REDEFINING COLOR IN SYNESTHEIA

A Dissertation

Presented to

The Faculty of the Department

of Psychology

University of Houston

In Partial Fulfillment

Of the Requirements for the Degree of

Doctor of Philosophy

By

Madeleine V. Z. Gorges

May, 2017

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ABSTRACT

Grapheme-color synesthesia is a condition in which letters and numbers automatically trigger the sensation of specific colors in a person's mind. Previous research on synesthesia revealed that certain letters seem to be associated with certain colors at a rate greater than chance. The studies that report these trends analyze the synesthetes' data by categorizing synesthetes' reports of their colors into the 11 basic color terms. The purpose of this study was to determine whether this simplification of the data is an acceptable representation of the synesthetes' experience, or if perhaps those analyses are discarding valuable information about the specificity, idiosyncracity, and diversity of synesthetes' color sensations. In a task that directly tested how well synesthetes' colors match standard color labels, non-synesthete participants attempted to classify data from over 1,000 synesthetes, as well as a set of prototypical standard colors. The synesthetes' colors came from an online website which allows synesthetes to choose from over 16.7 million possible color selections for each of their letters. The results demonstrate that synesthetes' colors are difficult to classify under the 11 basic color terms, suggesting that synesthesia may not be merely a magnification of "normal" or prototypical cross-modal associations. Additional analyses using powerful methods such as k-means clustering further supported the difficulty isolating meaningful group trends in synesthetes' data. Implications for understanding how synesthesia may or may not relate to creative metaphor are discussed.

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Dedication

This dissertation is dedicated to my husband, Jeffrey Gorges, to my parents, Tracy and Geraldine Warner, and to Kris and Tom Bassett. Thank you for your support throughout this process.

Introduction

For a person with grapheme-color synesthesia, letters, numbers, and other symbols each have a unique color. The color exists only in the mind of the person (called a synesthete), and most synesthetes have normal color vision, such that they can tell what color ink text is printed in. However, any time they see, hear, or think about a specific letter or number they automatically experience the color associated with that letter in their mind. For some synesthetes, called associators, the color is only in their mind's eye. In contrast, projector synesthetes experience the color as if it were projected onto the surface of written text (Dixon, Smilek, & Merikle, 2004). Synesthesia can be triggered by a much wider variety of stimuli, including sounds, tastes, smells, textures, etc., but this dissertation addresses only grapheme-color synesthesia, and within that only Roman letters, not numbers or other symbols.

Early research on synesthesia focused on verifying the condition. The most accepted validation of synesthesia involved tests to confirm that the colors associated with each stimulus remained the same over time. Synesthetes often report that their colors are extremely stable over long time periods (e.g. Hancock, 2013, p. 96; Johnson, Allison, & Baron-Cohen, 2013), but more objective evidence was needed to confirm the anecdotal claims. As a clear example of the constancy of the condition, Simner and Logie (2008) gave a lexical-color synesthete a surprise retest 27 years after his original test and his responses were a 100% match (Simner & Logie, 2008). The synesthete in this study was asked to report his associations by writing the names of his colors for each stimulus in a questionnaire. This format of testing was a very common practice in early synesthesia research (Johnson et al., 2013), however, it had some challenges, such as determining whether a response of “darkish yellow” on the first test and “gold” on the follow-up test counted as a consistent response.

In efforts to make the testing more objective and replicable, several research groups refined their Tests of Genuineness (TOG) by presenting synesthetes with a range of color samples to choose from. Baron-Cohen and colleagues first conducted a TOG with 309 color swatches (Baron-Cohen, 1996; Baron-Cohen, Harrison, Goldstein, & Wyke, 1993; Baron-Cohen, Wyke, & Binnie, 1987), though they did not provide a key for which colors counted as perfect matches, close matches, and inconsistent matches (Johnson et al., 2013). In 2006, Asher and colleagues revised the TOG with a more systematic color swatch system (Asher, Aitken, Farooqi, Kurmani, & Baron-cohen, 2006). They used 238 color swatches organized in grids based on color similarity (see Figure 1a). If a synesthete chose a color one step above, below, or to either side of their original choice they scored 3 points. Selections diagonal to the original choice or two steps above, below, or to the sides received 2 points. Selections outside of that range, but still within the same color group (red, yellow, blue, green, etc.) received 1 point. See Figure 1b for an illustration of the scoring.

Tests of Genuineness serve not only to verify synesthesia, but they also provide datasets for investigating many questions of interest. One of the questions that received the most attention in the synesthesia literature is whether there are regularities in the letter-color pairings across synesthetes. Numerous studies came out between 2005 and 2010 that discovered that synesthetes associated certain graphemes with the same color at a rate greater than chance (e.g. Barnett et al., 2008; Rich, Bradshaw, & Mattingley, 2005; Simner et al., 2005; Simner & Ward, 2008). In order to determine if synesthetes reported the same color the researchers categorized the synesthetes' detailed and often unusual color descriptions into the 11 basic color categories as defined by Berlin and Kay (red, orange, yellow, green, blue, purple, pink, brown, grey, black, and white) (Berlin & Kay, 1975). The most common approach in adult synesthetes was to allow them to either write their color names for each stimulus or select the color from a color palette, and then independent coders categorize each choice into one of the basic color terms (Day, 2004; Rich et al., 2005; Simner et al., 2005; Simner & Ward, 2008). Simner and colleagues (2005) found several trends in the categorized synesthetes' color associations that occurred at a rate greater than chance. The most frequent color terms overall were brown, yellow, and grey, in that order. For the letters, 30 out of the 70 synesthetes' selections for letter A were categorized as red, over 50% of the Os were categorized as white, and over 40% of Ys were categorized as yellow. The remaining associations were all below 40%, but every letter except K had at least 1 association above what would be expected by chance. Chance was determined for each color by calculating the percentage of the total dataset that coders categorized as that color. For example, 4% of all the colors were pink, so any letter that was pink at a rate above 4% was considered a greater than chance association. Many letters had multiple colors that exceeded the chance threshold, for example about 10% of the Js were purple, about 10% were orange, and about 15% were red (Simner et al., 2005, p. 1075).

Two other well-cited studies conducted similar tests of letter-color associations by simplifying synesthetes' responses into the 11 basic color categories, although they both had slightly different methods for determining the threshold for a "significant" association. Rich, Bradshaw, and Mattingley (2005) surveyed 150 grapheme-color synesthetes who reported their colors on a questionnaire. The authors discuss how they resolved difficult color descriptions, such as “gold,” “green and blue,” or “red with greeny-blue flecks.” Colors that could not be categorized, such as “transparent,” were excluded from the analyses. Some of the findings match the Simner et al. (2005) study, such as an association between O and white for more than 50% of the Os, however, other associations differ. In the Rich et al. study, over 20% of the Ws were associated with green; in contrast, W was not associated with green at a rate above chance in the Simner, et al. study. A third study, which studied 43 synesthetes, confirms some overlapping finding and adds additional discrepancies (Barnett et al., 2008). See Table 1 for a comparison of the similarities and differences between the color-letter trends in these three studies.

Once the evidence of some significant trends in synesthetes’ letter-color pairings came to light, the synesthesia literature saw a sharp increase in research dedicated to drawing some conclusions about *why* certain trends exists. Simner et al. (2005) attempted to explore several potential associations related to the frequency and order of the graphemes and color terms. They found that the order of the letters in the alphabet was not related to the colors in any way. However, the more frequent graphemes were associated with higher frequency color terms and the earliest learned color terms. A 2007 paper by Beeli, Esslen, and Jäncke (2007) came to a similar conclusion using a different method of examining the data. They had their participants select the color of their grapheme using an adjustable color-picker palette in the Adobe Photoshop computer program. This technique of color section provides 16.7 million potential pixels of color for participants to choose from. The researchers then examined the color choices using the continuous color dimensions of Hue, Saturation, and Lightness, which together provide a recipe for the color selection. (See Figure 2 for an illustration of the difference between HSL and HSV (Hue, Saturation, and Value), which is another popular color format. See (Smith, 1978) for a discussion of the differences between the two.) By using these continuous variables, Beeli et al. (2007) were able to conduct correlation and regression analyses. They found a small positive correlation between letter frequency and saturation ($r = .15$, $p < .001$), indicating that more frequent letters were brighter. The authors conclude that synesthetes' associations must be formed implicitly because the participants were not aware of the frequencies of the letters (Beeli, Esslen, & Jäncke, 2007).

In a response to this study, Simner and Ward published a commentary paper in which they re-analyzed the data from Beeli, et al. and pointed out that universal color name categories are related to patterns in HSL color space. Therefore, Simner and Ward argue, "a saturation-based account of synesthesia is less predictive than an account based on frequency of color terms" (Simner & Ward, 2008, p. 413). Regardless of whether or not the findings in these two studies are independent of each other, they both suggest that the letter color pairings that develop in synesthesia may be at least partially related to implicit statistical learning about the more frequent stimuli in the environment.

Other potential influences on the letter-color pairings include physical characteristics of the letters, such as shape and sound. Of these two possibilities, shape has received more continued attention because of early observations that for grapheme-color synesthetes the /k/ sounds in *cat* and *kite* have different colors if C and K are differently colored, whereas *cat* and *city* are the same color of the letter C (Simner, Hung,

& Shillcock, 2011). However, see Day (2004) for a discussion of trends related to phonemes.

Several researchers examined the role of shape by reasoning that more similarly shaped letters might be more similarly colored. Several studies have found some evidence of this relationship, although they must be interpreted with caution. In particular, Brang and colleagues compared color similarity and shape similarity in synesthetes by using an already existing letter similarity matrix (Brang, Rouw, Ramachandran, & Coulson, 2011). However, the color data collected from synesthetes was based on synesthetes taking an online test that presented them with capital letters. In contrast, the letter similarity matrix used lower-case letters (Courrieu, Farioli, & Grainger, 2004). See Simpson and colleagues for a comparison of lower-case and upper-case letter-shape correlation matrices (Simpson, Mousikou, Montoya, & Defior, 2013). Synesthetes ubiquitously report that the color of the letter is the same whether it is lower-case of upper-case, but the lowercase letters may sometimes be a little weaker (Witthoft & Winawer, 2006). However, the study by Brang and colleagues is not the only study to examine the shape-color relationship. Several other studies report that letters that are similar in their upper-case form (such as E and F) tend to be similarly colored (Simner, 2013). In a 2012 paper, Watson, Atkins, and Enns report that the letter similarity, as determined by five different methods from the literature, relates specifically to the Hue of synesthetes' colors, not the Saturation or Luminance (Watson, Blair, Kozik, Akins, & Enns, 2012) . Thus, the Hue of the synesthetes' letters may relate to the visual characteristics, whereas the saturation may relate more to the frequency of the letter (as described above). Additional evidence for the role of letter shape in synesthesia comes from bilingual synesthetes whose letters in their second alphabet often closely match similarly shaped letters in their first alphabet (Mills et al., 2002; Mroczko-Wasowicz & Nikoli´c, 2013; Rich et al., 2005; Witthoft & Winawer, 2006), This similarity seems to be more prevalent if the synesthetes acquired the second alphabet later in life (Mroczko-Wasowicz & Nikoli´c, 2013; Simner et al., 2011).

A final hypothesis about why certain letters are certain colors at a rate greater than chance is that the color relates to the meaning of the stimulus. Evidence of a higher-level, semantic basis of color comes from studies in which participants were presented with ambiguous graphemes and the color changed depending on their interpretation. For example, one research team presented participants with a grapheme that could either be the letter S or the number 5, depending on the context (see Figure 3; Dixon, Smilek, Duffy, Zanna, & Merikle, 2006; Myles, Dixon, Smilek, & Merikle, 2003). These studies demonstrated that graphemes with the exact same shape could change color depending on the synesthetes' semantic access to the meaning of the symbol. Similarly, a study by Kim, Blake, and Kim (2013) rotated the M/W grapheme so that the identification of the letter would switch after 90 degrees of rotation (Kim, Blake, & Kim, 2013). These different methods of testing grapheme ambiguity converge in their observation that the color for the stimulus changed depending on how the stimulus was identified.

The second most popular question of interest in the synesthesia literature is, "To what extent does it use cross-modal mechanisms common to us all?" (Ward, Huckstep, & Tsakanikos, 2006). In the early 2000s, Ramachandran, Hubbard, and colleagues published scientific articles as well as articles and books in the popular press suggesting that studying synesthesia would allow researchers to understand the neural basis of, “abstract thought, metaphor, and perhaps even language” (Ramachandran & Hubbard, 2003a). In their 2001 article titled, “Synesthesia—A window into Perception, Thought, and Language,” Ramachandran and Hubbard claim that, “...we can think of metaphors as involving cross-activation of conceptual maps in a manner analogous to cross-activation of perceptual maps in synesthesia” (Ramachandran & Hubbard, 2001, p. 17). Ramachandran and Hubbard reason that metaphor and creativity involve making connections between superficially unrelated concepts. They also observed that synesthesia seems to be characterized by neural hyperconnectivity (e.g. Hänggi, Wotruba, & Jäncke, 2011; Hubbard, Brang, & Ramachandran, 2011; Ramachandran & Hubbard, 2001a, 2001b; Rouw, 2013; Rouw & Scholte, 2007). (For more recent contrasting views, see Hupé & Dojat, 2015; Jäncke, Beeli, Eulig, & Hänggi, 2009). Thus, Ramachandran and Hubbard reasoned, a hyperconnected brain has greater potential for making conceptual connections (Ramachandran & Hubbard, 2003b).

