitch trials.

Table 7

Chi-Square Goodness-of-Fit Test Results for Individual Pitch Trials

Trial	Pitch	χ^2 value		*p*-value	Result
1	C	40.581	<	0.0001	Significant
2	F	28.194	=	0.0030	Significant
3	E	25.871	=	0.0068	Significant
4	A#/Bb	37.484	<	0.0001	Significant
5	F	15.806	=	0.1485	Not Significant
6	C#/Db	44.065	<	0.0001	Significant
7	A	31.290	=	0.0010	Significant
8	F#/Gb	11.161	=	0.4299	Not Significant
9	B	32.452	=	0.0006	Significant
10	G	13.871	=	0.2402	Not Significant
11	D	40.968	<	0.0001	Significant
12	C	30.903	=	0.0011	Significant
13	G#/Ab	23.548	=	0.0148	Significant
14	D	33.613	=	0.0004	Significant
15	B	45.226	<	0.0001	Significant
16	D#/Eb	20.839	=	0.0351	Significant
17	E	29.742	=	0.0017	Significant
18	G	29.742	=	0.0017	Significant
19	A	41.355	<	0.0001	Significant
20	C	36.323	=	0.0001	Significant

Table 8

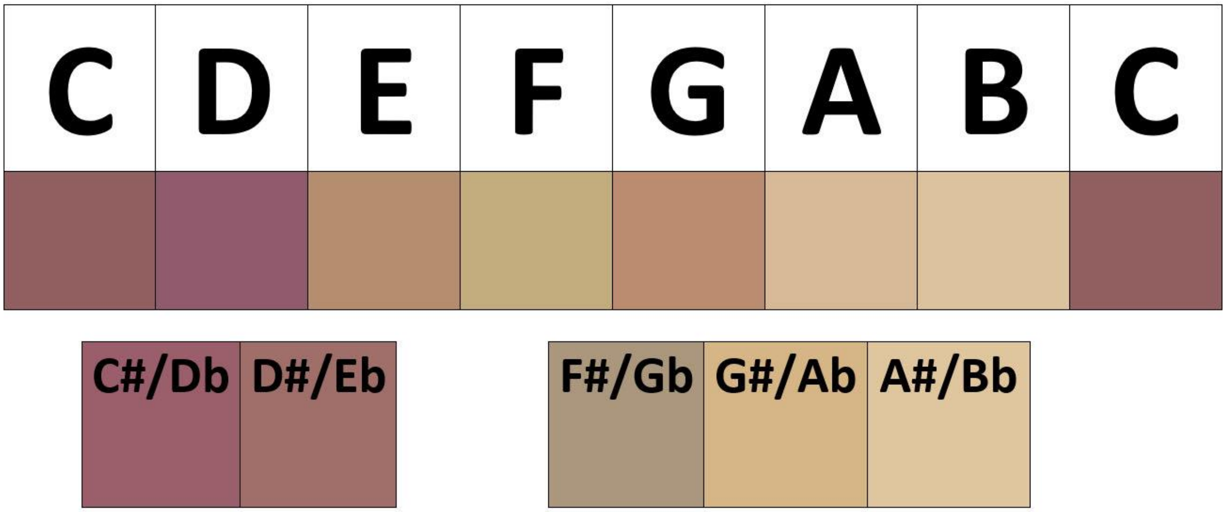
Chi-Square Goodness-of-Fit Test Results for Combined Pitch Trials

# of Trials	Pitch	χ^2 value		*p*-value	Result
3	C	94.258	<	0.0001	Significant
2	F	29.484	=	0.0019	Significant
2	E	45.161	<	0.0001	Significant
2	A	61.806	<	0.0001	Significant
2	B	71.290	<	0.0001	Significant
2	G	24.645	=	0.0103	Significant

After the chi-square tests were completed, this researcher set out to determine if any trends existed on the individual color responses for each pitch. For the first exercise, all of the color responses for each pitch were turned into each of their RGB numbered components (each color with three distinct parts). These components could have simply been averaged together and produced a combined color scheme. However, a more accurate way to average the components was to use a technique whereby each component value has its square summed. Once summed, the mean of that sum was found. Returning that mean's square root then produced a number closer to the true average than the traditional way to arrive at the mean. This task was completed for each pitch, producing the chromatic scale result found in Figure 16.

Figure 16

Averaged RGB for Chromatic Scale Using Sum of Squares Method

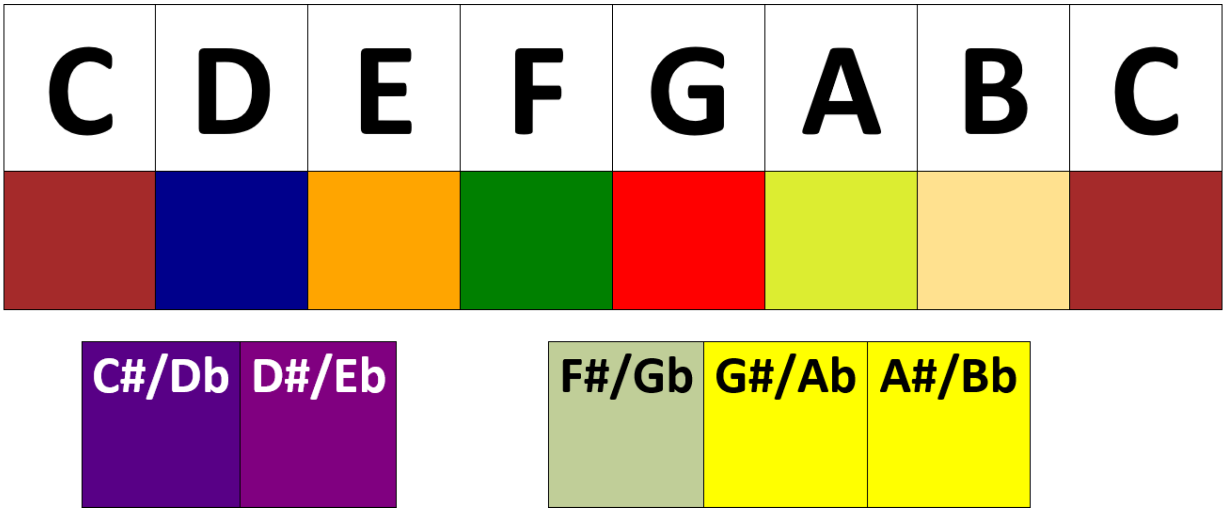


While the overall visual made for a fascinating look at a chromatic scale as factored over all of the color responses, this approach seemed to hover around the mean of pitch (referenced above), which was F#/Gb. This likely is a visual color representation of a bell curve around F#. This researcher had thought this method of summing over every color response might be more helpful than what resulted. While not particularly pedagogically helpful in assisting with identification of individual pitches, it was nonetheless an interesting take on how all of these chromatic pitches were related.

To make this exercise more dynamically helpful for potential student use, this researcher took the most prevalent color responses for each pitch to produce another colored chromatic scale. Most individual pitch responses were skewed heavily in favor of one color for each response. In cases where there were ties in color responses or where two or more responses were extremely close, those color responses were averaged using the sum of squares method. This chromatic scale is found in Figure 17.

Figure 17

Chromatic Scale Using Prevalent Color Responses



This second colored chromatic scale has much more vibrancy (though still subtly built around an F# mean) and much more potential for further auditory application given the clear differences in hues amongst all of the pitches.

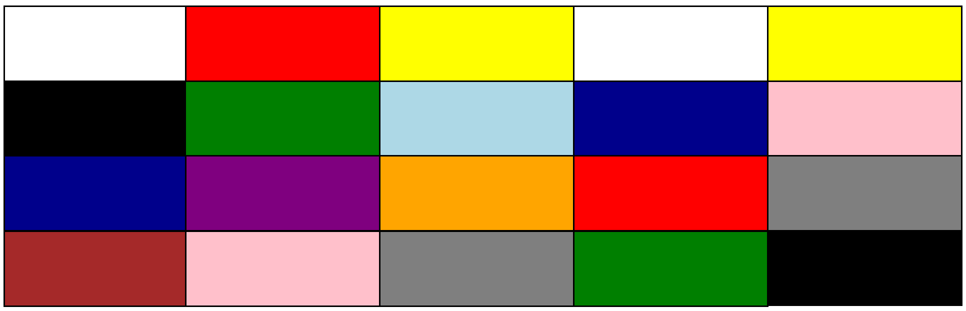
Color/Pitch Experiment Results

Respondents who participated in the first musical pitch and color experiment were likewise encouraged to participate in the second experiment involving color and musical pitch. In this second experiment, participants were presented with 20 colors and asked to audibly respond with the pitch they deemed the most appropriate sound representation of the color they saw. There was no limitation on octave or style of the pitch responses. The audio responses were captured with the Mote Internet browser add-on extension.

Although the opportunity to participate in this experiment was open to all respondents who participated in the initial survey and the first experiment, 58 chose to participate in this third requested research activity. All of those participating had, however, completed the previous pitch/color experiment. The presentation order of the colors (previously referenced in Figure 6) is found in Figure 18 without rainbow interleaf.

Figure 18

Presentation Order of Colors for Experiment #2



Note. Colors were presented from top to bottom of each column from left to right.

The documentation of pitch responses by participants proved to be especially challenging for a number of reasons. Firstly, responses were produced vocally and recorded unlike the previous experiment in which responses were 1 of 12 given colors. This resulted in a wide variety of octaves of pitch response. The iPhone application Zen Tuner was used to process these pitch responses into their respective note names. This application identified enharmonic pitches as sharps. For the actual documentation of participant responses, both sharps and flats were used for reporting these enharmonic pitches. A further complication was the variability of participant responses. Although there were 12 chromatic pitches, each possessed considerable variability (from very flat to very sharp). In all cases for the pitch responses in this experiment, the entire recorded response was processed to determine the central pitch submitted. In some cases, the beginning of a participant response would begin on one pitch and naturally tonally migrate to the next pitch. For these instances, the pitch with the longest duration was the one considered for each response. As a further and unexpected complication, some participants, when presented with a color, responded with “there’s no pitch for this color” or “silence,” thus producing an unexpected 13th possible category of response (the 12 possible pitches plus a non-pitch response). For any response without a pitch response, these were placed into a 13th “no response” category for data analysis. While a similar phenomenon might have possibly occurred in the previous experiment, participants were not given a “no response” option for color selection when presented with the musical pitches.

As in the previous experiment, the chi-square goodness-of-fit test was used to help determine the degree to which participant responses were a result of a natural distribution or if there was a level of significance to those responses. No one color was ever matched entirely with one pitch throughout the research. However, many colors had prevalent pitch responses from participants. Some colors included multiple trials in which all cases repeated the initial pitch preferences from the original responses. The degree to which the pitch selection in the experiment resulted from chance expectation was of interest in an activity such as this. Revisiting the chi-square goodness-of-fit test, this researcher wanted to determine if the pitch selection deviated from the expected values and, if so, if it was significant enough to warrant further consideration. The initial test took all of the 1,160 pitch responses into consideration over their 20 pitch trials. There was opportunity for participants to select any of the 12 pitches in their audiation, though no specific pitch names were listed as choices. Additionally, a “no response” option was gathered during this experiment (which is discussed below). Results for the test on 12 colors over the duration of the entire experiment showed a selection of pitches existing outside the expected and anticipated number, $\chi^2(11, N=1{,}160) = 86.90$, $p < .0001$. This difference was considered statistically significant, meaning the difference in the selection of these pitches over the course of the experiment from what we would expect under normal circumstances could not be explained as an accident or normal. As was the case in the previous pitch/color experiment, there was something at work behind the scenes in participant pitch responses governing the entire experiment.

Having assessed the chi-square goodness-of-fit for the entire experiment, it would now be appropriate to test each individual color trial in the same manner to determine if the observed values differ from the expected values. In the previous experiment, the participant color pitch distribution was under examination. In this current experiment, the distribution under consideration was participant pitch-to-color response. The 12 given colors in this experiment were factored over 20 trials, meaning while all 12 received at least one trial, only eight pitches received two trials. The colors of brown, purple, light blue, and orange were the colors receiving a single trial in this experiment. Since there were 58 participants and the addition of a "no response" category for the audio capture, a curious situation arose with the chi-square test for some of these trials. The chi-square goodness-of-fit test posed a potential reliability issue when expected values were less than 5 for a given observation. For eight of the colors presented, two trials were combined that produced expected values above 5. For these colors, the chi-square test was highly reliable as both trials were taken as part of a single chi-square test. For the aforementioned colors that only saw a single trial, the chi-square goodness-of-fit test was also used but results were taken cautiously.

Eight chi-square goodness-of-fit tests were performed for the eight colors that saw two trials each. Five of these tests returned results that differed significantly from chance. The remaining three colors returned results that were not significant and, thus, a chance pairing of colors and sound could not be ruled out. Detailed chi-square goodness-of-fit tests for these combined color trial tests are provided in Appendix H while Table 9 summarizes the individual chi-square goodness-of-fit tests for these combined color trials.

Table 9

Chi-Square Goodness-of-Fit Test Results for Combined Color Trials

# of Trials	Color	χ^2 value		*p*-value	Result
2	White	77.655	<	0.0001	Significant
2	Black	12.207	=	0.4292	Not Significant
2	Dark Blue	37.534	=	0.0002	Significant
2	Red	20.500	=	0.0582	Not Significant
2	Green	35.069	=	0.0005	Significant
2	Pink	33.052	=	0.0010	Significant
2	Yellow	32.828	=	0.0010	Significant
2	Grey	17.362	=	0.1365	Not Significant

As reported above, 4 of the 12 colors only received a single trial for which participants provided a sound response. While the results of these four chi-square tests provided considerable statistical information, further future research is necessary to determine the extent to which the results were 100% reliable given the lower expected values on the responses. The results of the four chi-square goodness-of-fit tests for single color trials revealed two significant diversions from chance and two instances in which chance selection of pitches could not be ruled out. Detailed chi-square goodness-of-fit tests for these individual color trial tests are provided along with the combined trial tests in Appendix H while Table 10 summarizes all the individual chi-square goodness-of-fit tests for these single color trials.

Table 10

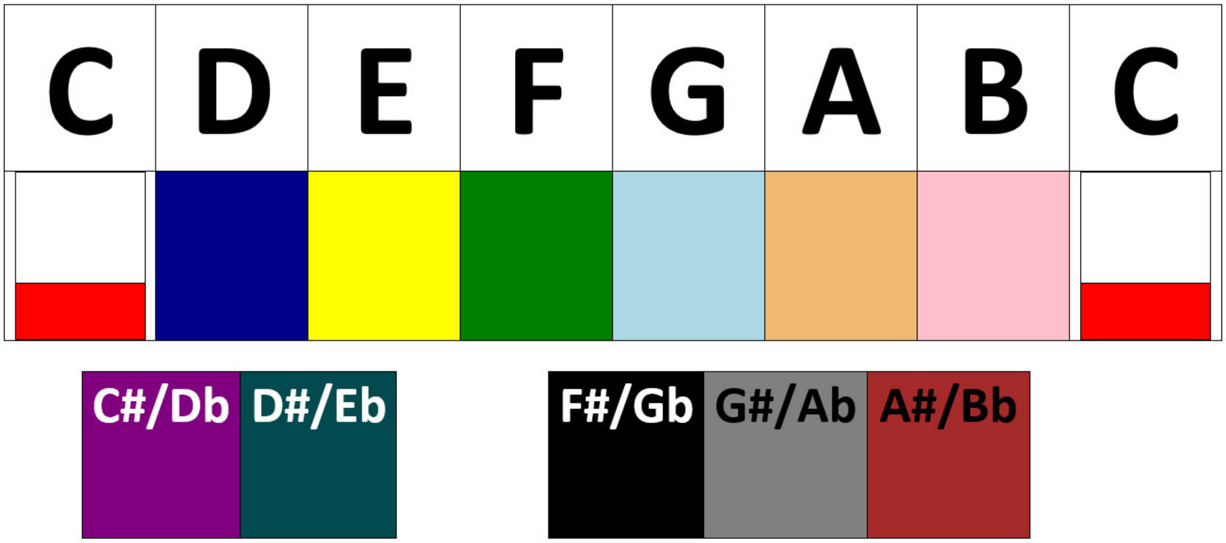
Chi-Square Goodness-of-Fit Test Results for Single Color Trials

# of Trials	Color	χ^2 value		*p*-value	Result
1	Brown	26.276	=	0.0098	Significant
1	Purple	14.172	=	0.2898	Not Significant
1	Light Blue	24.931	=	0.0152	Significant
1	Orange		=	0.0761	Not Significant

Using participant responses, this researcher then attempted to map a color scale to the pitch responses similar to the color scale derived from participant responses to the previous pitch/color experiment. In this regard, the end product might provide additional educational benefits for both student use as well as further study in the future. In many cases, a clear prevalent pitch response to a color was evident, which made the selection of the specific color for that particular note easier. In cases where there were ties in pitch responses or where two or more responses were extremely close, those pitch responses were averaged using the sum of squares method for their colors (as the averaging of actual pitches, because of their variability, would not prove particularly effective or useful). This chromatic scale is found in Figure 19.

Figure 19

Chromatic Scale Using Prevalent Pitch Responses Mapped to Color



Several brief observations should be noted about this chromatic scale. The colors generated for D#/Eb and A are derived through the RGB sum of squares method for averaging color as those two pitches presented the most challenging participant responses to evaluate. No color was mapped to those two pitches. In the instances of all other pitches (except for C), the color selection was very apparent and straightforward. In those cases, the visual color for each of those pitches matched the standard set of RGB numbers for the colors (i.e., the colors selected for those pitches matched the same color choice in the previous experiment exactly). Of additional interest was the note C. Close to 60% of responses to the color white elicited the pitch C. Approximately 30% of the color responses to the color red also elicited the pitch C. This 30% represented the second most C responses of all participant data for that specific note. Both colors were featured in the chromatic scale representation because of this prevalence. The literature also indicated that while many of these color/pitch correspondences were idiosyncratic, the note C tended to represent itself frequently as white or red to composers throughout history (Peacock, 1985). The data from the participants in this experiment supported this as well.

CHAPTER V

DISCUSSION

Summary of Procedures

The purpose of this research was to determine the existence and/or prevalence of correspondence between colors and musical pitch. Students were recruited through personal visits from the researcher to music and art classes in the targeted school. Adult recruitment proceeded as originally conceived. Once consent forms were received in hard copy, participants were contacted with instructions for completing the initial Google Survey as well as the actual link for the survey. This survey gathered demographic data as well as some qualitative narratives on the tasks to be undertaken. Additionally, participants were asked to participate in a color and shape correspondence, which then led to the first of two color and musical pitch experiments.

Summary of Results

Data produced from all three research tasks included quantitative and qualitative structures as well as data that fell into neither category such as individual color responses and individual sound responses. Both descriptive and inferential statistics were used to shed light on these responses. From the initial survey (and prior to any experimental procedures in either this survey or the two experiments that followed), half of all participants agreed a color and shape correspondence was a possibility. Approximately 85% of all participants thought a color and music or pitch correspondence could exist. As stated previously, the remaining 15% of participants suggested a correspondence “might” be possible. From this data, the participants indicated that while some correspondence between color and shape was likely, the probability of a color and pitch correspondence was even greater a possibility than that of color and shape.

Participants then began an experimental portion of the survey that sought to determine whether a previously proposed color and shape correspondence could be replicated. In addition to providing data on the specific tasks involved, it also was an opportunity to determine if a similar color and musical pitch correspondence might exist. In each of the three initial tasks involving free-response color selection, the overwhelming majority of participants selected, for each shape, the originally proposed color correspondence. This was particularly striking because in all cases no previews of the shapes involved or any description of colors were provided. Additionally, the area for responding once each shape was individually seen had no guiding color visuals or words to assist participants in the selection of their color choice. In each case, the color most often selected for each shape from a completely free choice of all possible colors matched Kandinsky's (2007) proposed correspondence (yellow for triangle at 45.2%, blue for circle at 38.1%, and red for square at 33.3% of all respondents). A frequently used statistical test for this research was the chi-square goodness of fit test which identifies if actual data responses exist within the normal expected distribution or outside of that distribution. In this particular case, however, in which the potential data set was an unlimited color palette, such a test was not a possibility. However, for each of the above shapes and colors, no other single-color family reached the percentages of responses the "correct" colors elicited. These results were important discoveries and influential as the next research component was explored. Each shape was tested with only the three specific colors in the entire correspondence: yellow, blue, and red. The assumption here was one of the four possible outcomes could likely occur and since only three colors were used for all shapes, whichever assumption held true in the first shape correspondence would likely hold true for all shapes. Specifically, the results would either closely resemble the previous data for color selection, more fully support the Kandinsky proposed color choices, more fully support a different color choice than the one proposed by Kandinsky or fall equally among all three possibilities. Prior to the data observation, each outcome of those four presented here was equally likely to occur.

What resulted over all three shape experiments was a further selection by participants of Kandinsky's (2007) originally proposed colors for each shape. Through chi-square goodness-of-fit tests, these color choices proved to be more than mere coincidence. They deviated significantly from expected values. Of the three colors presented for triangle, yellow was the most prevalent color choice at 67.9%, an increase of 22.7% over the previous color/shape task and an extremely statistically significant result. Likewise, the selection of blue for the circle shape, chosen by 51.2% of participants (an increase of 13.1% over the previous color/shape task), was also extremely statistically significant. In the final color/shape task in this sequence, not surprisingly (given the previous results), red was chosen by most participants as the color most appropriate for the square shape at 40.6%, an increase of 14.3% over the previous similar task. A chi-square result of statistically significant gave additional weight to this color/shape task. These tasks confirmed two things, both of which were interrelated. In the first, the notion of a universal color correspondence seemed clearly threatened as the results of these tasks were not unanimous. Participant responses did not all follow a single-color pattern for each of the aforementioned shapes. Kandinsky's original proposed correspondences fell short of completely universal as no one color was the sole response for each shape. Real-world associations might also play into the selection of a particular color or against a proposed color. Yet secondly, there did appear to be, beyond mere chance or normality, a clear preference for individual colors for individual shapes, which the data showed was unambiguous.

Kandinsky (2007) himself spoke and wrote of a grand connection between motion and color as crucial to a working of inner harmony (p. 51). Having provided his reasoning for the motions of various hues of color that were then manifested in the angles of the three aforementioned shapes, an exploration seemed a logical next step for my research. Participants were given carefully worded descriptions of these various types of movement within each of the three shapes and then asked to select a corresponding color that seemed to exemplify that motion. Each of the three shape tasks was repeated in turn with each acquiring a new movement or motion profile. The three proposed motion types (ex-centric, concentric, and intrinsic) were described both with words and a picture, and participants were not allowed to continue to answer each question that followed the specific motion until they selected they were comfortable with that definition. In all of these "understandings of comfortable," there was likely a degree to which uncertainty played into the potential affirmative responses of understanding for which this research task could not delineate. This was particularly true in the first task for triangle with this motion component. With participants now factoring in motion to the triangle shape, red was the selected color of choice by a margin of 41.7% with yellow close behind at 36.9% of responses. While this addition of motion seemed to violate Kandinsky's (2007) proposed color/shape correspondence, a chi-square test revealed the selection for this particular color/shape combination was not statistically significant. This might be the result of either normal color selection or in this case with previous results so strongly in favor of Kandinsky's yellow triangle correspondence, it might simply be a data response contributed to by a misunderstanding of the motion description. Whether this was a clarity issue on the participants' understanding or on the researcher’s wording (or a combination of both factors) is unknown but a reasonable issue for further investigation in future research.