But before looking for causal neural mechanisms of a condition it is crucial to describe behavioral and psychological manifestations of the condition accurately. The question remains, is synesthesia merely increased sensitivity to normal cross-modal associations? Is there a spectrum of synesthesia? Although many studies have suggested that synesthesia may underlie normal cross-modal associations, all of the studies in the synesthesia literature have established a threshold for categorizing participants as synesthetes or non-synesthetes, with no specification of the strength of the synesthetic association. In fact, when designing an online TOG called the Synesthesia Battery, Eagleman and colleagues (2007) found no overlap between a group of controls and the synesthetes on the color association tasks (Eagleman, Kagan, Nelson, Sagaram, & Sarma, 2007). The constancy of the synesthetes colors clearly divides synesthetes and controls in myriad studies, with synesthetes accurately responding with the same stimulus-color associations at a rate of between 90 and 100% on surprise tests, while controls often score between 20 and 40% consistency with advanced notice and less time between test and re-test (e.g. Baron-Cohen et al., 1987; Simner et al., 2005).

However, several studies report similarities between the responses from synesthetes and controls asked to choose a color that they think best matches the presented grapheme. Note that studies with controls always categorize responses into the 11 basic color terms. In the seminal 2005 study by Simner and colleagues already described in detail above, the researchers also collected data from two types of controls. One group was told they had to choose an association for each letter; the other group was asked only to indicate a color selection if it came to them easily. Both groups of controls did associate certain letters and colors at a rate greater than chance, and in some cases their selections matched the synesthetes'. The matching colors for the synesthetes and controls were B and blue, G and green, R and red, V and purple, X and black, Y and yellow, and Z and black (Simner et al., 2005). Rich and colleagues (2005) found the same overlap between synesthetes and controls, and their groups also agreed at a rate greater than chance with the association between D and brown and P and pink (Rich et al., 2005). However, there were more differences than similarities between the groups and one exceptional difference stands out: O is associated with white at a rate above 50% for synesthetes in several studies, whereas O is associated with orange at a rate of between 40 and 90% in control groups. Simner and colleagues also examined the effect of order and frequency of the graphemes and the color terms in the control groups. They found that the order of the letters in the alphabet was related to the typicality of the color terms. The letter frequency was not significantly related to the color for the controls. Recall that for synesthetes the association was the opposite: the researchers found a significant effect of frequency, but not alphabet order. The researchers conclude that the "similarities between populations suggested that grapheme-color synesthesia, like the music-color variant, may stem from an exaggeration of mechanisms for cross-modal associations that are common to us all. Both populations are influenced by linguistic priming, in that colors tend to be paired with the initial letter of the color name (e.g., *b* → *b*lue), although this effect was more dominant in non-synesthetes" (Simner et al., 2005, p. 1082). I highlight the full text of this quote because of the contradiction that arises: if synesthesia is an *exaggeration* of normal cross-modal processes, why do synesthetes show *less* of an association between b and blue than the "normal" population? In the discussion of their findings, Simner and colleagues waver between claims of mechanistic overlap and claims of fundamentally distinct patterns in the data, unable to reconcile the similarities and differences into a coherent theory and explain why the trends in synesthesia might diverge.

Although it may be tempting to use synesthesia as a means to study normal development, perhaps a more likely hypothesis is that we all posses varying degrees of "normal" cross-modal abilities to some extent, and synesthetes do not lack the normal associations. Thus, their colors may be somewhat influenced by the same neural bases of metaphor that exist in the normal population, but that does not mean synesthesia is merely a salient, automatic form of metaphor. If synesthesia were an exaggeration of metaphor, why do over 70% of synesthetes associate G with colors other than green (see Table 1)?

Creating metaphor is a flexible, fluid, process that involves making novel but meaningful associations. In contrast, synesthesia is a rigid, fixed, automatic link that does not necessarily have meaning to anyone other than the synesthete. Deroy and Spence (Deroy & Spence, 2013a, 2013b) argue against the popular ideas that we are all born as synesthetes or that we all remain weakly synesthetes. They suggest that researchers are biased in their focus on finding similarities between synesthesia and normal cross-modal associations, "to the detriment of hypotheses looking for differences and possible distinctions" (Deroy & Spence, 2013b, p.645). Deroy and Spence argue that the hypothesized link between synesthesia and other cross-modal associations has lead to confusion in the literature about key terms such as crossmodal correspondences, natural crossmodal mappings, metaphorical mappings, and multisensory development. The variety of labels and definitions of these terms lead to confusion when reviewing the relevant literature for the normal population.

Given the well-documented specificity of synesthetes' colors, researchers should consider carefully is whether the distinct idiosyncrasy of synesthetes' experience provides any clues about the neural mechanisms. Simner and colleagues (2005) found striking differences between how the synesthetes and controls described their colors. Synesthetes used an average of 45 words to describe all 26 letters, versus an average of 26.5 words to describe the 26 letters for controls. The synesthetes' responses that were categorized as "green" were comprised of 54 unique descriptions, ranging from "lettuce green" to "blackish green," whereas controls only reported five types of green. Several researchers have anecdotally reported that synesthetes often express frustration if they cannot find the exact match for their color during tests of genuineness (e.g. Simner, 2005) and they may even claim that they have never seen the colors in the real world (Odgaard, Flowers, & Bradman, 1999). Myriad other studies also provide fascinatingly unique descriptions of the detail in synesthetes' mental color experience. Eagleman and Goodale present several examples in a 2009 paper: "the color of ale with a bubbly, soft texture," "a deep burgundy red that is almost like a liquid," and "a baby blue and has plaid yet silky texture" (Eagleman & Goodale, 2009, p. 298). Is it reasonable for researchers to categorize the color of a rich, almost reddish chocolate and the color of bubbling ale as the same "brown" experience?

Synesthetes' descriptions seem like detailed exemplars. In contrast, controls seem to rely on more prototypical associations. In a study of prototype versus exemplar based processing Laeng, Zarrinpar, and Kosslyn (2003) found that prototypical labels for pictures (e.g., "man") are processed in the left hemisphere, whereas specific exemplar labels (e.g. "Einstein) are processed in the right hemisphere (Laeng, Zarrinpar, & Kosslyn, 2003). This leads to the prediction that synesthetes might rely more on the right hemisphere when performing a lexical task. However, the neuroimaging studies of synesthesia have revealed a variety of structural and functional differences between synesthetes and controls, including white matter differences in both left and right hemisphere fusiform gyri as well as the left superior parietal cortex, bilateral frontal cortex projections to the corpus callosum, and hippocampus (Rouw, 2013, p. 508). Thus, the neuroimaging studies have not honed in on one specific mechanism underlying synesthesia, and they leave room for the possibility of several sub-types of synesthesia with different etiologies. While the scientific method of aggregating and averaging data is certainly necessary to find trends and see the overarching picture, understanding individual differences can also provide valuable clues about any neurological condition.

A recent critique of neuroscience more broadly emphasized the need for careful observation of behavior before using neuroscientific approaches to draw conclusions (Krakauer, Ghazanfar, Gomez-Marin, Maciver, & Poeppel, 2017). In grapheme-color synesthesia, the "behavior" is the synesthetes' mental percept of color. Perhaps the simplification of synesthetes' wordy descriptions into 11 basic color categories eliminates too much information and thus cannot come close enough to describing and explaining the phenomenon.

The Current Study

The primary goal of this study is to determine whether synesthetes' colors can be acceptably categorized under the 11 basic color terms. Given the idiosyncracity and specificity of synesthetes' descriptions of their colors, this study will examine qualities such as the saturation and value of the color choices, as well as clustering techniques and categorization by non-synesthetes, to evaluate how well the synesthetes' data matches prototypical basic colors.

A second goal of the current study is to use a large dataset of over 1,000 synesthetes to resolve discrepancies in the literature about specific letter-color pairings. To evaluate relationships between specific letter–color pairings we asked non-synesthetes to categorize the synesthetes' data into color names. Although we predict that the majority of the data will fall into the "Other" category, we may also find certain pairings at a rate above chance, aligning with some findings in the literature. These analyses will provide a more definitive answer than the small-sample size studies of the past and will enable researchers to evaluate their hypotheses about the neural bases of the development of synesthesia based on representative, generalizable trends.

Method

The synesthetes' data for the current study comes from an online synesthesia verification website (www.synesthete.org) called the Synesthesia Battery. This website was designed in 2006 by Eagleman and colleagues to overcome the constraints of laboratory visits in the collection of data from synesthetes (Eagleman et al., 2007). This study only includes a subset of the Synesthesia Battery because the purpose is to evaluate whether the data can be meaningfully categorized. Therefore, we designed a task in which non-synesthete participants viewed the data and determined if it could be easily categorized with a basic color label.

Synesthesia Battery Participants

There are 32,998 verified grapheme-color synesthetes in the Synesthesia Battery dataset. The participants did not all provide honest information about their age, which ranged from 4 to 9E+45 and included values such as "ou." Of those who reported their age, 18 was the mode, with 289 unique responses. For gender, of the participants who responded, 71.5% indicated female. Participants were also given the opportunity to report their native language. Due to the nature of the fill in the blank answer, there were over 340 different spellings of English. English-only native speakers comprised 70.4% of the participants who gave a response. This includes variants of English such as "broken English," "southern Ohio dialect," "the original one, from England," and "English walnut," as well as the more traditional "American English," "Australian English," "Canadian English," and "British English." Race and ethnicity of the participants are not currently available from the database.

Synesthesia Battery Procedure

The Synesthesia Battery is open to anyone who has access to a computer and the Internet. Participants in the Synesthesia Battery are presented with graphemes, one at a time, and a color picker palette (see Figure 4). Participants adjust the color until it matches the color that they experience for the given grapheme, and then they submit the color and continue with the next grapheme. Each grapheme is presented three times in random order. One of the criteria for qualifying as a synesthete is the consistency of the color choice between the three instances of each grapheme. In the original design of the verification task, Eagleman and colleagues compared control participants' responses and synesthetes' responses and established a threshold for the synesthetes' consistency score (Eagleman et al., 2007).

The Synesthesia Battery includes a second task to verify the automaticity of the synesthetes' colors. In a speed congruency task, participants are presented with graphemes that either match or don't match the colors they selected in the previous color selection task. Participants indicate whether or not the color matches their synesthetic color, and the time it takes them to answer is recorded. This prevents users from "cheating" such as consulting a color-coded key. Eagleman and colleages (2007) found that the combination of the color consistency and speed congruency checks provide reliable verification of synesthesia (Carmichael, Down, Shillcock, Eagleman, & Simner, 2015).

The Synesthesia Battery website programmer, Joshua Jackson, provided access to the filtered synesthetes' data. Only data from participants who passed the synesthesia criteria on the Synesthesia Battery were used in the labeling task for the current study.

University of Houston Color Naming Task Participants

Two hundred seventy-four participants came to the Laboratory for the Neural Basis of Bilingualism to participate in the color labeling task. Data from 6 participants were discarded due to errors in recording the data or incomplete participation. Data from the remaining 268 participants were analyzed in this research. Participation was anonymous and participants did not provide any demographic information.

University of Houston Color Naming Task Stimuli

Each participant viewed 208 colors, one at a time, on a computer screen. The colors consisted of data from the Synesthetesia Battery, as well as a set of basic colors selected by the researcher. The synesthetes' data in this task only included synesthetes that selected a color for every letter of the alphabet. Note that 79.0% of synesthetes in the Synesthesia Battery selected a color for every letter.

Each participant in the University of Houston study saw the colors from the alphabets of four unique synesthetes (26 letters X 4 synesthetes = 104 synesthete colors) and 104 basic colors. Thus, at the completion of the study we had color labels for each letter of the alphabet from 1072 synesthetes' data.

The study was designed so that every participant in the lab would see the same 104 basic colors, serving as a check to make sure they agreed on the most prototypical forms of each color. However, partway through the study the researcher evaluated the agreement between participants on the basic colors and determined that it was necessary to create a better set of basic colors (Figure 5). Therefore, the first 121 participants saw basic colors that were pulled from six different sources (see Table 2) and the remaining 153 participants saw basic colors that came from the Stanford Vis Lab's online color dictionary ("Color Dictionary," 2016). The color dictionary uses data from over 200,000 online users in a color naming survey conduced by Randall Munroe (Munroe, 2010). (See Figure 4 for a comparison of the first and second basic color sets and the color label agreement between participants.)