The motion component addition to the square produced a response of blue from most participants at 52.4%, which through chi-square analysis proved extremely statistically significant. Similarly, red was the most selected color response for the circle at 47.6%, evidencing statistical significance through chi-square testing. As both of these shape/color responses supported not only Kandinsky’s (2007) original proposed correspondence but also the previous color preferences elsewhere in this survey, a misunderstanding of the motion description for the ideally ex-centric yellow triangle seemed more likely. Further, in two complete cases from the sequence of correspondence tasks (color selection to shape with unlimited color permutations, color selection to shape from finite choices, color selection to shape from finite choices with motion component), the percentage responses of the proposed color correspondence increased over each successive trial. Blue was chosen as the color for the circle shape first in 38.1%, then in 51.2%, and finally in 52.4% of all responses over these three activities. Red was selected as the color for the square shape in 33.3%, 40.6%, and 47.6% of responses over the same similar three trials. Yellow was the only color selection that, while seeing similar patterns in both the first and second of its triangle trials (45.2% and 67.9%, respectively), saw a selection of yellow decrease to 36.9%, again lending further strength (combined with the chi-square result for that trial sequence of non-significance) that this was most likely the result of a misunderstanding of the motion descriptors that were not present in the other motion descriptors.

Final questions in the survey were designed to lead into the next experiments, which were genuinely music and color related. Percentages of participants still remained quite high for thoughts regarding the possibility of correspondence between color and pitch, a question asked again at the end of this survey. Notably, no participant at any point indicated they thought correspondence between color and music correspondence was an impossibility (again with an understanding that in the first question participants were asked about color and music correspondence possibilities and in the second they were asked about color and musical pitch correspondences, which may to some, or many, be two very distinct realms of tonal possibilities). In either circumstance, the high level of belief in a possibility of such a correspondence held for a high degree of promise in the experiments that followed this survey, which targeted this very notion in two separate but connected ways. The final two questions, while very specific, offered the possibility of inaccuracy due to misreporting. With regard to the perfect pitch question asked of participants, those who knew they possessed this skill likely accurately reported the ability in the question. If a participant was not 100% certain or had not had an instance where this claim was checked, they might not have been aware of the skill and thus might have reported it as “unsure” if it was reported at all. There was also a possibility it was a misunderstanding of the question and a selection of “yes” to the perfect pitch question for someone who merely possessed a good sense of relative pitch or did not possess either sense truly but assumed they did. Likewise, with regard to hearing music in color, this term could vary widely in its understanding or even in its actual possessor’s experience and so might not be completely accurate due to under or over reporting on this question.

Given these survey findings, it could be said that initial research question from Chapter I might be partially answered. With both previous experiments in color/shape correspondence and the current survey tasks, a correspondence on some level seems likely. As to whether this initial answer to the first part of the research question supported a correspondence between color and music pitch (the second part of the research question) is a matter to be determined through the data derived through subsequent experiments.

Experiments into Color and Musical Pitch Correspondence

Pitch and Color Experiment

The first experiment beyond the survey approached color and musical pitch correspondence through the lens of providing a pitch participants would then align with 1 of 12 provided colors. The color selection matched the Berlin and Kay (1969) color terms and was displayed in the order Berlin and Kay themselves ordered these colors through their research. Seventy-four percent of the participants in the survey took part in this first musical pitch and color experiment. A universal color for every pitch was not found during the data analysis but several intriguing trends did present themselves from the data. Through the 12 sound trials provided to participants during the research, 1,240 individual color responses were submitted, resulting in many data points to analyze. While most all of the presented pitches received some level of color prevalence, in all cases this prevalence was not unanimous. There were always multiple colors selected for each pitch. However, in some pitch cases, there were colors not selected by any participants. While this occurred in four of the five pitches that received a single trial (including two instances on one pitch of two colors not selected), it more interestingly occurred in four of the seven cases where pitches received multiple trials and in each of those cases, the non-selected color was the same throughout all of those trials. The note C received no color selection as light blue for any of its three experiment trials. For the notes F and A, black was never selected over two trials for each respective pitch. The note D likewise received no selections under the color pink during either of its two trials. Of the pitches that received only single trials, A#/Bb received no selection under black or brown. The pitch C#/Db received no light blue color selection, G#/Ab received no black selection, and D#/Eb received no pink color selection. It is also interesting to note that the colors not selected for many of the single trial colors were similar to the missing colors for closely related notes with multiple trials.

In the absence of unanimously selected colors for pitches, the next best statistic to use was the chi-square goodness-of-fit test to determine if the distribution of color choices in the experiment data was of a normal distribution. Results that might be returned with any level of statistical significance would point to a better than chance occurrence of the color selection. Ideally, for this research, the more of these statistically significant sightings for individual pitches, the more likelihood some level of innate correspondence might be at work. In all but three tests out of 27, the results were of some level of statistical significance, meaning the distribution of these 24 tests was not likely generated via an expected normal distribution. In two of the three tests that could not reach statistical significance (one trial on F and one trial on G), this significance was confirmed through the chi-square test on the combined trials. The only other statistically non-significant test result came from the single trial of F#/Gb. Worth noting is this F#/Gb trial sat halfway between F and G, which also experienced one trial each of a statistically non-significant result.

Statistical significance of response distribution and pitch/color prevalence (and even preference) occupied two separate, but interconnected, realms of study. Using only participant responses of color, all data were averaged using the sum of squares method for RGB numbers in which the individual number for each element component (Red, Green, and Blue) was squared, added together, divided by the total number, the square root taken, and the resulting number used as the new component number for that element. This averaging method was factored over all color responses for each pitch and the resulting new color was plugged into each pitch. Using this method, the resulting color scale took on variations of brown hues, which for as accurate as it might have been to all color responses combined was largely unhelpful as a visual tool for pitch and color discrimination. A better method to produce a color scale was then employed that used prevalent color responses for individual pitches when those responses seemed most clear. In instances where there were multiple colors provided by participants, only those colors were averaged using the sum of squares method above. Not only was this method easier and cleaner to execute but it also produced a visual that had far more potential to be memorable for future application. While many pitches were easy to assign single colors for from the 12 presented colors, the pitches of C, D, and F especially had an exceedingly high prevalence and were thus the easiest of all the pitches to assign a single color. Several other colors benefited from the sum of squares method for RGB color, producing individual color schemes that appeared as "slightly off" from the 12 established colors under consideration. In particular, the pitches of G#/Ab-A-A#/Bb proved challenging in this setting and appeared very similar in hue but wre different in RGB number.

This first pitch/color experiment further answered the second half of the first research question as some musical pitches did seem to lend themselves to a more or less consistent correspondence with color. This experiment was also able to address the second research question in roughly the same manner; some consistent color associations were made when applied to musical pitch by participants.

Color and Pitch Experiment

The final experiment in this research setting inverted the previous experiment and allowed for far greater participant responses. In this experiment, 20 colored slides were presented. Each required participants to intone (through singing, humming, whistling, or otherwise) the musical pitch they believed most closely represented the color they were seeing. The browser add-on used for this experiment also transcribed audio into written text responses. Over 93% of participants in the previous experiment participated in the current experiment. Again, while a unanimous correspondence could not be determined for every individual color, the data received in this experiment led to many details of interest for both current and future study. Some data confirmed earlier research efforts in this study while other data seemed to point to different color and musical pitch pathways. A total of 1,160 separate audio and/or written responses were compiled and processed. Pitch prevalence and chi-square test data were used to identify significance levels of responses as well as create a color scale matrix (similar to the previous experiment but approaching it with different data aspects).

Chi-square goodness-of-fit tests revealed extremely significant statistical results for the entire collection of pitches participants offered as responses. Eight of the 12 color slides had two trials each that allowed for additional chi-square tests to be run with each of these combined trials (as all assumptions when using a chi-square test were met through these combined trials). The combined trials for white, dark blue, green, pink, and yellow all displayed varying levels of significance from very significant to extremely significant (and actually only yellow yielded a “very significant” result. Results for all other colors were “extremely significant”). Chi-square results for combined trials in black and grey proved not to be statistically significant with the combined trials for red barely falling into the non-statistically significant result. Brown, light blue, purple, and orange were the only colors that received a single trial due to the design of the research experiment. This limitation caused the chi-square test to fall short of one of its assumptions of expected values and as such might have produced probability values that were less than 100% reliable. Still, brown and light blue results showed very statistically significant and statistically significant results, respectively, with test results for purple and orange test results appearing to be not statistically significant. All combined, these data served to illuminate another attempt at a color scale using the same approach as previously adopted for the pitch and color experiment. When this method was applied to the data set in the current experiment, three immediately apparent facts came to light surrounding pitch and color. Initially, while the totality of color scales was decidedly different between both experiments, the notes of C#/Db, D, and F all saw identical color prevalence responses over two different experiments with two different mechanics for combining the two elements. Secondly, many colors in this experiment migrated to closely related pitches from participant responses. This was seen to some extent also in the previous experiment where chromatic alterations of notes saw many elements of adjacent color choices. This proximity of frequency in sound created a connection with the proximity of hue in color. Finally, it is notable that the note C and the color white became an overwhelming connection. Participants also connected the note C and the color red. These two colors were correlated with C in examples throughout the literature and in previous testing as well as documented by many composers. The pitches D#/Eb and A were the only two pitches that did not have clear pitch prevalence responses so the sum of squares method of combining RGB color was used with these two pitches, producing compelling individual hues of color for those pitches. In all, this experiment tackled the third and final research question of this study, providing an affirmative response, at least in part, to whether there were consistent musical pitch associations elicited when a color was presented.

Limitations

Although the elements of this study found powerful and important color and pitch connections, several factors arose during the research that might have had an impact on overall results of the study. The most glaring limitation was encountered at the onset of the call for participants for research. An assumption was made that colleagues across the researcher's district would be more than happy to share this call for participation with their students and increase the potential body of knowledge for themselves and their students, a benefit the researcher was clear to share with them as their assistance was sought in recruitment. Instead, these efforts were met with silence and inaction, thus necessitating an overhaul of the procedures that had originally been mapped out. This changed the research timetable and methods significantly. Had there been more time available to deal with this sudden and unexpected shift, new recruiting procedures might have produced far more participants.

The design of this research also saw significant changes due to the COVID-19 pandemic. This research was originally conceived, pre-pandemic, as an in-person study with each component occurring under direct researcher supervision. This would have made many aspects of the study easier to execute and put far less responsibility on the individual participants to complete aspects of the research. Unfortunately, when the pandemic hit, there was no guarantee any of these research activities could be completed in a face-to-face fashion so the decision was made to transition them into virtual activities. While this resulted in considerable portability of the research tasks, it also made those same activities more complicated to complete for participants. The addition of a necessary audio-capture function on the final experiment caused issues in user error and audibility. Attrition over the duration of all three research activities was suspected due in some small part to the added complications of this new virtual set-up, particularly in the final experimental activity.