University of Houston Color Naming Task Procedure

Participants were welcomed to the lab and gave informed consent before participating in the research. They were told that the study was about color perception and that they would see squares of color and be asked to choose the best label for each color. The choices were:

1 Red

2 Orange

3 Yellow

4 Green

5 Blue

6 Purple

7 Pink

8 Brown

9 Grey

0 Black

w White

q In between/questionable

Participants used the computer keyboard to select the number or letter next to what they thought best described the color. If they selected anything other than "In between/questionable" they then saw a new screen with the same color and the prompt, "How well does the color match the color name you chose?" The options were:

1 Perfect

2 Good

3 Okay

4 Poor

5 I chose the wrong color

After participants indicated their response the screen went blank for 1000 ms before the presentation of the next color. See example stimuli in Figure 6.

After completing all trials on the computer participants filled out a brief exit questionnaire that asked how difficult they found the task and if they had any other comments. See the Appendix for the full questionnaire.

Results

Basic Colors Versus Synesthetes' Colors

Data analysis involved the use of many R packages, including plyr, dplyr, scales, and matlab, as well as material from an online course (Anderson, Kross, & Peng, 2016; Bengtsson, 2016; Wickham, 2016; Wickham, Francois, & RStudio, 2016; Wickham & RStudio, 2016). Because the first set of basic colors presented in the task at the University of Houston were later determined to be poor examples of the basic colors (see Figure 5), all analyses including standard colors will only include the second set of standard colors for the remainder of the paper. One hundred and fifty one participants labeled the second set of standard colors. Their average accuracy was 93.93% with a range of 78.10% to 99.05%. The average rating of how well the presented basic colors matched the label the participant chose was 1.57. Recall that the rating scale ranged from 1 (“Perfect”) to 4 (“Poor”). Very few participants chose “In between/questionable” for the basic colors. The average number of “In between/questionable responses per participant was 2.28 and the mode was 0.

In comparison to the basic colors, the synesthetes’ colors contained significantly more “In between/questionable” responses. The average number of “In between/questionable” selections for the synesthetes’ colors per participant was 8.76, which was significantly greater than for the standard colors ($t = -12.84$, $p < .0001$). Figure 7 shows a scatterplot depicting the colors that were classified as “In between/questionable.” The rating for the synesthetes’ colors was significantly worse than for the basic colors, with an average rating of 1.88 ($t = -14.04$, $p < .0001$). The number of brown, grey, black, and white letters in the synesthetes’ alphabets also provides information about how colorful the synesthetes’ alphabets are. Five percent of the synesthetes color choices were labeled as brown, 5.32% grey, 4.93% black, and 5.17% white. When combined, brown, grey, black, white, and other comprised 28.97% of the synesthetes’ colors. There was also a significant difference in reaction time after removing outliers greater than 1.5 interquartile ranges above the third quartile of the data. The difference in reaction time indicates the participants took significantly longer to respond to the synesthetes’ colors compared to the basic colors, $t(143) = -14.183$, p

< .0001. The mean reaction time for synesthetes' colors was 3.73 seconds and the mean for the standard colors was 3.23 seconds.

K-means Clustering

Before computing the k-means cluster analyses, the original color data was transformed from RGB space to CIELAB space using the colorspace package in R (Ihaka et al., 2016; Team, 2015). The first k-means clustering analysis was a test of the basic colors. Using the kmeansruns function in the fpc package in R (Hennig, 2015), we gave the program a range of potential clusters for the 104 basic colors from the second set. We set the range of clusters from 2 to 26 and the program calculated the number of clusters that best fit the data. Contrary to our expectation that the basic colors would cluster into 11 groups because of the 11 color names represented, the optimal number of clusters ranged from 23 to 26. Therefore we plotted the between sums of squares divided by the total sums of squares to see if there is an inflection point at which the improvement from adding additional clusters flattens out. See Figure 8 for a plot of the (between SS / total SS) for the standard colors. As seen in the plot, after 11 clusters the slope of the improvement flattens at about 99%, which is likely a ceiling effect. See Table 3 for the comparison of the clustering and the color names with 11 clusters. Data points labeled in the standard key as orange, brown, blue, and purple were each included in two clusters. The remaining colors were perfectly clustered.

K-means analyses of the data from synesthetes shows worse between sums of squares divided by total sums of squares. When given a range of 2 to 26 clusters, the optimal number of clusters was consistently 6, with a (between SS / total SS) of 80.6 %. See Figure 8 for a comparison of the curve of the (between SS / total SS) for the standard data versus the synesthetes' data. See Figure 9 for visualizations of the 3D clusters. When comparing the color labels to the cluster assignment for the synesthetes' data the boundaries are not clean-cut, however there are some trends. For example, cluster 1 contains data points with every color label, but 40% of the points were labeled as black. Cluster 2 also included data points for every color label, and the most well represented color labels were blue (23%), white (22%), and grey (17%). The cluster that best represented one color name was the cluster in which 97% of the data points were labeled as green. See Table 3 for the full comparison of color labels and clusters for the synesthetes' data.

A final interesting question that could be addressed with k-means clustering is whether the letters fall into clusters in color space. As can be seen in Table 4 and Figure 10 no cluster contains a majority of any letter, and all clusters contain at least one instance of every letter, created using the treemap package in R (Tennekes & Ellis, 2017).

Letter Trends

Contrary to our hypothesis, the "In between/questionable" selection was not the modal choice for the synesthetes data. Even when examining the data grouped by letters, several letters revealed associations with standard color labels at a rate greater than chance, aligning with findings commonly reported in the literature. The letter A was labeled red for 49.1% of synesthetes. The letter B was blue for 37.0% of synesthetes. The letter C was yellow for 34.4% of synesthetes. Other supported trends include white for I and O (30.5% and 29.0%, respectively), and black for X and Z (21.5% and 21.3% respectively). Table 1 reports the current findings in comparison with the findings from three previous studies in the literature. Given the much larger sample size of this study, the current findings provide a more reasonable estimate of true trends. See Figure 11 for plots of every letter. Chi-squared analyses revealed for every letter there was a statistically significant difference between the frequencies of colors in the 12 color categories (the 11 basic colors and “In between/questionable”). The chi-squared statistics ranged from 221.29 (letter K) to 2477.20 (letter C).

Although this study does replicate most accepted letter-color associations from the literature, additional analyses may help researchers address why B is *not* blue for 63% of synesthetes. It is possible that within grapheme-color synesthetes there are certain sub-groups. To investigate whether some synesthetes largely match the modal responses while others might not match at all, for each synesthete we counted the number of letters that match the modal response. The maximum number of letters that matched the mode was 15 for two synesthetes (0.1%). The greatest number of modal matches was 7 (15% of the synesthetes). See Table 5 for complete results. We also examined whether certain synesthetes might be more influenced by semantic factors, such as the first letter of color words (R and red, B and blue, etc.). Only 3 synesthetes’ data matched all six of the most frequent color words (R = red, O = orange, Y = yellow, G = green, B = blue, and P = pink or purple). See Table 6 for the complete results.

Conclusion

The results of this study reveal that synesthetes’ colors do differ from what is traditionally considered a standard or prototypical color. Participants in this study were more likely to label synesthetes’ colors as “In between/questionable,” they rated synesthetes’ colors as poorer examples of a typical color, and they responded slower to synesthetes’ colors than to the set of standard colors. In addition, the synesthetes’ colors did not cluster as well in color space, and clustering did not reveal clear patterns with letters. These findings support the suggestion that synesthetes' experiences are not a typical, metaphorical association. Through several forms of analysis this study demonstrates that the 11 basic colors do not fully capture the synesthetes' experiences.

On the other hand, even with the "In between/questionable" option included as a possible response, participants in this study still classified the majority of the synesthetes data points as a basic color (though with reduced ratings of how well they matched an ideal form of that label). Therefore this study did replicate findings of associations between some typical colors and letters at a rate greater than chance. This suggests that continued investigations focused on understanding what influences the letter-color link in those cases may increase our understanding of the neural mechanisms of synesthesia. A recent study Witthoft, Winawer, and Eagleman used data from over 6,000 synesthetes through the Synesthesia Battery and made a compelling case for the influence of colored alphabet toys in 6% of a the participants (Witthoft, Winawer, & Eagleman, 2015). The approach to this investigation could be used as a model for studies interested in other potential influences on trends in the letter-color associations. However, these should not be the only types of questions we ask, as for each letter at least 60% of the synesthetes did not experience the modal association.

An ideal next step would be to examine individual differences. A limitation of the Synesthesia Battery dataset used for the current study was the absence of meaningful predictors to use in models of individual differences. Although the dependent variable of color can be described on continuous scales, the deeper questions of interest in understanding the etiology of synesthesia all relate to what external or internal factors predict variation in color associations. During the Spring 2017 semester we have collected data from more than 40 control participants and two synesthetes at the University of Houston. One of the most important questions we are asking both the controls and the new synesthetes is a follow-up to the Vividness of Visual Imagery Questionnaire (VVIQ; See Campos, 2011; Marks, 1973), which is already included in the Synesthesia Battery. The VVIQ describes scenes such as a lake in the wilderness or a rainbow in the sky and asks participants how vividly they can picture the scene. The follow-up question we are adding is whether they think of specific scenes from their memory (exemplars) or more general ideas about the scene (prototypes). So far the majority of the participants indicate that they use both, but with continued data collection we may be able to determine if scores on the VVIQ are influenced by the type of imagery (exemplar vs. prototype), rather than indicating a continuous scale of the strength of the imagery. The hypothesis is that the suggested relationship between synesthesia and higher VVIQ scores (Barnett & Newell, 2008) may be due to a greater reliance on exemplar based processing.

In addition to the VVIQ, future investigations will also collect data on a variety of convergent and divergent creativity assessments. Measures related to creativity in synesthetes are of particular interest because, as emphasized in the introduction, one of the main goals of this line of research is to tease apart the suggested link between synesthesia and creativity (e.g. Domingo, Lalwani, Boucher, & Tartar, 2010; Domino, 1989; Meier & Rothen, 2013; Mulvenna, 2007, 2012, 2013; Rothen & Meier, 2010; Sitton & Pierce, 2004; Ward et al., 2006; Ward, Thompson-Lake, Ely, & Kaminski, 2008). Much of the research about this topic has focused narrowly on quantifying the overlap between synesthesia and expected or typical cross-modal trends, such as high notes and lighter colors, or harsh sounds with jagged shapes (Ramachandran & Hubbard, 2001b, 2003b; Ward et al., 2006). However, studies that compare synesthetes and controls on letter-color associations report that controls make the expected associations (e.g. b and blue, r and red, etc.) at a greater rate than the synesthetes. In addition, recent research in creativity has found that creativity is related to unusual experiences throughout life (Damian & Simonton, 2014), and exposing people to unexpected events can improve their performance on creativity measures (Ritter et al., 2012). Thus, perhaps the link between synesthesia and creativity comes not from facilitation of normal associations, but rather from acceptance or tolerance of unusual associations. There are two ways this hypothesis could be tested in the future. One would be to compare synesthetes and controls on a task involving normal associations, such as the "bouba/kiki" demonstration made famous by Ramachandran (Ramachandran & Hubbard, 2001b). As described by Dr. Arturo Hernandez in personal communication, if coupled with neuroimaging this type of task would help elucidate the overlap between the neural underpinnings of metaphor and synesthesia in synesthetes. Another task that would test whether or not the unusualness of synesthetes' experience may relate to creativity would be to expose people to events that match synesthetes' experience as closely as possible and examine if the exposure boosts scores on a variety of creativity measures.

In combination with studies of metaphor in synesthetes and exemplar vs. prototype processing, these future directions will continue to build on the foundation laid by the current study. The goal of the study was to shed light on the idiosyncracity of synesthetes' colors and to describe the synesthetes' experience quantitatively without sacrificing the detail that is lost in many studies. This study has revealed that claims such as “A is red for synesthetes” do not accurately capture the diversity of the synesthetic experience, and by considering the specificity of synesthetes’ percepts as an important defining characteristic we may be able to reframe hypotheses about the links between synesthesia and creativity.