Subjectivity also limited what data were returned by participants. For the first experiment involving musical pitch and color, all pitches were sounded in the C4 octave, meaning color associations for participants that might have been octave specific were not wholly activated during the activity. Participants were given only the 12 predetermined colors to choose from, which meant a participant who could not find an exact color a pitch elicited had to choose a close neighboring color and, in some cases, that might have slightly distorted the true pitch and color correspondence. Participants also had no option for selecting a response that indicated no color was elicited from the ones presented upon hearing a pitch. This could have affected the results either positively or detrimentally.

In the second and final experiment involving presented colors to which participants then gave audio responses, the unexpected opportunity to include an audio captured or written response of anything along the lines of “there is no pitch for this color” added a 13th possible response option for data. This effectively moved the chi-square testing for that data into a violation of one of its assumptions, making the results for any of those color trials that only saw a single instance not 100% reliable. The results for those particular tests have enough strength to be taken legitimately but cautiously. This potential difficulty was mitigated through combining trials of the other multiple trial colors. Future research endeavors with similar designs will be aided by increasing the number of trials to a minimum of two for every desired data point and ensuring the total number of possible responses for an activity is matched at the very least by five possible expected outcomes, thus fully satisfying the chi-square assumption. Also, having participants sing, hum, whistle, or otherwise make sounds had with it the inherent risk of natural pitch fluctuations. In some cases, a participant might have intended one response but the intonation of that response might have risen slightly higher or fallen slightly lower than originally intended. If a participant did not notice the intonation fluctuation, the final resulting pitch response might or might not have been different than what was originally desired. There was no way to account for this difficulty in execution of pitch replication during the data processing. For future studies, keeping responses on an instrument or checked with an instrument might prove helpful in dealing with this difficulty.

Lastly, the biggest limitation to this research was having as participant responses mere color labels and pitch sounds and names. There was only so much analysis that could be processed with these responses in particular when they were given in these terms. Great effort was made to convert these qualitative responses into something of a quantitative nature for analysis. Experiments that work exclusively and extensively in one medium for responses would likely provide greater opportunity to treat the resulting data in both high qualitative and quantitative ways. With these limitations, however, came an opportunity to learn and resolve these elements, especially as many basic ideas of this research would inform additional research in the future.

Discussion

This research and the resulting data were thrilling to design and enjoyable to process, personally. It is one thing to have some deeply held thoughts on a particular matter and believe those to be guiding principles for how various activities might function. It is quite another story to put those ideas under a research microscope of sorts and begin to be able to speak about other peoples' experiences in these same realms. For me personally, color has been a big part of my academic life, even in seemingly insignificant ways. I could never study for a test, take notes, or make any sort of chart or plan without employing and appropriating some level of color into those activities. Music has also been at the center of my life for quite some time, even from some of my earliest memories with my mom as the guiding force behind those early pitch explorations. While my interest in color and musical pitch correspondence was really inspired during my college years, it had been brewing for quite some time prior to that. A brand new fire was lit when five years ago, walking in on my eight-year old daughter who was playing piano at the time, it became obvious through a brief interaction that she indeed not only possessed perfect pitch but also clearly exemplified the very chromesthetic concepts I was undertaking in a doctoral research setting. Quizzed every couple of months to identify colors she heard with pitches, her associations have remained unchanged over these last five years.

While color and pitch did seem to be elements that were inherently very individual for participants, they also seemed to be consistent over time for those individuals. As a real-world example, the creator of the elementary music instruments “Boomwhackers” took the chroma-notes theory, which had been around for some time, and applied it to the tubes to produce different colors for each pitch (Ramsell, 1994). A fair amount of mixing and assigning colors occurred. The three basic colors on the color wheel (red, yellow, and blue) were mixed to create color hues in-between those primary colors. Those now six colors mixed again produced the 12 colors that occupied the chromatic pitches of those Boomwhackers. Thus, everything came back to the three colors Kandinsky (2007) indicated 100 years ago through his questionnaire had purposeful and consistent correspondence. The Boomwhacker colors also have not changed since their inception roughly 30 years ago. Although ironically or perhaps intuitively, C in that system is red (one of the frequent color associations for C historically) and other colors hovered around similar colors the present research discovered through participant responses. The colors were not completely the same but the effect likely was the same. If I revisited participants on their color choices or their pitch choices in response to the other element, these responses might very likely remain consistent or close to consistent over time.

Along this journey, many have been intrigued by the possibilities potential correspondence might produce. There have also been those along the way who have doubted any type of correspondence with color and pitch. Perhaps some of the latter participated in the early parts of this and decided not to continue on with the activities. As this research was planned, I saw this as a springboard for much larger and grander study. This was to be the first foray into this realm of research with the age group with future studies to occur (with modifications) in the middle schools and then elementary schools within the school district, thereby creating a color and musical pitch study universe that was both deep and wide. While this is still the intention, it seems more problematic to execute at this point given the experience with the current research activity and the lack of cooperation of colleagues as the process started. Perhaps there was skepticism from them as well that these connections existed. While I believe this is an erroneous statement as this research has brought to light, I am encouraged by the high school participant I quoted earlier in the previous chapter: **"**Color and pitch are both perceptions. A person could correlate perceptions." I believe such correlated perceptions might be the key to unlocking the potential of the findings of this first phase of research in a much longer and life journey for me of exploring these color and pitch connections.

Future Implications

As I look ahead to how to use what I have found in this research within my own classroom, I am struck by the "correlate perceptions" comment referenced several times in this document. The correlation of perceptions is the key to unlocking any of the power of these correspondences. Simple correspondence possibilities might include academically linking pitch with a color, perhaps even independent of sound: "We're going to call F4 green, so every time I suggest we start on green, I need you to write F4 on your staff paper." Creating an entire color scale for students could produce, again thinking academically not sonically, a sort of Pavlovian conditioning. Ascribing the corresponding pitch sounds to that conditioning could then begin to make correspondence a relevant tool for teachers in training and students in processing. A possible concern in this, at least for me as a professional, is the making of these connections for students. A student who does not already associate color with sound likely might enjoy many of the benefits such a correspondence could offer in terms of how to hear sound. However, a student who already has some degree of color/pitch correspondence would essentially be asked to relearn or rewire their existing connections. If these pre-existing connections are strong, then this would amount to psychological manipulation, which I do not personally feel comfortable implementing.

Broadly, and from a music theory perspective (especially in regard to the acquisition of the finer skills of successful hearing and transcribing melodic and harmonic dictation), implementing any aspects of correspondence could result in students "seeing" particular pitches played in a given exercise as a color, which then could be correspondingly turned into a pitch. If enough of these correspondences are made during an exercise, a tonal picture could be created from these correspondences, thereby increasing the likelihood a student could "connect the dots" musically and either fill in gaps of pitches or ultimately turn the exercise into a completely organic color-related activity. If it is one aspect of cognition I have learned in my time as an educator, it is that the more tangible and memorable an experience is, the more likely the knowledge from that experience is to be retained. Essentially, if the color correspondence can activate a schema in the educational experience of the student, this memorable experience can translate to increased fluency and thus accuracy in pitch identification. In a task such as taking a melodic or harmonic dictation, these correspondences could potentially mean the difference between college credit and no college credit as they play out over the course of the class and ultimately to the annual AP exam in music theory in May of every year. However, the true goal is not passing an exam (which could be viewed as an arbitrary metric for some "tested" skills but not all "learned" skills). It is the practical application of those learned skills that produces what I might call "conversational literacy" in the area of pitch and pitch identification. Any student who can hear pitch and perceive pitch better and more accurately because of a connection they perceive is nature and inherent would be more successful (and this interplay also goes beyond music into other realms where such connections can be made with Kandinsky himself being a great example).

In terms of practical application, I will begin employing the use of a color scale with my next AP Music Theory class. These 27 students (and perhaps more by the time schedules are finalized) will receive additional color-correspondence inspired instruction. This will include discussions of color and pitch throughout the course, tangible uses and descriptions of pitches in color terms (not unlike Kandinsky's descriptions of visual art in musical terms), frequent opportunities to practice unifying color and pitch, simple tasks completed on different colored paper, and conversations that place color terminology hand-in-hand with musical experiences. The goal may be to say to the students "Sing me red" and have them generate the same pitch altogether from their conditioning. If the students themselves are a part of creating their own color correspondences (not unlike the research activities that took place in this study), the connections likely will be all the more strong and convincing to them as individuals. With previous experiments creating a color correspondence but not applying those to educational settings or having a researcher-led set of correspondences thrown at students, the results have been less than successful. If students can own their own color and musical pitch correspondence, it will become an innate tool they can harness for success.

Outside of theory applications, the benefits to performing ensembles are equally positive and exciting. A color-focused hearing system would make all of the traditional elements of highly successful musicians (tuning, balance, blend, ensemble, etc.) even more dynamic. A student who could ascribe a specific color to a specific pitch would be able to hone his or her intonation into perfectly reproducing that color in sound. The effects of such a system could have dynamically positive effects on an entire band, choir, orchestra, or other small ensemble. Clearer and cleaner musicianship would be the envy of any musical director.

Lastly, the benefit to students from a perfect pitch or relative pitch standpoint should not be missed. If a student could be prompted to hear color in every pitch, they could use it to recall pitches perfectly and accurately. If such a system was generated naturally BY the individual student, the notion of memorable experiences leading to retained knowledge would be much higher than in a pre-formed system (with this being an opportunity for students who hear some sounds in color to develop their own systems as opposed to a class of students in which no one hears sound in color).

The goal of this study was to explore the relationship of color and pitch (with a color and shape correspondence stop along the way). What resulted from this work is far greater than anything I could have imagined. Perhaps even more important than actual correspondences and statistically significant responses (for which there were many of both in this research) is the ability of participants to join in a journey of discovering the true connection, be it universal, individual, or otherwise, of how visual color and musical pitch interact and thrive together. The next step is turning these interactions into life-long musicianship-building tools for the next generation of young musicians!

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APPENDIX A

CONSENT FORMS FOR HUMAN PARTICIPANTS IN RESEARCH

UNIVERSITY OF
NORTHERN COLORADO

Informed Consent Form for Participation in Research

Title of Research Study: An examination of musical pitch/color correspondence in music, arts, and non-arts students and adults with respect to integrating approaches into melodic and harmonic dictation tasks within an AP Music Theory classroom.

Researcher(s): Luciano (Louie) R. Silvestri, Jr. (School of Music)
Phone Number: ____ email: lsilvest@psdschools.org or silv0582@bears.unco.edu
Research Advisor: Dr. Nancy Glen
Phone Number: (970) 351-2484 email: Nancy.Glen@unco.edu

Procedures: We would like to ask you to participate in a research study on musical pitch and color associations. Participation will include the completion of a Google survey as well as the completion of several color experiments designed to be completed and submitted virtually at a convenient time. You may also complete these experiments in person at a time to be arranged. If you participate in this study, you will be asked to complete a Google survey that will take about 5 minutes to complete.

Additionally, you will be asked to participate in several color experiments which have been designed to be completed and submitted virtually (or in person) at a convenient time. These experiments in total should take no longer than 10 minutes. Data collected will include your responses to both the survey and experiments and any demographic information associated with those responses for further identification. Responses will remain and be kept confidential. To further help maintain confidentiality, computer files of students' responses will be created and students' names will be replaced by numerical identifiers. The names of subjects will not appear in any professional report of this research. There is no additional incentive for participating in this research study.

Questions: If you have any questions about this research project, please feel free to contact Louie Silvestri at ____ and/or lsilvest@psdschools.org or silv0582@bears.unco.edu. If you have any concerns about your selection or treatment as a research participant, please contact Nicole Morse, Research Compliance Manager, University of Northern Colorado at nicole.morse@unco.edu or 970-351-1910.