Table 1. Letter-color trends

Letter	Barnett et al. (2008) N = 43	Rich et al. (2005) N = 150	Simner et al. (2005) N = 70	Current Study N = 1072
A	**Red (32%)**	**Red (36%)**	**Red (42%)**	**Red (49%)**
B	Brown (28%)	Blue (32%)	Blue (32%)	Blue (37%)
C	**Yellow (33%)**	**Yellow (33%)**	**Yellow (27%)**	**Yellow (34%)**
D	Brown (33%)	Brown (47%)	Brown (34%)	Blue (20%) Green (20%)
E	**Green (39%)**	**Green (25%)**	**Green (28%)**	**Green (27%)**
F	**Green (39%)**	**Green (20%)**	**Green (27%)**	**Green (26%)**
G	Brown (22%)	Green (29%)	Brown (33%)	Green (37%)
H	Grey (20%)	Brown (17%)	Green (26%)	Orange (16%)
I	**White (52%)**	**White(48%)**	**White (34%)**	**White (31%)**
J	Blue (15%)	Orange (16%)	Red (15%)	Green (15%)
K	Blue (20%)	Blue, Green (13% ea.)	No color above chance	
L	Yellow (23%)	Yellow (26%)	Grey (17%)	Yellow (23%)
M	Blue (26%)	Red (25%)	Brown (28%)	Red (26%)
N	Blue (27%)	Green (25%)	Brown (28%)	Red (26%)
O	**White (76%)**	**White (56%)**	**White (52%)**	**White (29%)**
P	Green (20%)	Pink (13%)	Blue (25%)	
Q	Purple (26%)	Yellow (13%)	Purple (25%)	Purple (20%)

R	**Red (30%)**	**Red (36%)**	**Red (38%)**	**Red (33%)**
S	**Pink (15%)** **Yellow (28%)**	**Yellow (30%)**	**Yellow (37%)**	**Yellow (20%)** **Red (19%)**
T	Green (24%)	Blue, Green (15% ea.)	Black (18%)	Green (22%) Blue (18%)
U	Brown (30%)	Brown (22%)	Grey (24%)	Yellow (17%)
V	Red, Orange, Yellow (14% ea.)	Purple (18%)	Purple (18%)	Purple (18%) Green (17%)
W	Blue (18%)	Brown (15%)	Blue (15%)	Blue (21%)
X	**Black (24%)**	**Black (30%)**	**Black (20%)**	**Black (22%)** **Grey (20%)**
Y	**Yellow (50%)**	**Yellow (45%)**	**Yellow (42%)**	**Yellow (38.5%)**
Z	Metallic (25%)	Black (30%)	Black (25%)	Black (21%)

Table 2.

a) Set 1 Basic Colors

RGB Values			Color Name	Source
229	0	0	Red	(Munroe, 2010)
249	115	6	Orange	(Munroe, 2010)
255	255	20	Yellow	(Munroe, 2010)
21	176	26	Green	(Munroe, 2010)
3	67	223	Blue	(Munroe, 2010)
126	30	156	Purple	(Munroe, 2010)
255	129	192	Pink	(Munroe, 2010)
146	149	145	Grey	(Munroe, 2010)
0	0	0	Black	(Munroe, 2010)
255	255	255	White	(Munroe, 2010)
101	55	0	Brown	(Munroe, 2010)
227	151	66	Orange	(Benavente, Vanrell, & Baldrich, 2006)
131	87	65	Brown	(Benavente, Vanrell, & Baldrich, 2006)
128	90	64	Brown	(Benavente, Vanrell, & Baldrich, 2006)
116	92	69	Brown	(Benavente, Vanrell, & Baldrich, 2006)
239	220	105	Yellow	(Benavente, Vanrell, & Baldrich, 2006)
82	125	67	Green	(Benavente, Vanrell, & Baldrich, 2006)
63	102	74	Green	(Benavente, Vanrell, & Baldrich, 2006)
52	121	73	Green	(Benavente, Vanrell, & Baldrich, 2006)
55	125	93	Green	(Benavente, Vanrell, & Baldrich, 2006)
69	147	105	Green	(Benavente, Vanrell, & Baldrich, 2006)
86	165	117	Green	(Benavente, Vanrell, & Baldrich, 2006)
46	125	98	Green	(Benavente, Vanrell, & Baldrich, 2006)
14	125	101	Green	(Benavente, Vanrell, & Baldrich, 2006)

68	126	110	Green	(Benavente, Vanrell, & Baldrich, 2006)
44	162	203	Blue	(Benavente, Vanrell, & Baldrich, 2006)
138	190	215	Blue	(Benavente, Vanrell, & Baldrich, 2006)
23	143	191	Blue	(Benavente, Vanrell, & Baldrich, 2006)
58	162	212	Blue	(Benavente, Vanrell, & Baldrich, 2006)
156	193	223	Blue	(Benavente, Vanrell, & Baldrich, 2006)
215	216	226	Grey	(Benavente, Vanrell, & Baldrich, 2006)
112	93	135	Purple	(Benavente, Vanrell, & Baldrich, 2006)
170	162	207	Purple	(Benavente, Vanrell, & Baldrich, 2006)
224	112	164	Pink	(Benavente, Vanrell, & Baldrich, 2006)
230	137	160	Pink	(Benavente, Vanrell, & Baldrich, 2006)
255	247	245	White	(Benavente, Vanrell, & Baldrich, 2006)
221	222	233	Grey	(Benavente, Vanrell, & Baldrich, 2006)
211	212	223	Grey	(Benavente, Vanrell, & Baldrich, 2006)
208	209	220	Grey	(Benavente, Vanrell, & Baldrich, 2006)
204	205	216	Grey	(Benavente, Vanrell, & Baldrich, 2006)
200	201	210	Grey	(Benavente, Vanrell, & Baldrich, 2006)
195	196	205	Grey	(Benavente, Vanrell, & Baldrich, 2006)
190	191	200	Grey	(Benavente, Vanrell, & Baldrich, 2006)
187	189	198	Grey	(Benavente, Vanrell, & Baldrich, 2006)
183	183	193	Grey	(Benavente, Vanrell, & Baldrich, 2006)
175	179	188	Grey	(Benavente, Vanrell, & Baldrich, 2006)
171	173	182	Grey	(Benavente, Vanrell, & Baldrich, 2006)
165	168	177	Grey	(Benavente, Vanrell, & Baldrich, 2006)
158	164	174	Grey	(Benavente, Vanrell, & Baldrich, 2006)
152	160	170	Grey	(Benavente, Vanrell, & Baldrich, 2006)
148	154	164	Grey	(Benavente, Vanrell, & Baldrich, 2006)

133	140	149	Grey	(Benavente, Vanrell, & Baldrich, 2006)
67	72	76	Black	(Benavente, Vanrell, & Baldrich, 2006)
212	70	65	Red	(Benavente, Vanrell, & Baldrich, 2006)
213	70	66	Red	(Benavente, Vanrell, & Baldrich, 2006)
207	71	77	Red	(Benavente, Vanrell, & Baldrich, 2006)
209	64	56	Red	(Benavente, Vanrell, & Baldrich, 2006)
202	64	59	Red	(Benavente, Vanrell, & Baldrich, 2006)
0	255	0	Green	*https://en.wikipedia.org/wiki/List_of_colors:_G–M
127.5	127.5	0.5	Green	*https://en.wikipedia.org/wiki/List_of_colors:_G–M
0	0	1	Black	*https://en.wikipedia.org/wiki/List_of_colors:_A–F
127.5	0	0.5	Red	https://en.wikipedia.org/wiki/List_of_colors:_N–Z
128	0	0	Red	https://en.wikipedia.org/wiki/List_of_colors:_G–M
255	0	0	Red	https://en.wikipedia.org/wiki/List_of_colors:_G–M
0	127.5	0.5	Green	https://en.wikipedia.org/wiki/List_of_colors:_G–M
127	0	1	Red	https://en.wikipedia.org/wiki/List_of_colors:_N–Z
192	203	1	Yellow	https://en.wikipedia.org/wiki/List_of_colors:_N–Z
20	147	1	Green	https://en.wikipedia.org/wiki/List_of_colors:_G–M
140	0	1	Red	https://en.wikipedia.org/wiki/List_of_colors:_N–Z
165	0	1	Red	https://en.wikipedia.org/wiki/List_of_colors:_N–Z
165	42	42	Red	https://en.wikipedia.org/wiki/List_of_colors:_N–Z
90	147	60	Green	Pilot study conducted at UH
216	4	33	Red	Pilot study conducted at UH
0	0	255	Blue	Pilot study conducted at UH
0	0	150	Blue	Pilot study conducted at UH
255	75	0	Orange	Pilot study conducted at UH
255	255	0	Yellow	Pilot study conducted at UH
0	0	0	Black	Pilot study conducted at UH

64	64	64	Grey	Pilot study conducted at UH
20	20	20	Black	Pilot study conducted at UH
240	240	240	White	Pilot study conducted at UH
255	255	240	White	Pilot study conducted at UH
231	210	91	Yellow	(Boynton & Olson, 1987)
228	165	192	Pink	(Boynton & Olson, 1987)
116	159	201	Blue	(Boynton & Olson, 1987)
109	183	131	Green	(Boynton & Olson, 1987)
223	123	79	Orange	(Boynton & Olson, 1987)
224	118	49	Orange	(Boynton & Olson, 1987)
93	156	184	Blue	(Boynton & Olson, 1987)
80	174	108	Green	(Boynton & Olson, 1987)
151	151	149	Grey	(Boynton & Olson, 1987)
207	116	50	Orange	(Boynton & Olson, 1987)
90	162	83	Green	(Boynton & Olson, 1987)
97	162	55	Green	(Boynton & Olson, 1987)
64	128	158	Blue	(Boynton & Olson, 1987)
125	125	123	Grey	(Boynton & Olson, 1987)
63	106	151	Blue	(Boynton & Olson, 1987)
106	92	149	Purple	(Boynton & Olson, 1987)
28	132	81	Green	(Boynton & Olson, 1987)
55	129	51	Green	(Boynton & Olson, 1987)
56	114	53	Green	(Boynton & Olson, 1987)
97	97	97	Grey	(Boynton & Olson, 1987)
104	78	126	Purple	(Boynton & Olson, 1987)
118	90	74	Brown	(Boynton & Olson, 1987)
27	27	27	Black	(“Color Dictionary,” 2016)

255	245	0	Yellow	(“Color Dictionary, 2016”)
255	170	209	Pink	(“Color Dictionary, 2016”)
255	252	255	White	(“Color Dictionary, 2016”)

**Note.* The RGB values for all colors from Wikipedia were incorrectly copied into the final stimulus presentation list. The values presented here are what participants saw. The key name (column 4) is coded to the color that best matches the presented RGB value.

b) Set 2 Basic Colors

RGB Values			Color Name
0	0	0	Black
0	90	202	Blue
0	57	240	Blue
0	53	249	Blue
0	55	231	Blue
0	89	255	Blue
0	67	214	Blue
0	70	205	Blue
0	0	252	Blue
0	86	219	Blue
0	69	255	Blue
21	15	255	Blue
0	64	223	Blue
0	65	255	Blue
3	67	223	Blue
0	77	246	Blue
0	33	234	Blue

0	61	231	Blue
0	74	255	Blue
110	75	34	Brown
119	72	0	Brown
104	61	13	Brown
118	72	13	Brown
116	72	34	Brown
101	55	0	Brown
117	72	25	Brown
115	72	43	Brown
35	152	13	Green
83	157	30	Green
21	176	26	Green
0	169	46	Green
42	166	58	Green
0	154	0	Green
28	152	32	Green
33	167	8	Green
0	169	6	Green
49	166	46	Green
0	168	58	Green
12	168	46	Green
49	181	47	Green
0	154	12	Green
0	154	45	Green
0	169	31	Green
0	162	46	Green

25	167	31	Green
2	183	46	Green
0	154	32	Green
18	152	45	Green
40	152	0	Green
54	166	32	Green
132	132	132	Grey
123	119	111	Grey
146	149	145	Grey
171	171	171	Grey
158	158	158	Grey
249	115	6	Orange
255	139	33	Orange
255	139	9	Orange
251	120	0	Orange
255	134	49	Orange
254	143	6	Orange
255	148	204	Pink
255	124	200	Pink
255	122	182	Pink
250	108	169	Pink
255	129	191	Pink
255	143	214	Pink
255	170	209	Pink
255	129	192	Pink
255	123	191	Pink
255	152	195	Pink

255	147	195	Pink
140	59	160	Purple
138	54	177	Purple
132	30	164	Purple
126	0	150	Purple
126	30	156	Purple
135	17	172	Purple
146	46	177	Purple
135	60	169	Purple
124	40	164	Purple
120	0	158	Purple
143	53	169	Purple
133	65	160	Purple
127	32	172	Purple
130	38	155	Purple
140	13	164	Purple
238	13	14	Red
244	0	0	Red
229	0	0	Red
255	22	40	Red
255	21	19	Red
255	21	15	Red
255	255	255	White
251	248	0	Yellow
250	248	28	Yellow
255	245	0	Yellow
255	255	20	Yellow

249	248	53	Yellow
233	253	0	Yellow
255	245	30	Yellow
255	245	54	Yellow
242	251	0	Yellow
241	252	26	Yellow

Note. All colors in Set 2 are from the Stanford Color Dictionary ("Color Dictionary," 2016)

Table 3.

a) Color labels across 11 clusters in 104 standard colors. Clusters labeled with numbers across top row.

	1	2	3	**4**	5	**6**	7	8	9	**10**	11
Red	0	0	0	0	0	0	0	0	0	0	
Orange	0	0	0	5	0	1	0	0	0	0	0
Yellow	10	0	0	0	0	0	0	0	0	0	0
Green	0	0	0	0	0	0	0	23	0	0	0
Blue	0	0	16	0	0	0	0	0	2	0	0
Purple	0	0	0	0	11	0	0	0		0	0
Pink	0	0	0	0	0	0	11	0	0	0	0
Brown	0	0	0	2	0		0	0	0	0	0
Grey	0	0	0	0	0	0	0	0	0	5	0
Black	0	1	0	0	0	0	0	0	0	0	0
White	0	0	0	0	0	0	0	0	0	1	0

b) 27,872 synesthete colors. Clusters labeled with numbers across top row.