Voluntary Participation: Please understand that your participation is voluntary. You may decide not to participate in this study and if you begin participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled.

Please take all the time you need to read through this document and decide whether you would like to participate in this research study.

If you agree to participate in this research study, please sign below. You will be given acopy of this form for your records.

______________________________ ____________

Participant Signature Date

______________________________ ____________

Investigator Signature Date

UNIVERSITY OF
NORTHERN COLORADO

CONSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO

Title of Research Study: An examination of musical pitch/color correspondence in music, arts, and non-arts students and adults with respect to integrating approaches into melodic and harmonic dictation tasks within an AP Music Theory classroom.

Researcher(s): Luciano (Louie) R. Silvestri, Jr. (School of Music)
Phone Number: email: lsilvest@psdschools.org or silv0582@bears.unco.edu

Research Advisor: Dr. Nancy Glen
Phone Number: (970) 351-2484 email: Nancy.Glen@unco.edu

I am researching the possibility of connections between colors and shapes as well as between colors and music pitches among students and adults who are both involved in the arts and not involved in the arts. If you grant permission and if your child indicates to us a willingness to participate, I will ask him or her to participate in a survey that will take about 5 minutes to complete. Additionally, your child will be asked to participate in 2 additional color experiments which have been designed to be completed and submitted virtually at a convenient time. These may also be completed in-person. The first color experiment will ask students to assign visual colors to pitches that they hear. The second color experiment will ask students to assign musical pitches to colors presented visually. These experiments in total should take no longer than 10 minutes. Data collected will include his or her responses to both the survey and experiments and any anonymous demographic information associated with those responses for further identification. Responses will remain and be kept confidential. There is no additional incentive for participating in this research study.

I foresee no risks to subjects beyond those that are normally encountered through listening to discreet sounds and visually identifying pitches. Since all of these experiments are to be conducted virtually and submitted afterwards, your child will determine when participation in these activities is appropriate given his or her individual schedule. The experiments are straightforward with no single "correct" answers thus no feedback on progress will be provided to your child. This study is not designed to improve your child's musical or visual abilities, but your child will likely enjoy the diversity of the activities presented.

Be assured that we intend to keep the contents of these experiment responses private. By signing below, you indicate that we may use the confidential responses as qualitative examples as part of this research at UNC. To further help maintain confidentiality, computer files of students' responses will be created and students' names will be replaced by numerical identifiers. The names of subjects will not appear in any professional report of this research.

Please feel free to phone me if you have any questions or concerns about this research and please retain one copy of this letter for your records.

Thank you for assisting me with my research.

Sincerely,

Louie Silvestri

Participation is voluntary. You may decide not to allow your child to participate in this study and if (s)he begins participation you may still decide to stop and withdraw at any time. Your decision will be respected and will not result in loss of benefits to which you are otherwise entitled. Having read the above and having had an opportunity to ask any questions, please sign below if you would like to allow your child to participate in this research. A copy of this form will be given to you to retain for future reference. If you have any concerns about your selection or treatment as a research participant, please contact Nicole Morse, Office of Research & Sponsored Programs, University of Northern Colorado, Greeley, CO; 970-351-1910 or nicole.morse@unco.edu.

____
Child's Full Name (please print)

______________________________ ____________________
Parent/Guardian's Signature Date

______________________________ ____________________
Researcher's Signature Date

UNIVERSITY OF
NORTHERN COLORADO

ASSENT FORM FOR HUMAN PARTICIPANTS IN RESEARCH
UNIVERSITY OF NORTHERN COLORADO

Hi!

My name is Louie Silvestri and I'm a doctoral student at the University of Northern Colorado. I'm also the orchestra and AP Music Theory teacher at Fossil Ridge High School. I do research on music and color. That means I study the way music and color both connect and interact. I would like to ask a lot of high school students about music and color. If you want, you can be one of the students I talk with.

If you want to talk with me, I'll ask you some questions about shapes, colors, and music. I will ask you about these things first in a brief survey. If you'd like to discuss these items more, I have a couple virtual experiments/surveys I'll send you. For each question I will want you to think carefully about your answer. But this isn't a test or anything like that. There are no right or wrong answers and there won't be any score or grade for your answers. I will keep track of your responses, but I won't even write down your name. It will take about 5 minutes for you to answer my questions about shapes, colors, and music in the initial survey. If you'd like to answer additional questions in the follow-up experiments/survey, it would probably take an additional 10 minutes. Since all of these activities are designed to be completed virtual, you can choose the most convenient time to complete any or all of them. You may also choose to do these last 2 experiments in-person.

Completing these surveys and experiments with me probably won't help you or hurt you. Your parents have said it's okay for you to talk with me, but you don't have to. It's up to you. Also, if you say "yes" but then change your mind, you can stop any time you want to. Do you have any questions for me about my research?

If you want to be in my research and talk with me about shapes, colors, and music, sign your name below and write today's date next to it. Thanks!

Student   Date

Researcher   Date

APPENDIX B

RECRUITMENT MATERIALS

UNIVERSITY OF
NORTHERN COLORADO

RECRUITMENT, VERBAL SCRIPTS, FOLLOW-UP, & REMINDERS

Recruitment Email/Letter

Dear [Name]:

I am conducting a research study on color correspondence and musical pitch/color correspondence in arts and non-arts students and adults. Participation will take about 10 minutes for a brief survey with additional research opportunities available after the initial survey completion. If you are interested in participating in this research study, please contact me at the email or phone number below, and I will provide further instructions in a follow-up email. There is no compensation offered for participating in this study. There are no known risks involved in this research.

If you have any questions, please let me know.

Researcher(s): Luciano (Louie) R. Silvestri, Jr. (School of Music)
Phone Number: [redacted] email: silv0582@bears.unco.edu
Research Advisor: Dr. Nancy Glen
Phone Number: (970) 351-2484 email: Nancy.Glen@unco.edu

Verbal Script: Recruitment First Contact

Hi! My name is Louie Silvestri from the University of Northern Colorado. I am conducting a research study on color correspondence and musical pitch/color correspondence in arts and non-arts students and adults. Participation will take about 10 minutes for a brief survey with additional research opportunities available after the initial survey completion. If you are interested in participating in this research study, please contact me at the email or phone number below, and I will provide further instructions in a follow-up email. There is no compensation offered for participating in this study. There are no known risks involved in this research.
You may reach the investigators at

Researcher(s): Luciano (Louie) R. Silvestri, Jr. (School of Music)
Phone Number: [redacted] email: silv0582@bears.unco.edu
Research Advisor: Dr. Nancy Glen
Phone Number: (970) 351-2484 email: Nancy.Glen@unco.edu

UNIVERSITY OF
NORTHERN COLORADO

Verbal Script: Consent Following Recruitment

OPENING:

Hi! My name is Louie Silvestri from the University of Northern Colorado. I am conducting a research study on color correspondence and musical pitch/color correspondence in arts and non-arts students and adults. Participation would involve the completion of a brief survey with additional research opportunities available after the initial survey completion. The survey will take about 10 minutes. There are no known risks involved in this research and participation is voluntary.
Would you be interested in participating?

CLOSING:

Do you have any questions you would like answered now?
You may contact the researchers at
Researcher(s): Luciano (Louie) R. Silvestri, Jr. (School of Music)
Phone Number: email:silv0582@bears.unco.edu
Research Advisor: Dr. Nancy Glen
Phone Number: (970) 351-2484 email: Nancy.Glen@unco.edu

If you prefer to speak with someone else, please call the Nicole Morse, Research Compliance Manager, University of Northern Colorado at nicole.morse@unco.edu or 970-351-1910.

Reminder Message: Research involving participation to occur at a specific time/location.

This is a reminder that you have signed up to participate in a research study about color correspondence and musical pitch/color correspondence in arts and non-arts students and adults. You are scheduled to complete the study on between [date] and [date]. The study will be conducted virtually. If you have any questions, please contact Louie Silvestri at (719) 459-0789 or silv0582@bears.unco.edu.

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Reminder message: Completion of a certain study step

This is a reminder that last week we sent you a survey link via email. The survey will be available for you to to complete until [date survey is no longer available]. If you have already completed the survey, we thank you for your time. If you have not completed the survey, we would greatly appreciate any input you could provide.

If you have any questions, you may contact me at (719) 459-0789 or silv0582@bears.unco.edu

Thank you,

Researcher(s): Luciano (Louie) R. Silvestri, Jr. (School of Music)
Phone Number: [redacted] email: silv0582@bears.unco.edu
Research Advisor: Dr. Nancy Glen
Phone Number: (970) 351-2484 email: Nancy.Glen@unco.edu

APPENDIX C

INSTITUTIONAL REVIEW BOARD APPROVAL

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Date: 05/16/2022

Principal Investigator: Luciano Silvestri

Committee Action: **Expedited Approval - New Protocol**

Action Date: 05/16/2022

Protocol Number: 2111032751

Protocol Title: A study of Color correspondence and musical pitch/color correspondence in arts and non-arts students and adults.

Expiration Date:

The University of Northern Colorado Institutional Review Board has granted approval for the above referenced protocol. Your protocol was approved under expedited category (7) as outlined below:

Category 7: Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies. (NOTE: Some research in this category may be exempt from the HHS regulations for the protection of human subjects. 45 CFR 46.101(b)(2) and (b)(3). This listing refers only to research that is not exempt.)

All research must be conducted in accordance with the procedures outlined in your approved protocol.

If continuing review is required for your research, your project is approved until the expiration date listed above. The investigator will need to submit a request for Continuing Review at least 30 days prior to the expiration date. If the study's approval expires, investigators must stop all research activities immediately (including data analysis) and contact the Office of Research and Sponsored Programs for guidance.

If your study has not been assigned an expiration date, continuing review is not required for your research.

For the duration of the research, the investigator(s) must:

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

- Submit any change in the research design, investigators, and any new or revised study documents (including consent forms, questionnaires, advertisements, etc.) to the UNC IRB and receive approval before implementing the changes.
- Use only a copy of the UNC IRB approved consent and/or assent forms. The investigator bears the responsibility for obtaining informed consent from all subjects prior to the start of the study procedures.
- Inform the UNC IRB immediately of an Unanticipated Problems involving risks to subjects or others and serious and unexpected adverse events.
- Report all Non-Compliance issues or complaints regarding the project promptly to the UNC IRB.

As principal investigator of this research project, you are responsible to:

- Conduct the research in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Obtain informed consent and research privacy authorizations using the currently approved forms and retain all original, signed forms, if applicable.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any unanticipated problems involving risks to subjects or others and serious and unexpected adverse events.
- Maintain accurate and complete study records.
- Report all Non-Compliance issues or complaints regarding the project promptly to the IRB.

Please note that all research records must be retained for a minimum of three (3) years after the conclusion of the project. Once your project is complete, please submit the Closing Report Form.

If you have any questions, please contact Nicole Morse, Research Compliance Manager, at 970-351-1910 or nicole.morse@unco.edu. Please include your Protocol Number in all future correspondence. Best of luck with your research!

Sincerely,

Michael Aldridge
IRB Co-Chair, University of Northern Colorado: FWA00000784

UNIVERSITY OF
NORTHERN COLORADO

Institutional Review Board

Silvia Correa-Torres
IRB Co-Chair, University of Northern Colorado: FWA00000784

Carter Hall 2008 | Campus Box 143 | Greeley, CO 80639 | Office 970-351-1910

APPENDIX D

POUDRE SCHOOL DISTRICT APPROVAL LETTER

POUDRE
SCHOOL
DISTRICT

4/22/22

Louie Silvestri,

Please consider this document as formal approval for you to conduct research within Poudre School District (PSD) based on your application materials originally received 4/13/22. Research project name: "A study of Color correspondence and musical pitch/color correspondence in arts and non-arts students and adults."