	1	2	3	4	5	6	7	8	9	10	11
Red	27	2	3	10	7	1	618	98	2130	4	7
Orange	1719	1	1	94	3	3	165	4	203	6	3
Yellow	415	3	1	2890	1	14	26	7	2	164	0
Green	65	185	0	405	46	2274	63	749	0	54	20
Blue	1	945	2	3	716	13	0	446	3	177	1494

Purple	2	53	721	0	1030	1	25	232	2	58	159
Pink	23	4	742	0	27	1	82	6	160	178	0
Brown	148	7	1	9	10	0	861	351	2	11	1
Grey	3	379	1	0	562	1	17	252	0	267	0
Black	2	1	1	0	6	0	2	1350	0	11	1
White	1	15	0	2	0	0	0	4	0	1418	0
Other	337	233	120	408	192	34	328	168	139	355	62

Table 4. Six clusters by letter name for synesthetes' data.

Letter	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
A	154	169	583	32	79	55
B	154	236	130	102	372	78
C	247	535	86	29	106	69
D	162	246	106	153	215	190
E	218	284	91	71	152	236
F	209	250	87	102	205	219
G	138	221	89	131	144	349
H	316	356	105	106	80	109
I	577	205	42	123	87	38
J	223	249	128	89	261	122
K	185	271	147	113	264	92
L	322	325	69	77	170	109
M	113	170	328	102	290	69
N	183	335	143	115	174	122
O	560	156	50	176	113	17
P	200	196	119	89	336	132
Q	314	158	74	157	296	73
R	75	143	400	132	208	114
S	226	302	222	63	158	101
T	166	236	121	185	165	199
U	408	285	42	121	168	48
V	253	218	79	134	241	147
W	290	174	70	181	263	94
X	287	136	83	382	150	34
Y	293	548	42	67	81	41

Z	199	184	89	354	164	82

Table 5. Number of matches with the modal color for each letter

Modal Matches	Number of Synesthetes
0	4
1	13
2	35
3	73
4	105
5	129
6	154
7	171
8	154
9	81
10	62
11	52
12	26
13	9
14	2
15	2
16	0

Table 6. Number of matches with the first letter of basic color words

Color Word Matches	Number of Synesthestes
0	404
1	477
2	359
3	205
4	99
5	39
6	12
7	3

Note. Seven modal color words are R = Red, O = Orange, Y = Yellow, G = Green, B = Blue, and P = Pink or Purple, and V = Purple. This table counts how many matches the synesthetes had, but does not specify which ones.

Figure 1. Example color swatches and scoring from Asher et al. (2006).

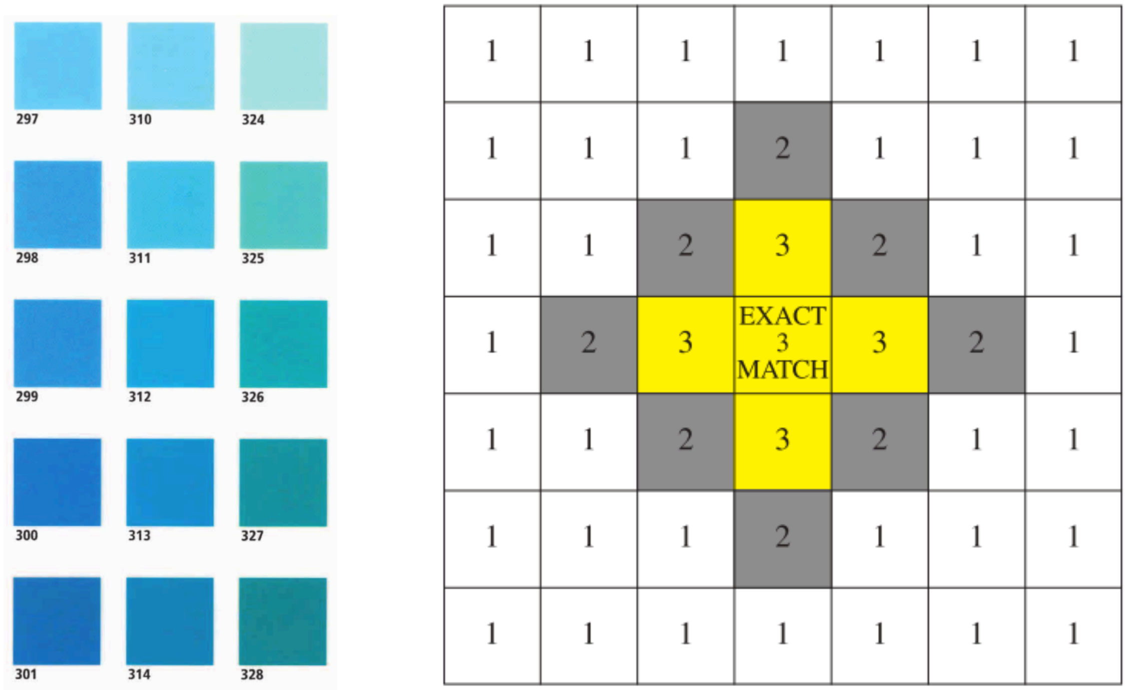
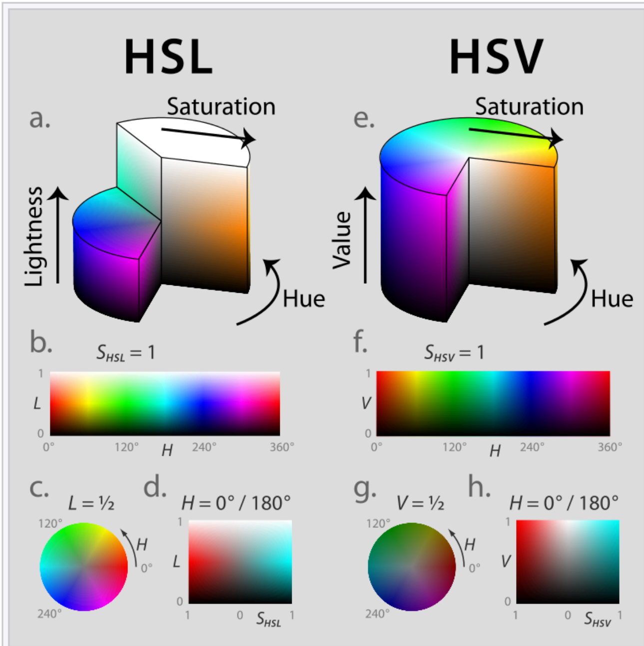


Figure 2. HSL and HSV color spaces.

a) HSL and HSV models copyright Jacob Rus (Rus, 2010).



b) Example of changes in Saturation and Value.

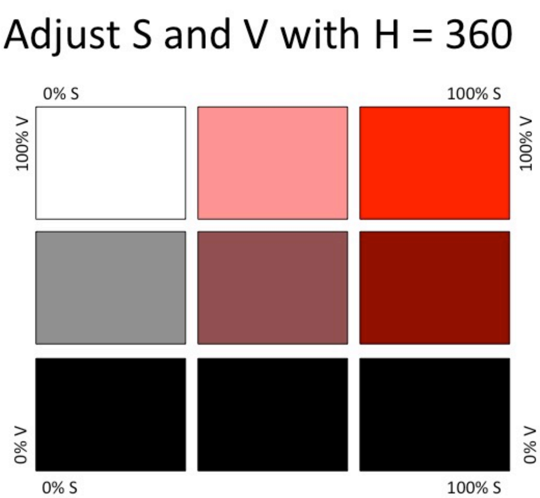


Figure 3. From Dixon et al. (2006), p. 247.

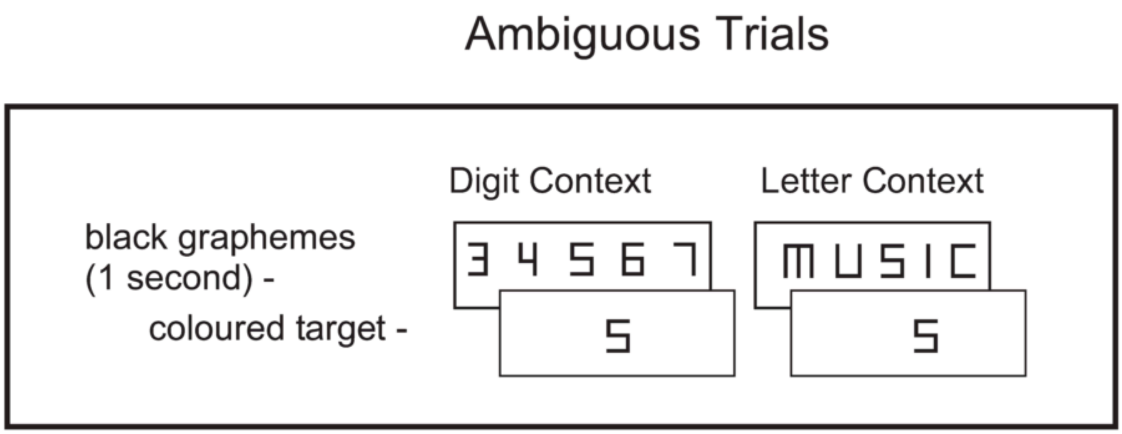


Figure 4. Example trial in the color selection task in the Synesthesia Battery (Eagleman et al., 2007)

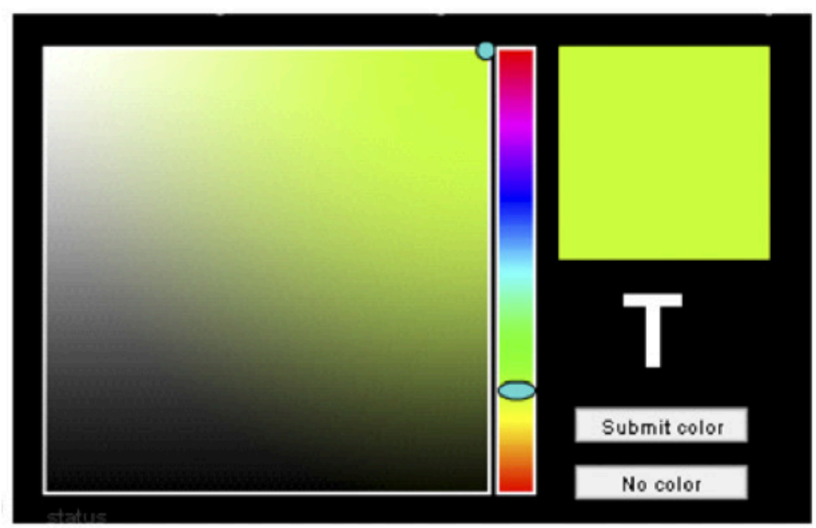
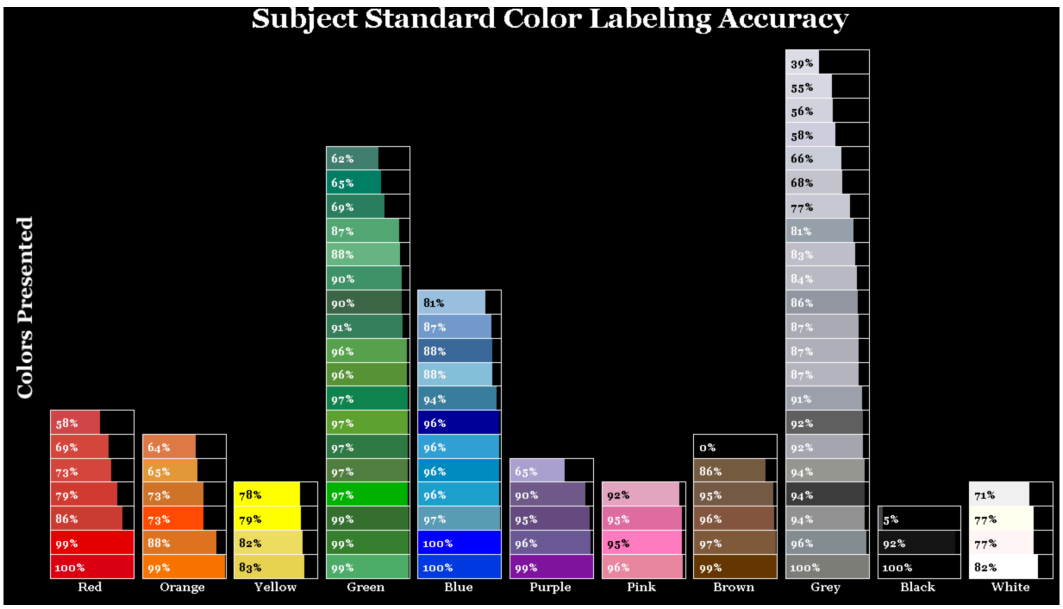


Figure 5. Comparison between the first and second sets of basic colors. The number of colors in each basic color category were determined based on literature demonstrating that green and blue cover a wider range of the visual spectrum and they are much easier for participants to agree on when labeling colors (Boynton & Olson, 1987, 1990; Paggetti, Bartoli, & Menegaz, 2011). Figure created in Matlab (Mathworks, 2014). Code for plot written by Jeffrey Gorges.