* Date of project: Between April 2022 and June 2023 (If additional time is needed to complete the study, please notify me via email).

* I would like to add two conditions: 1) It is requested that the researcher provide PSD an electronic copy of the project summary at the end of the project, and 2) if you decide to submit an article for publication, please provide an electronic version of the article to PSD when completed.

* Priority consideration for future research partnerships with PSD will be given to individual researchers that have a demonstrated track record of submitting final reports for PSD consideration.

* Please feel free to use this email in your correspondent with PSD schools and personnel regarding this research project.

This approval letter signifies that you have successfully met all PSD criteria for conducting research within PSD. Approval from building principals where research activities may occur is also needed prior to beginning research activities at any PSD school. Providing principal(s) with a copy of this letter is an important step in your communication with principals, but please keep in mind that principals have the right to refuse to participate in any proposed research activities that involve the students, teachers, or facilities that they are responsible for. Furthermore, a principal or the superintendent of PSD may exercise their right of refusal at any point during the implementation of an authorized research proposal. Thank you for considering Poudre School District as a research partner. Please feel free to contact me if you have any questions, and I look forward to reading your findings.

Dwayne Schmitz

Dwayne Schmitz, Ph.D. | *Chief Institutional Effectiveness Officer*

POUDRE SCHOOL DISTRICT

970-490-3693
dschmitz@psdschools.org

APPENDIX E

GOOGLE SURVEY QUESTIONS

Correspondence Survey

The following survey is designed to gather information regarding colors, shapes, and music and their possible associations.

* Required

1. CONSENT FOR RESEARCH

   Check all that apply.

   ☐ Please click once you have read this consent form in it's entirety

2. Consent Request *

   Mark only one oval.

   ◯ I have read the statement and hereby give my consent to continue with this survey.

   ◯ I have read the statement and do NOT give my consent to continue with this survey.

Classifications

3. How best would you classify yourself? *

   Mark only one oval.

   ◯ Art student
   ◯ Music student
   ◯ Both an Art and Music Student
   ◯ Adult participant

Classifications

4. Are you male or female?

Mark only one oval.

- Male
- Female
- Prefer not to say

Classifications

5. What is your current grade?

Mark only one oval.

- 9th Grade (Freshman)
- 10th Grade (Sophomore)
- 11th Grade (Junior)
- 12th Grade (Senior)
- Other

Classifications

6. Which high school do you attend?

Mark only one oval.

- Fossil Ridge High School
- Other or Out of High School

7. Are you familiar with the artist Wassily Kandinsky? *

Mark only one oval.

- Yes
- No *Skip to question 9*
- Unsure *Skip to question 9*

8. If you answered yes to the previous question, please describe what you know about Kandinsky and his work: *

9. Kandinsky believed that certain shapes corresponded with certain specific colors. Do you believe this could be true? *

Mark only one oval.

- Yes
- No
- Maybe

10. Do you believe that such a correspondence between color and music could also possibly exist? *

Mark only one oval.

- Yes
- No
- Maybe

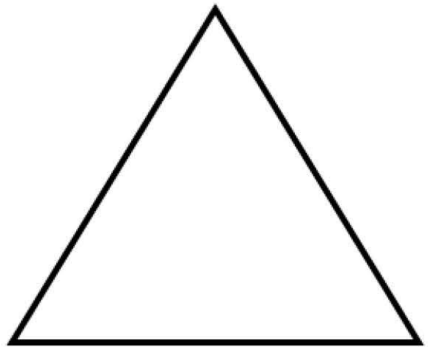
11. The following questions will ask you to make some assumptions regarding specific shapes and specific colors. *

Mark only one oval.

- Click here to continue

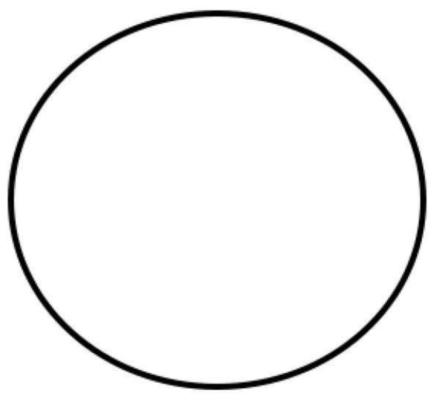
Triangle

12. If you were to assign a color to this shape, which would you choose: *



Circle

13. If you were to assign a color to this shape, which would you choose: *

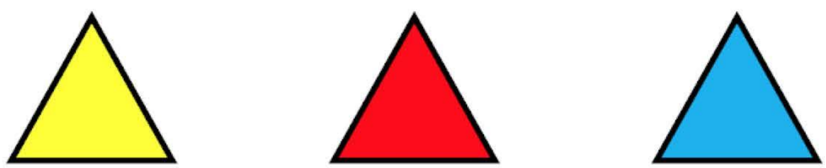


Square

14. If you were to assign a color to this shape, which would you choose: *

Triangles

15. As you look as these shapes, imagine that each color is motionless. If you could only pick one colored shape, which represents the most correct color for this triangle? *

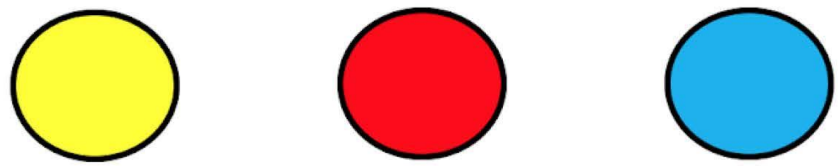


Mark only one oval.

- Yellow Triangle
- Red Triangle
- Blue Triangle

Circles

16. As you look as these shapes, imagine that each color is motionless. If you could only pick one colored shape, which represents the most correct color for this circle? *

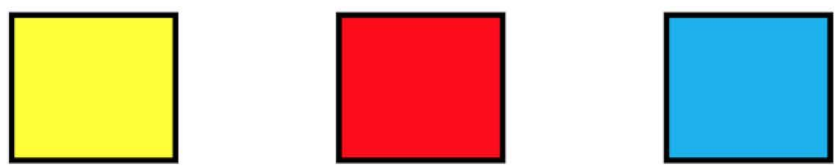


Mark only one oval.

- Yellow Circle
- Red Circle
- Blue Circle

Squares

17. As you look as these shapes, imagine that each color is motionless. If you could only pick one colored shape, which represents the most correct color for this square? *

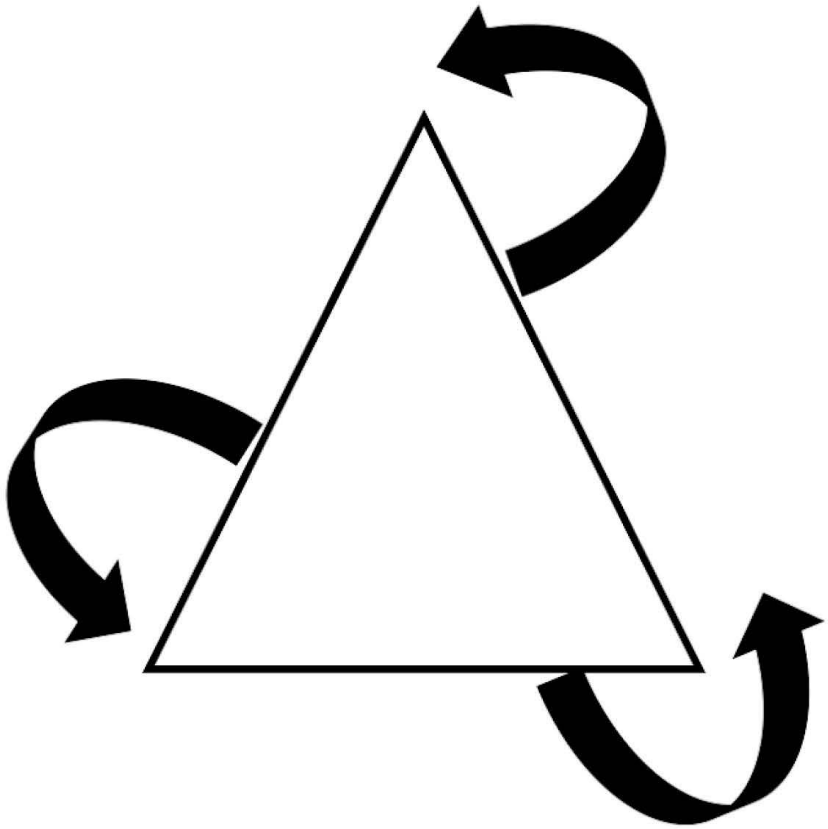


Mark only one oval.

- Yellow square
- Red Square
- Blue Square

Ex-centric Motion & Triangles

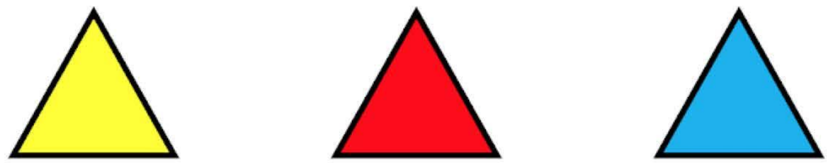
18. The following question will ask you about a specific motion direction related to the shape presented. It is important you understand the specifics of the motion direction. EX-CENTRIC motion is a motion outward and counter-clockwise. This motion can be depicted below: *



Check all that apply.

☐ When you believe you are visually comfortable with the definition of ex-centric motion, please check the box.

19. As you look as these shapes again, imagine each color moving in the direction of the previous visual ex-centrically (that is outward and counter-clockwise). With this motion in mind, if you could only pick one colored shape, which represents the most correct color for the this triangle? *

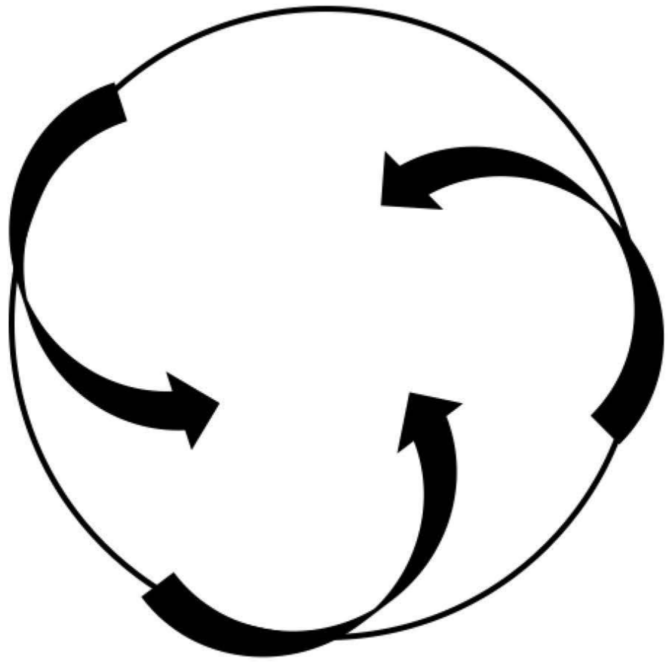


Mark only one oval.

- Yellow Triangle
- Red Triangle
- Blue Triangle

Concentric Motion & Circles

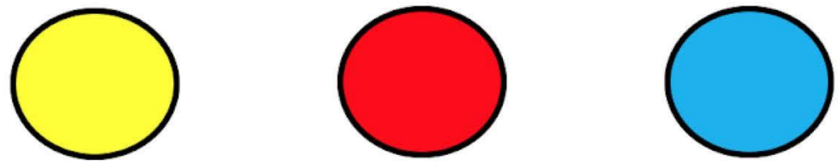
20. The following question will ask you about a specific motion direction related to the shape presented. It is important you understand the specifics of the motion direction. CONCENTRIC motion is a motion inward and counter-clockwise. This motion can be depicted below: *



Check all that apply.

☐ When you believe you are visually comfortable with the definition of concentric motion, please check the box.

21. As you look as these shapes again, imagine each color moving in the direction of the previous visual concentrically (that is inward and counter-clockwise). With this motion in mind, If you could only pick one colored shape, which represents the most correct color for the this circle? *

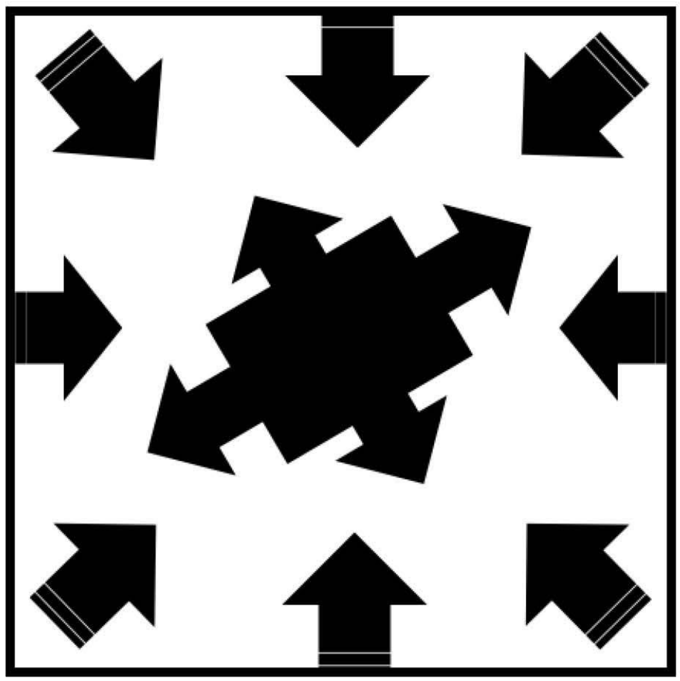


Mark only one oval.

- Yellow Circle
- Red Circle
- Blue Circle

Intrinsic Motion & Squares

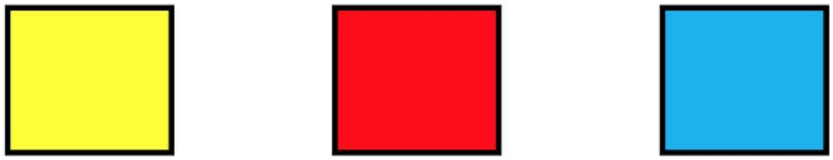
22. The following question will ask you about a specific motion direction related to the shape presented. It is important you understand the specifics of the motion direction. INTRINSIC motion is a motion within the shape itself. This motion can be depicted below: *



Check all that apply.

☐ When you believe you are visually comfortable with the definition of intrinsic motion, please check the box.

23. As you look as these shapes again, imagine motion to each color within itself (that is random motion inside the shape). With this motion in mind, If you could only pick one colored shape, which represents the most correct color for the this square? *



Mark only one oval.

- Yellow square
- Red Square
- Blue Square

Color and Music

The following questions will ask you about the potential relationships of colors and musical pitch.

24. Similar to a possible color and shape connection, do you believe that a possible color and musical pitch connection could exist? *

Mark only one oval.

- Yes
- No
- Maybe
- Unsure

25. Please briefly provide the reasoning behind your response to the previous question: *

26. Do you possess "perfect pitch"? *

Mark only one oval.

- Yes
- No
- Maybe
- Unsure

27. Do you yourself hear music in colors? *

Mark only one oval.

- Yes
- No
- Maybe
- Unsure

Thank you for taking the time to complete this survey. If you would be interested in participating in additional color/musical experiments which can be completed virtually, please check the box below, and you will be contacted with further directions!

28. I would be interested in assisting with additional research related to color and music which can be completed virtually. *

Mark only one oval.

- ( ) Yes
- ( ) No

APPENDIX F

PARTICIPANT RESPONSES TO CORRESPONDENCE QUESTIONS IN SURVEY

I'm skeptical about the connection but I was also sceptical of colors belonging to specific shapes so I'm open to a solid maybe.

I've been an instrumental musician for 35 years... it just makes sense to my brain even though i don't experience pitch in color

For a long time all sound would have color or emotions would have color for me and they still do

I believe that music pitch and color are highly coordinated. Whether you just recognize a color and a pitch due to previously seeing the pitch set as that specific color, or you can visualize notes as colors, they are very coordinated.

I have heard of stories of people who correlate a color to a tone and they are on pitch every time. Certain songs make me think of certain colors. That makes me think that there could be a reason why I think of certain colors when I hear certain songs.

I believe there could be or more accurately IS a connection between musical pitch and color because I also believe there is a connection between colors and shapes and since they're both in the artistic world I think they're all connected.

The brain is complicated. There are many perceptions we may not yet know how to access. music has motion same as color at times.

Music evokes emotions, which are also tied to colors I believe.

It seems logical that if Artists can here the landscapes they paint or kids can see photos of animals and imagine that animals sound then the reverse is true. We see flowers and create smells in our heads, why not hear the bees as well?

knowledge of the composer associating pitches with colors

I associate different key signatures with different colors, as well as different groups of notes. I have heard people discuss synesthesia, although I don't experience it myself
I myself sometimes see colors when playing a chord or note.

Yes because as humans we like to find connections with new thing with things that we already know! So when people hear music stories, colors, shapes spring to mind as the music is preformed.

Since there is a connection between two similar yet mostly unrelated things such as color and shape, there is also a connection between music and colors and shapes.

To me, pitches have varying effects (stability, finality, unsettledness, etc). Colors have similar impacts to perception, so I think it's possible that the two are similarly processed by the brain.

Colors and music both connect with emotions so I believe that sounds cause you to feel certain emotions that may turn into colors

I think that when I listen to music I can almost see colors form in my head when I like, envision what is happening in my head in colors.

Different pitches could bring different emptions, which could bring colors to mind.

Certain musical pitches often bring the same colors to mind to multiple people, but it could also just be affected by other things - for example, minor chords are often associated with sadness, which is associated with the color blue - therefore leading to some people thinking of the color blue.

I think in our daily lives, there are a lot of correlations between color and the activities we do. It's even a fun game to play with your friends; asking them what color they associate with you. I think the psychology of color is more present in our lives that we think.

People with color synesthesia can see colors based on pitch so there must be at least some connection

It's hard to explain. Music just has colors to it. The sound has colors.

I have a friend with synesthesia…I'm still unsure about it but trust him!

I've seen videos on YouTube of a visual representation of what people some people see when they hear music while closing their eyes.

I know a select group have chromesthesia and the cross wiring and their brain allows them to see colors that correspond to certain pitches. I don't see why this link couldn't exist in the general population without being able to physically see the colors.

I think that our brains are very complex and are able to form these connections, whether we realize them or not. It could be that we were "trained" from a young age where certain pitches on kids toys were always the same color. We could also associate our favorite color with our favorite note and every person is slightly different.

I don't listen to musical pitches themselves often enough to have any thoughts about it?

I think of people with synesthesia and sensory issues. Each one that I have talked with could tell you the representation for each shape and color and sound. Such as Tuesday is an orange pyramid and wiggly.

I do believe music pitch and color are connected, but I feel like it’s very opinionated. When I hear a pitch I can assign it the first color it reminds me of, but I might be the only one who sees their correlation.

I think that music is art, and art is made of colors, so music is too. Also, it makes sense to me that color and music have a close resemblance.
Your perception to music and color is all personal so I believe that there is correspondence but it depends on what you grew up with and how you were raised to believe what colors and sounds are what.

I believe that what you see can have some affect on what you hear and vice versa.

Music and color seem deeply intertwined and influenced by each other, so a connection should exist.
I think it's possible for the brain to assign certain pitches a color in order to differentiate and categorize the different frequencies.

From a young age music is correlated to colors, whether it be the keys on a child's piano or the background color of the solfege scale in the music rooms, among other things. This can subconsciously create connections between sounds and colors.

I believe my perfect pitch is largely attributed to chromesthesia. I almost always visualize a color before thinking of a pitch when I hear it.

I think higher musical pitch could have lighter colors and lower musical pitch would have darker colors

I believe that some people experience synesthesia

Music, like art makes us feel things. We often connect feelings to colors, and overall I think all of these things would connect.

I’ve always been interested in synesthesia. Musical keys and intervals seem to have different colors for me.

I have heard of people who connect colors with sounds. I hadn't heard of connecting them to shapes before, but after my previous answers, perhaps there is more to that than I thought. Scientifically, I could see a relationship between pitch and colors, connected to sound waves and light waves, perhaps.

lower pitches seem like they could be deeper/darker colors

Just like how certain rhythmic patterns or pitches can reflect or capture emotions, I feel that colors and musical pitch can have a similar relationship.

Lower pitchs are darker and cooler colors. Higher pitchs are lighter and warmer colors.

I am skeptical about the color-pitch connection because, similarly, I felt like I was randomly forced to select the colored shapes in the previous section when I would have preferred to select something to the effect of "indifferent," particularly on the motion questions.

our mind processes audio/video/and other senses plus memories to create an output we may or may not or only partially perceive. We might be able to smell color!

I believe this because, as I see color matched with shape, a part of my brain feels that there is also some sort of connection to music with anything. If you play something slow and deep, that gives off the tone of sadness. If you play something upbeat, it gives off the tone of joy. I believe this applies to color as well.

I think there's a correspondence between feelings and colors and between music and feelings. As in, I'm feeling "blue"

I know that there are some people that see color when they hear noise so it could be possible that other people have that just in a smaller degree.

I know people who have described their personal experiences with "seeing" color when they hear a pitch, both adults and children.

I've always heard about the possibility. I've also met people who see colors when notes and music are played. And I've always described music as making colors more vibrant. It provides color to life.

Certain genres of music are correlated with certain colors, this is especially shown in their album covers.

I have a mild case of Synesthesia. So as I am playing my music I typically start seeing the notes in different colors.

I personally can see/connect colors to sounds, pitches, chords, and music

F sharp to me is bright and rough, like a yellow. and that's what the first piece in Fantasia was about, music as colors.

I have a form of synesthesia where letters and numbers are associated with colors. I've read that some synesthetes have color connections with music, taste, smell, etc. so I believe color associations with many senses are possible!

Certain songs, and certain notes provide certain feelings which can be simplified to just a color

Color and pitch are both perceptions. A person could correlate perceptions.

Considering the meaning of "possible," until I can disprove a concept or show a very limited degree of possibility, I choose to keep an open mind and accept that I could be shown a connection is possible.

The sounds of music do things different to everyone’s brain but if you think about colors or shapes while you are listening to it I don’t see why someone wouldn’t be able to connect the two.

Music doesn’t necessarily have to exclusively be an auditory experience. I think it could absolutely have color or be associated with any of the other 5 senses.

I don't feel it, but given the other weird things my brain does, I have no doubt that others can. Correlations between color and emotions have already been drawn, as have the connections between sound and color - evoking emotions that have been perceived before us and shared with us.