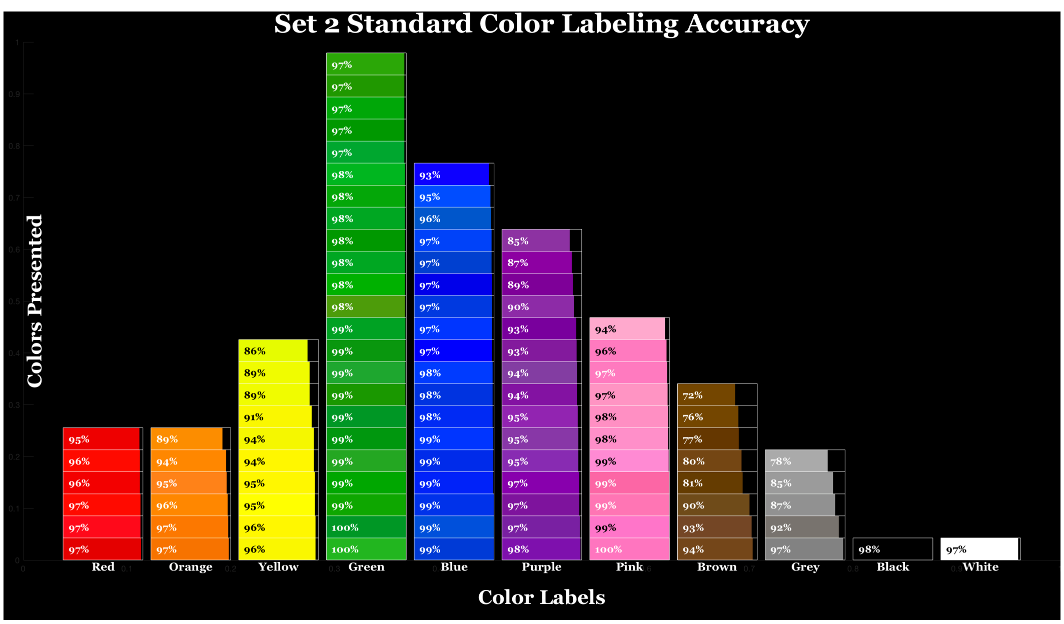


Figure 6. Example of one trial in the color labeling task

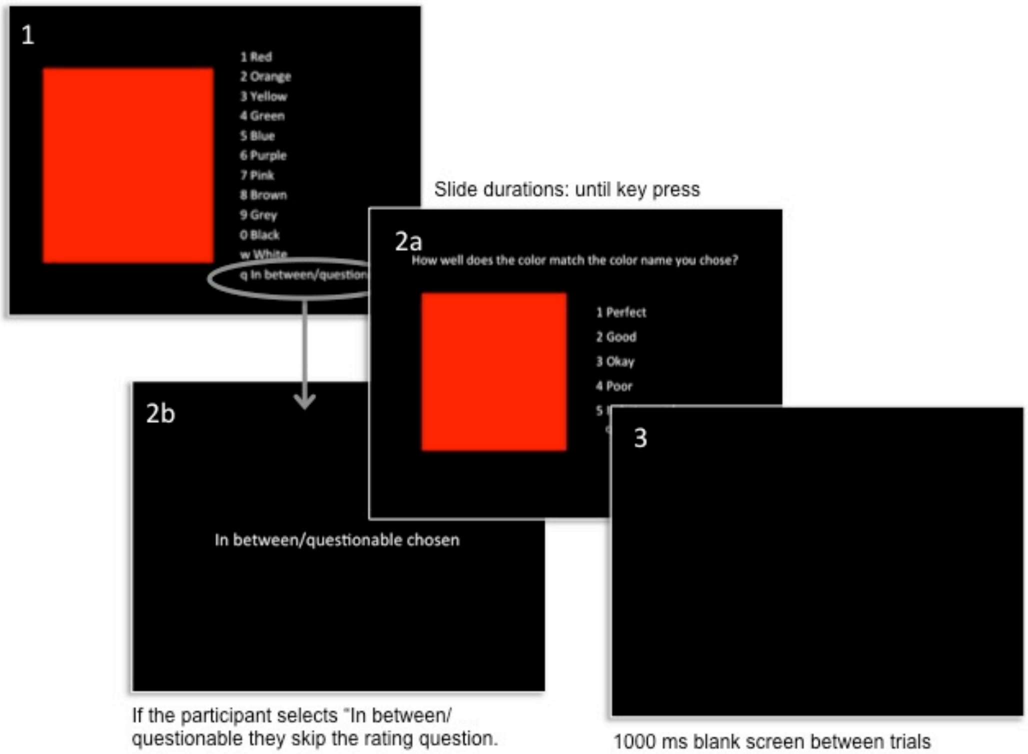
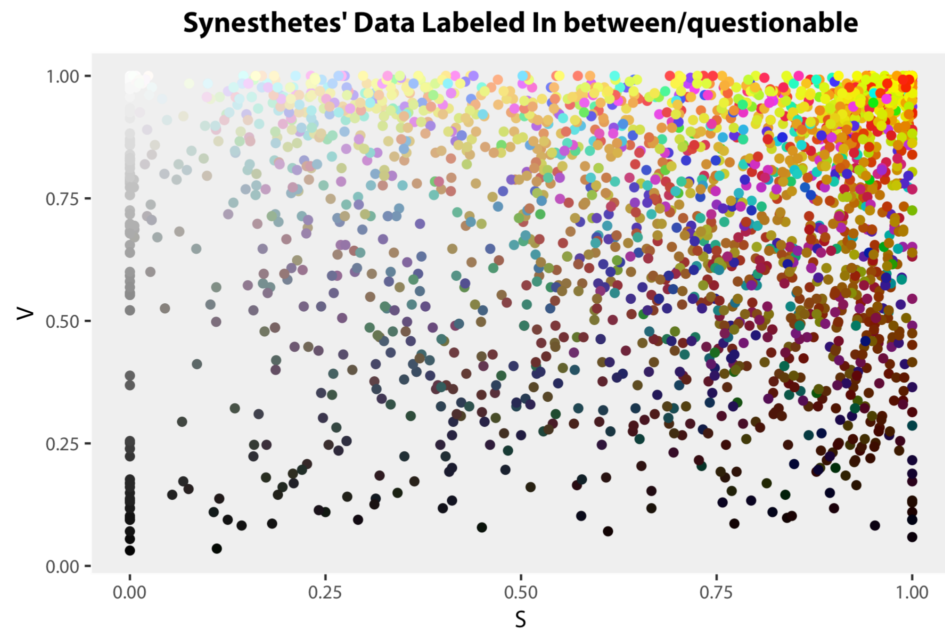


Figure 7. All of the data points participants labeled as "In between/questionable" shown from the S and V axis (top) as well as the H and V axis (bottom).



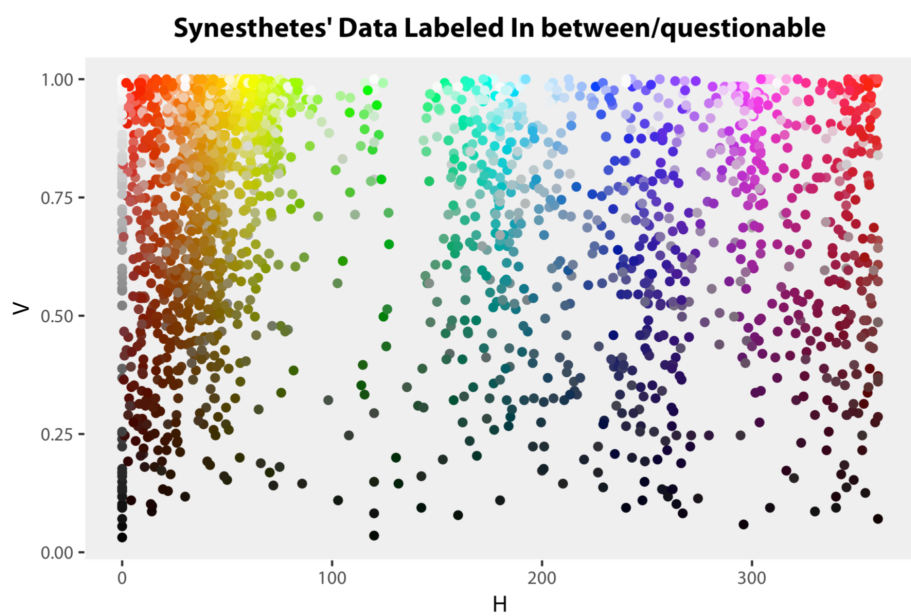
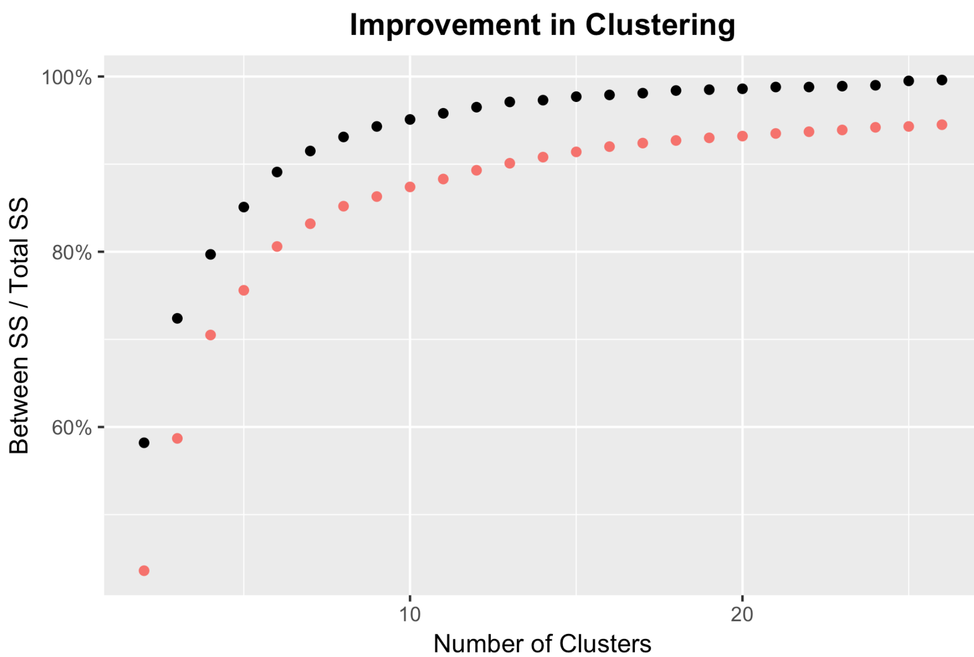


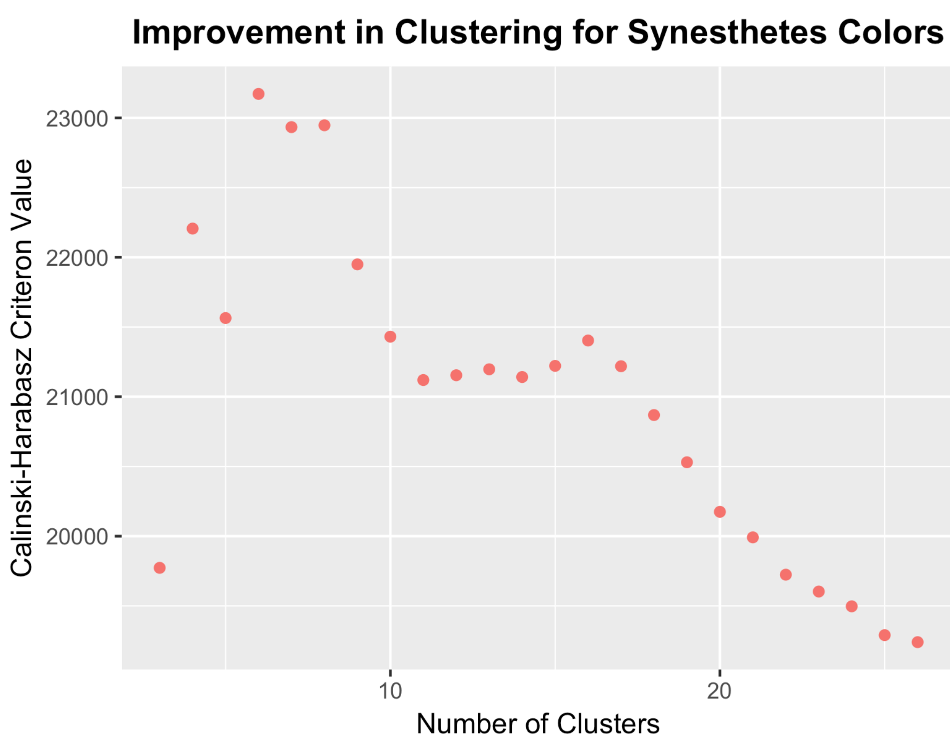
Figure 8.

a) Fit of k-means clusters as represented by SS_b / SS_w



b) Calinski-Harabasz criterion value for synesthetes (top) and controls (bottom).

Maximum value is best fit of clusters.