I think that music can elicit certain emotions. Some colors may be associated with specific feelings or emotions such as red representing anger or yellow representing happiness.

I often experience association of colors with different pitch, especially with different harmonics and tonalities; the same way I associate colors with spatial definitions, ie- left is green, right is red, etc.

I believe certain colors can give off feelings and certain musical pitches can match the feelings of the colors.

Some times when listening to music, I can imagine a general color for the tone of the music. Example - something in a minor key and slow sad sounding, reminds me of dark blues, purples or grays and black

Succinctly, emotional connections. Certain colors evoke emotional responses, although not necessarily the same emotions by the same people for the same colors. Different intervals - major, minor, perfect, diminished, augmented, etc. - are clearly used by composers to evoke different emotions. If the listener has an emotional "tonal center" - say, the key of C - then memory/association/hearing the other pitches can evoke those same emotions. This indirectly results in correlation between color and pitch, reinforced more strongly as the subject sees more colors in context, hears more music in context, etc. over time.

Certain pitches could make someone feel a certain way, and could let them imagine certain colors.

Your mind connects music to a lot of things - why not color?

When listening to music -emotions form. I feel colors are linked to emotions our mind interacts with our ears, eyes, and other senses

It makes sense that there is a universal connection.

Music and sounds could be assigned a color depending on their "happiness" and the way they sound.

Music often brings an emotional response to the listener, and often feelings and moods are related to colors, also.

Connections of learning, joy, art, music, etc. are always formed between neurons through experience and depending on experience these connections can be triggered with varying results.

I don't know. .... It seems a little weird but it is also very possible.

I believe music does have a connection with colors.However, I do not think each note has a specific color but it depends on its relationship within a pitch class, mode or scale. When I hear the Chromatic scale I see a lot of mixed color on a canvas. An Example of a Artist, that I think portrays the idea of the Chromatic scale well would be “Knight Watch” painted by Jean Paul Riopelle. For example, when I hear a Major scale I think of Royal colors (Gold, Purple, scarlet, and dark blue) When I hear a Minor, Natural scale, Minor, melodic and Minor, harmonic I think of (Brown, White, and gray, with glimmer of natural light and gold) The image that comes to mind would be the “Muqarnas Dome, Hall of the Abencerrajes, Palace of the Lions, Alhambra”. When I hear a Whole tone scale I think of Red boxes evenly spaced and shaped. When I hear the Gypsy scale I see pale bright colors with a mixture of dark colors mixed in. (Red, Yellow, andDark Blue) The Pentatonic scale I think of pink, red and white cherry blossoms. The Octatonic scale I hear gray on C red, C# yellow, D# light blue, E and F# as Red, G as gray, A as light blue, A# as red and C as blue.

My daughter has this unique relationship to music and color. Because I hear music in color.

I know that through my music education I've heard the term of invoking a "color change" which I think is a very valid thing in terms of music. Music is greatly tied to emotions as are colors, so the connection between music and colors ought to be strong as well.

APPENDIX G

INDIVIDUAL AND COMBINED CHI-SQUARE TESTS FOR PITCH

Chi-Square Results

Pitch # 1: C

A Chi-square goodness-of-fit test was used to determine if the color responses on this pitch task could prove or disprove the theory that generated the expected values. The determination as made that in such a task, an expected value might well be that each color would receive an equal number of responses from the respondents which would support the notion that the selection of color for pitch was more random than intentional. Only the color responses for this task (62) were evaluated. This was the first of 3 trials for the note C. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 40.58, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #2: F

This was the first of 2 trials for the note F. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 28.19, $p = .003$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #3: E

This was the first of 2 trials for the note E. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 25.87, $p = .0068$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #4: A#/Bb

This was the only trial in the experiment for the note A#/Bb. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 37.48, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #5: F

This was the second trial in the experiment for the note F. Results for the test on 12 colors during this task showed a selection of colors existing within the expected and anticipated number, χ^2 (11, N=62) = 15.81, $p = .148$. This difference is statistically significant, meaning the difference in the selection of these colors over this task is what we would expect under normal circumstances and can be explained as normal or accidental. Interestingly, the initial trial found a Chi-square result different than this trial. A combined test for both trials will follow results for each individual pitch trial.

Pitch #6: C#/Db

This was the only trial in the experiment for the note C#/Db. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 44.06, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #7: A

This was the first of two trials in the experiment for the note A. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 31.29, p = .001. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #8: F#/Gb

This was the only trial in the experiment for the note F#/Gb. Results for the test on 12 colors during this task showed a selection of colors existing within the expected and anticipated number, χ^2 (11, N=62) = 11.16, p = .430. This difference is statistically significant, meaning the difference in the selection of these colors over this task is what we would expect under normal circumstances and can be explained as normal or accidental.

Pitch #9: B

This was the first of two trials in the experiment for the note B. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 32.45, p = .0006. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #10: G

This was the first of two trials in the experiment for the note F#/Gb. Results for the test on 12 colors during this task showed a selection of colors existing within the expected and anticipated number, χ^2 (11, N=62) = 13.87, p = .240. This difference is not statistically significant, meaning the difference in the selection of these colors over this task is what we would expect under normal circumstances and can be explained as normal or accidental.

Pitch #11: D

This was the first of two trials in the experiment for the note D. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 40.97, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #12: C

This was the second of three trials in the experiment for the note C. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 30.90, $p = .0011$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #13: G#/Ab

This was the only trial in the experiment for the note G#/Ab. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 23.55, $p = .015$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #14: D

This was the second of two trials in the experiment for the note D. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 33.61, p = .0004. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. A combined test for both trials will follow results for each individual pitch trial.

Pitch #15: B

This was the second of two trials in the experiment for the note B. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 45.23, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. A combined test for both trials will follow results for each individual pitch trial.

Pitch #16: D#/Eb

This was the only trial in the experiment for the note D#/Eb. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 20.84, p = .0351. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Pitch #17: E

This was the second of two trials in the experiment for the note E. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 29.74, p = .0017. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. A combined test for both trials will follow results for each individual pitch trial.

Pitch #18: G

This was the second of two trials in the experiment for the note G. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 29.74, p = .0017. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. Interestingly, the initial trial found a Chi-square result different than this trial. A combined test for both trials will follow results for each individual pitch trial.

Pitch #19: A

This was the second of two trials in the experiment for the note A. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 41.35, p < .0001. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. A combined test for both trials will follow results for each individual pitch trial.

Pitch #20: C

This was the third of three trials in the experiment for the note C (and the only pitch to receive 3 trials in the experiment). Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=62) = 36.32, p = .0001. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. A combined test for all three trials will follow results for each individual pitch trial.

Combined Results for C on 3 Trials

Each of the three trials for the note C were combined into one Chi-square test. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=186) = 94.26, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Combined Results for F on 2 Trials

Each of the two trials for the note F were combined into one Chi-square test. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=124) = 29.48, p = .0019. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Combined Results for E on 2 Trials

Each of the two trials for the note E were combined into one Chi-square test. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=124) = 45.16, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Combined Results for A on 2 Trials

Each of the two trials for the note A were combined into one Chi-square test. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=124) = 61.81, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Combined Results for B on 2 Trials

Each of the two trials for the note B were combined into one Chi-square test. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=124) = 71.29, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Combined Results for G on 2 Trials

Each of the two trials for the note G were combined into one Chi-square test. Results for the test on 12 colors during this task showed a selection of colors existing outside the expected and anticipated number, χ^2 (11, N=124) = 24.64, $p = .0001$. This difference is statistically significant, meaning the difference in the selection of these colors over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. This Chi-square test represents the weakest significant test of the entire combined test series.

APPENDIX H

COMBINED AND INDIVIDUAL CHI-SQUARE TESTS FOR COLOR

Chi-Square Results Combined results for the color white on 2 trials

Each of the two trials for the color white were combined into one Chi-square test.

Results for the test on 12 pitches during this task showed a selection of pitches existing outside the expected and anticipated number, χ^2 (12, N=116) = 77.65, $p < .0001$. This difference is statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. An overwhelming collection of responses for this color centered on the note C.

Combined results for the color black on 2 trials

Each of the two trials for the color black were combined into one Chi-square test.

Results for the test on 12 pitches during this task showed a selection of pitches existing within the expected and anticipated number, χ^2 (12, N=116) = 12.20, $p = .4292$. This difference is not statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances may be explained as a likely normal distribution.

Combined results for the color dark blue on 2 trials

Each of the two trials for the color dark blue were combined into one Chi-square test.

Results for the test on 12 pitches during this task showed a selection of pitches existing outside the expected and anticipated number, χ^2 (12, N=116) = 37.53, $p = .0002$. This difference is statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. An overwhelming collection of responses for this color centered on the note D.

Combined results for the color red on 2 trials

Each of the two trials for the color red were combined into one Chi-square test. Results for the test on 12 pitches during this task showed a selection of pitches existing just slightly within the expected and anticipated number, χ^2 (12, N=116) = 20.50, p = .0582. This difference is not statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances may be explained as a likely normal distribution.

Combined results for the color green on 2 trials

Each of the two trials for the color green were combined into one Chi-square test. Results for the test on 12 pitches during this task showed a selection of pitches existing outside the expected and anticipated number, χ^2 (12, N=116) = 35.07, p = .0005. This difference is statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. An overwhelming collection of responses for this color centered on the note F.

Combined results for the color pink on 2 trials

Each of the two trials for the color pink were combined into one Chi-square test. Results for the test on 12 pitches during this task showed a selection of pitches existing outside the expected and anticipated number, χ^2 (12, N=116) = 33.05, p = .0010. This difference is statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. An overwhelming collection of responses for this color centered on the note B.

Combined results for the color yellow on 2 trials

Each of the two trials for the color yellow were combined into one Chi-square test. Results for the test on 12 pitches during this task showed a selection of pitches existing outside the expected and anticipated number, χ^2 (12, N=116) = 32.83, p = .0010. This difference is statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. An overwhelming collection of responses for this color centered on the note E.

Combined results for the color grey on 2 trials

Each of the two trials for the color grey were combined into one Chi-square test. Results for the test on 12 pitches during this task showed a selection of pitches existing just slightly within the expected and anticipated number, χ^2 (12, N=116) = 17.36, p = .1365. This difference is not statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances may be explained as a likely normal distribution.

Single Trial: Brown

This was the only trial in the experiment for the color brown. Results for the test on 12 pitches during this task showed a selection of pitches existing outside the expected and anticipated number, χ^2 (12, N=58) = 26.27, p = .0098. This difference is considered statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances cannot be explained as an accident or normal. An overwhelming collection of responses for this color centered on the note A#/Bb.

Single Trial: Purple

This was the only trial in the experiment for the color purple. Results for the test on 12 pitches during this task showed a selection of pitches existing within the expected and anticipated number, χ^2 (12, N=58) = 14.17, p = .2898. This difference is considered not statistically significant, meaning the difference in the selection of these colors over this task is what we would expect under normal circumstances and can be explained as normal or accidental. **Single Trial: Light Blue**

This was the only trial in the experiment for the color light blue. Results for the test on 12 pitches during this task showed a selection of pitches existing outside the expected and anticipated number, χ^2 (12, N=58) = 24.93, p = .0152. This difference is statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances cannot be explained as an accident or normal.

Single Trial: Orange

This was the only trial in the experiment for the color orange. Results for the test on 12 pitches during this task showed a selection of pitches existing just slightly within the expected and anticipated number, χ^2 (12, N=58) = 19.55, p = .0761. This difference is considered not statistically significant, meaning the difference in the selection of these pitches over this task from what we would expect under normal circumstances falls within the expected normal distribution.