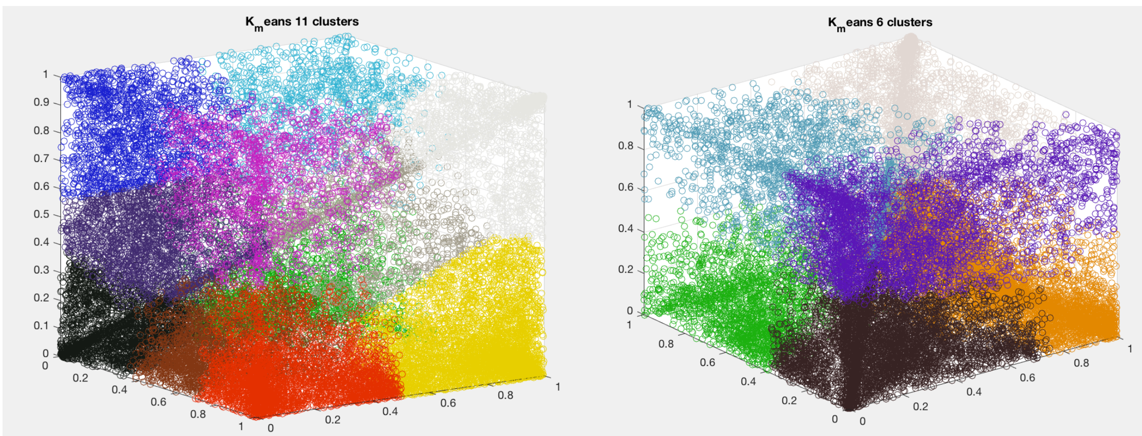



Improvement in Clustering for Standard Colors
Calinski-Harabasz Criteron Value
300
200
10
20
Number of Clusters

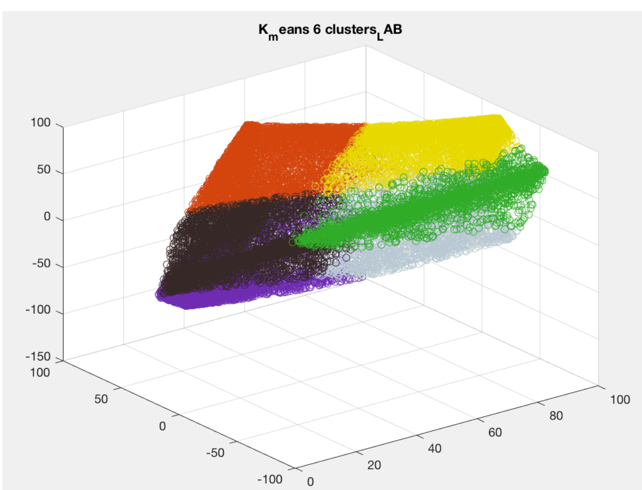
Figure 9. Cluster Analyses

Visualizations of k-means cluster analyses. The computer program (MATLAB or R) chooses points as centroids for each cluster. In these plots the entire cluster is colored the same color as its centroid. The 55,744 data points come from colors presented to participants in the color naming task.

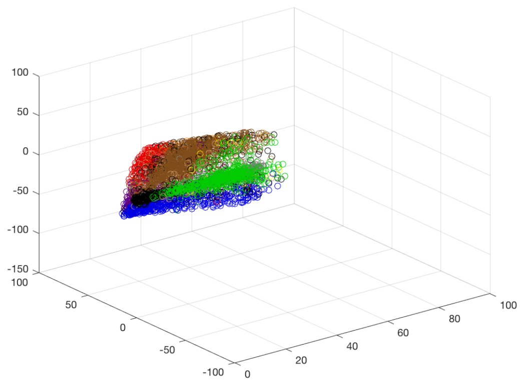
a) RGB space comparison between 11 and 6 clusters colored the centroid color.

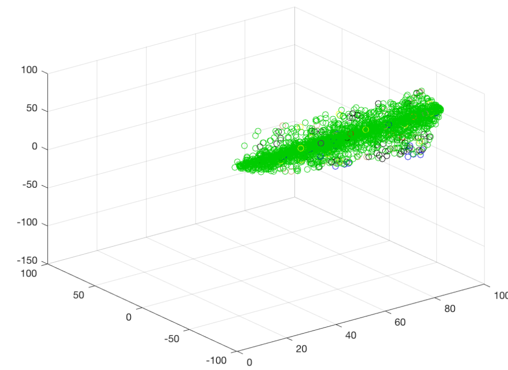


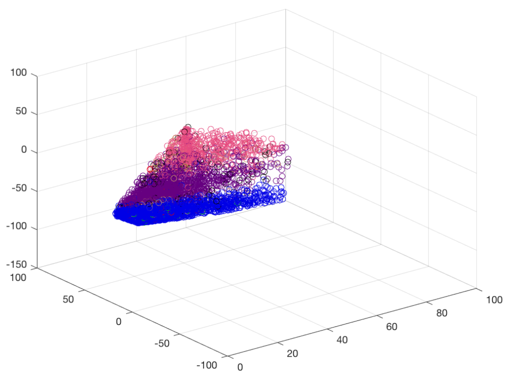
b) 6 Clusters in CIELAB space colored the centroid color.

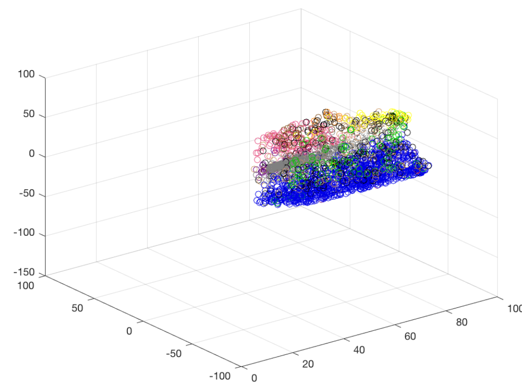


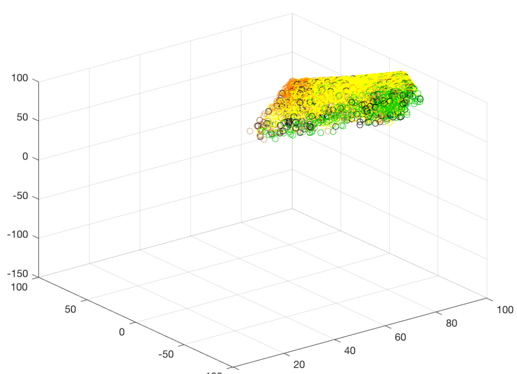
c) 6 Clusters in CIELAB space with data points colored by participants' color labels.











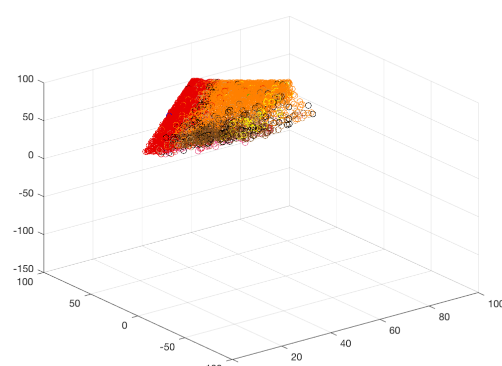


Figure 10. Letter clustering

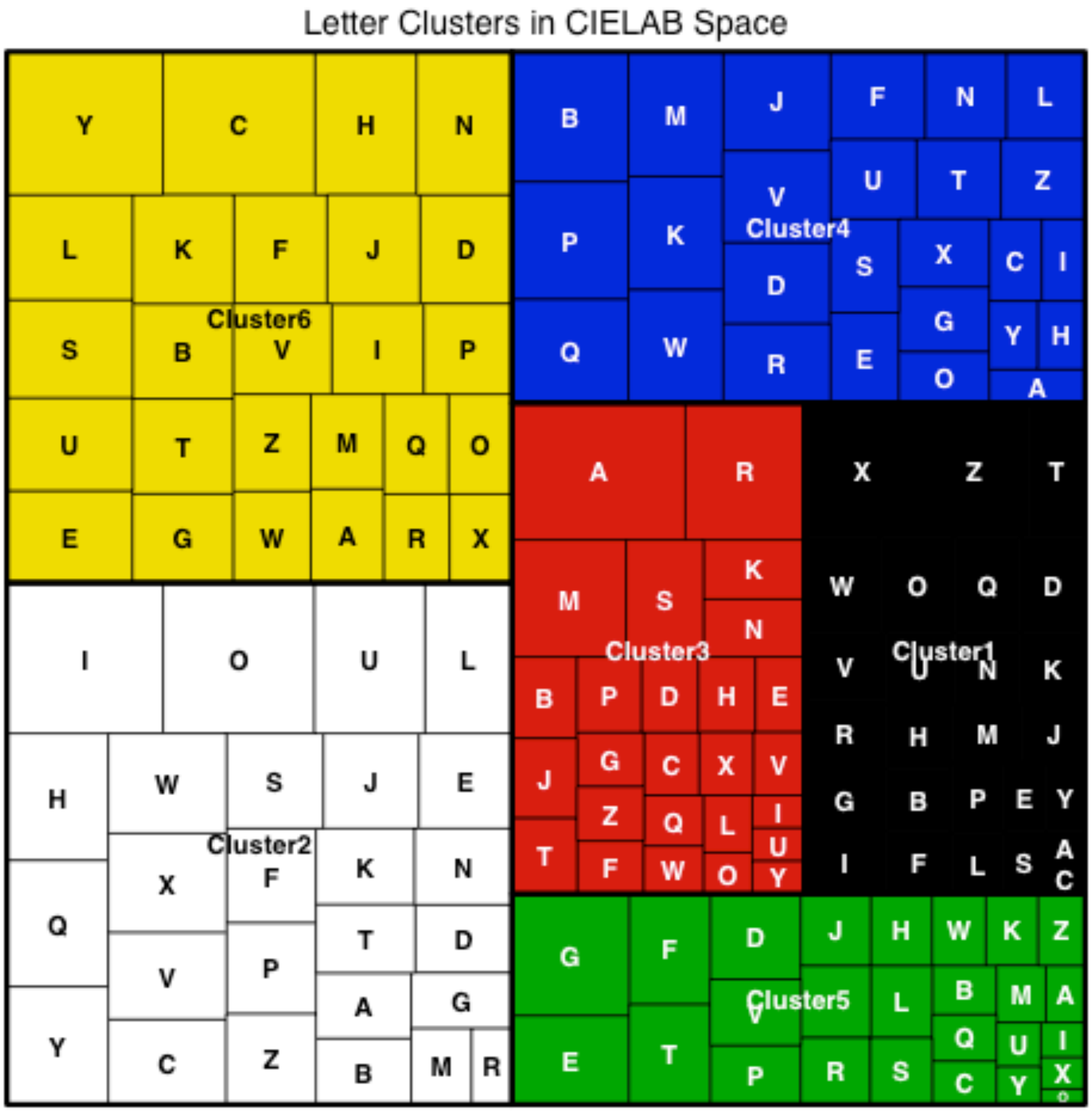
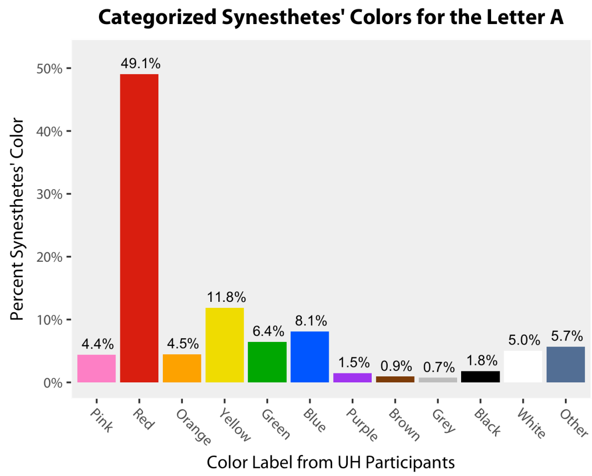
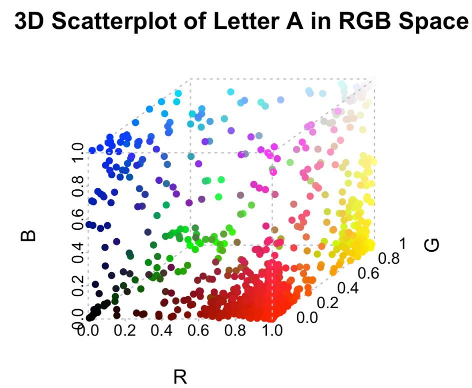
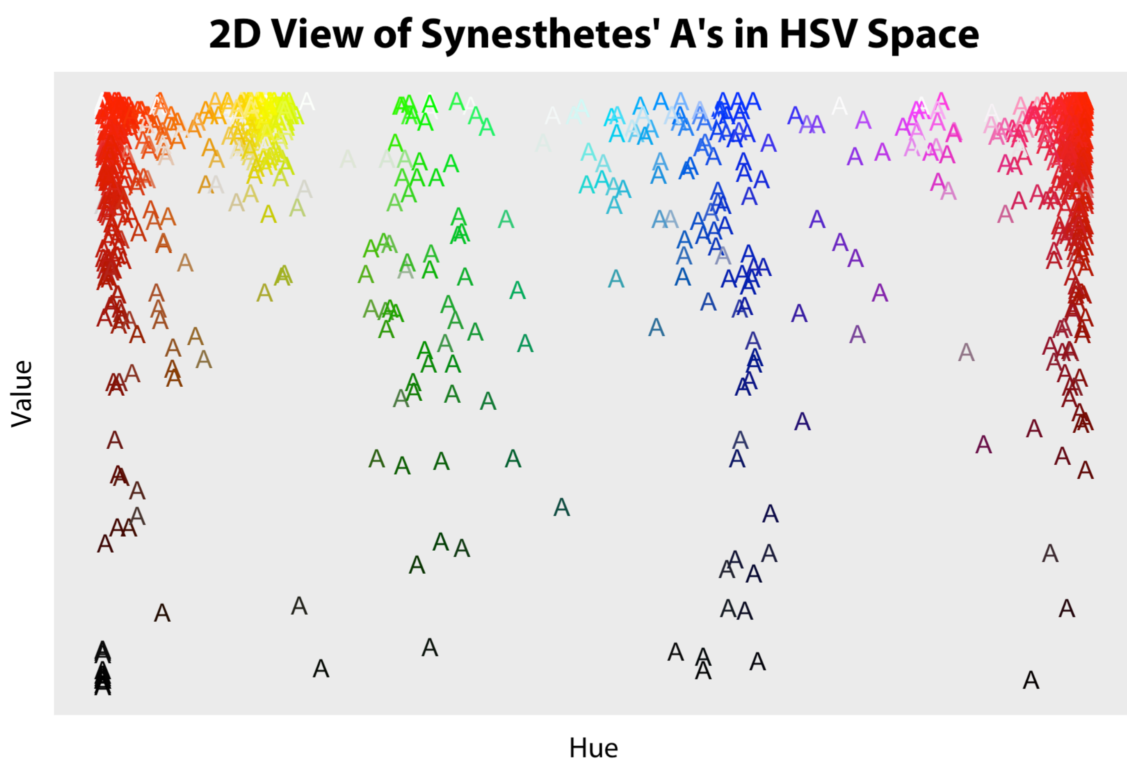


Figure 11. Results by letter.

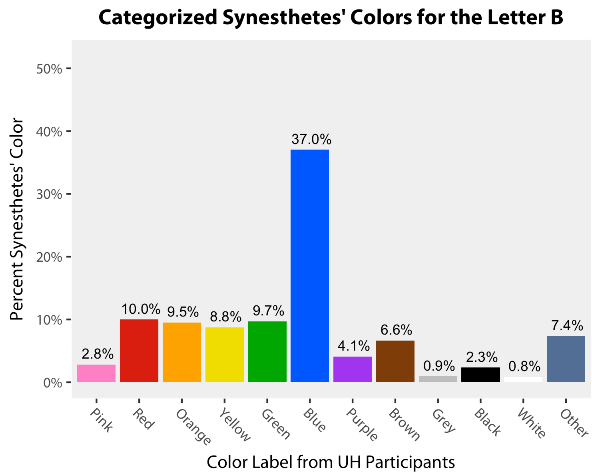
Letter A



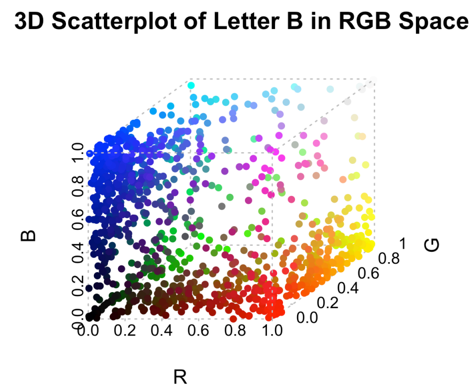




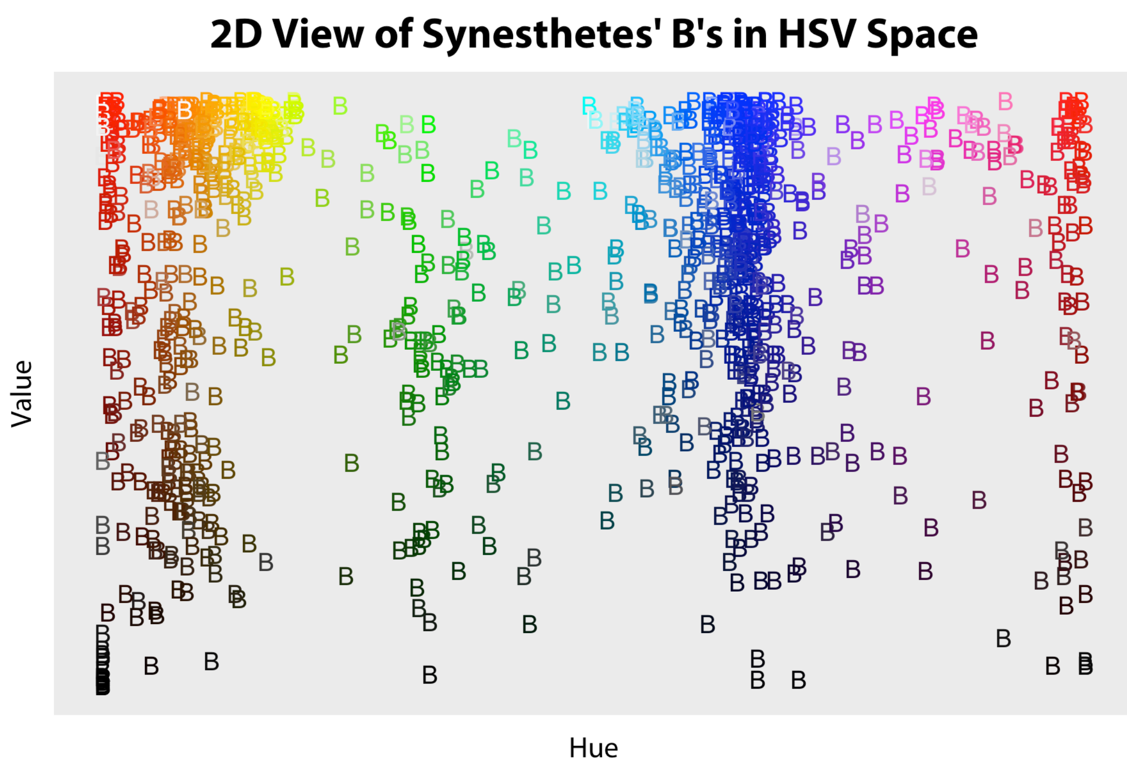
Letter B



Categorized Synesthetes' Colors for the Letter B
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
2.8%
10.0%
9.5%
8.8%
9.7%
37.0%
4.1%
6.6%
0.9%
2.3%
0.8%
7.4%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

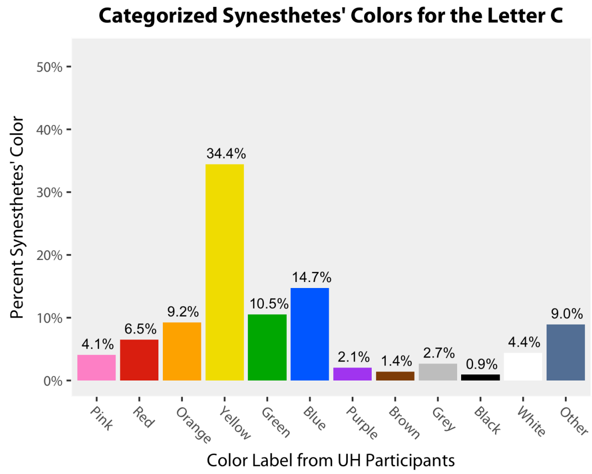


3D Scatterplot of Letter B in RGB Space
B
R
G
0.0
0.2
0.4
0.6
0.8
1.0



2D View of Synesthetes' B's in HSV Space
Value
Hue

Letter C



Categorized Synesthetes' Colors for the Letter C
Percent Synesthetes' Color
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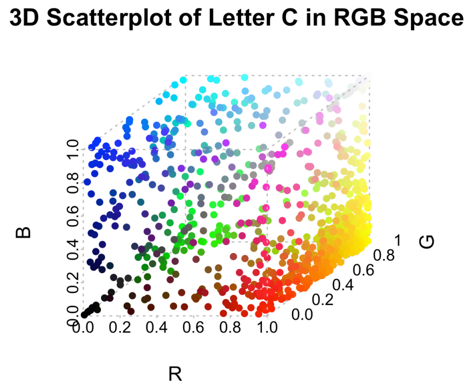
30%
20%
10%
0%
4.1%
6.5%
9.2%
34.4%
10.5%
14.7%
2.1%
1.4%
2.7%
0.9%
4.4%
9.0%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants



3D Scatterplot of Letter C in RGB Space
B
R
G
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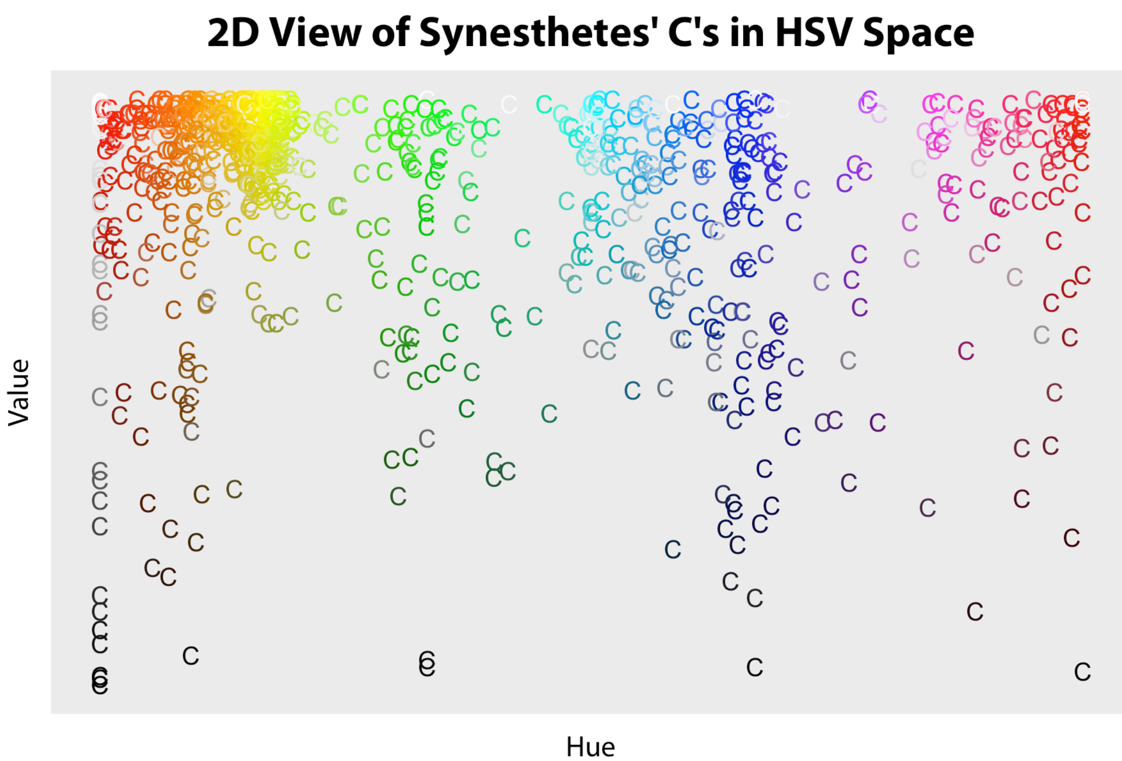
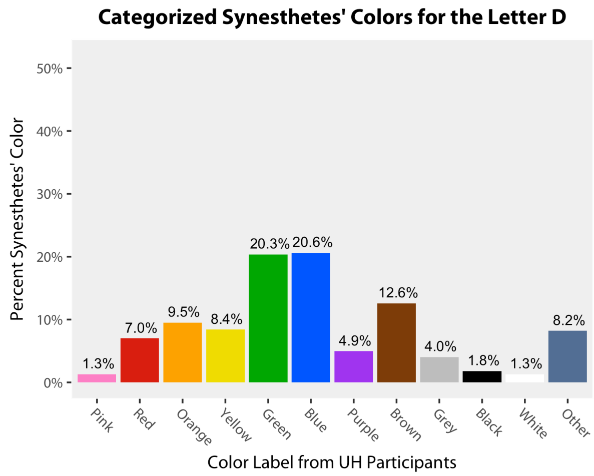
0.4
0.6
0.8
1.0



2D View of Synesthetes' C's in HSV Space
Value
Hue

Letter D


Categorized Synesthetes' Colors for the Letter D
Percent Synesthetes' Color
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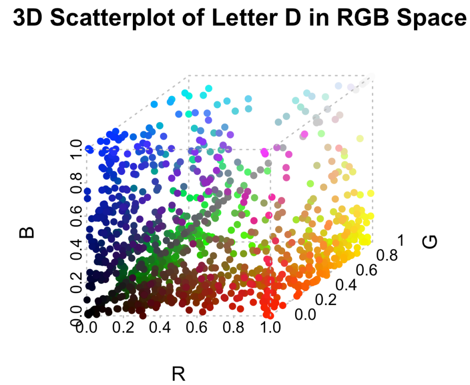
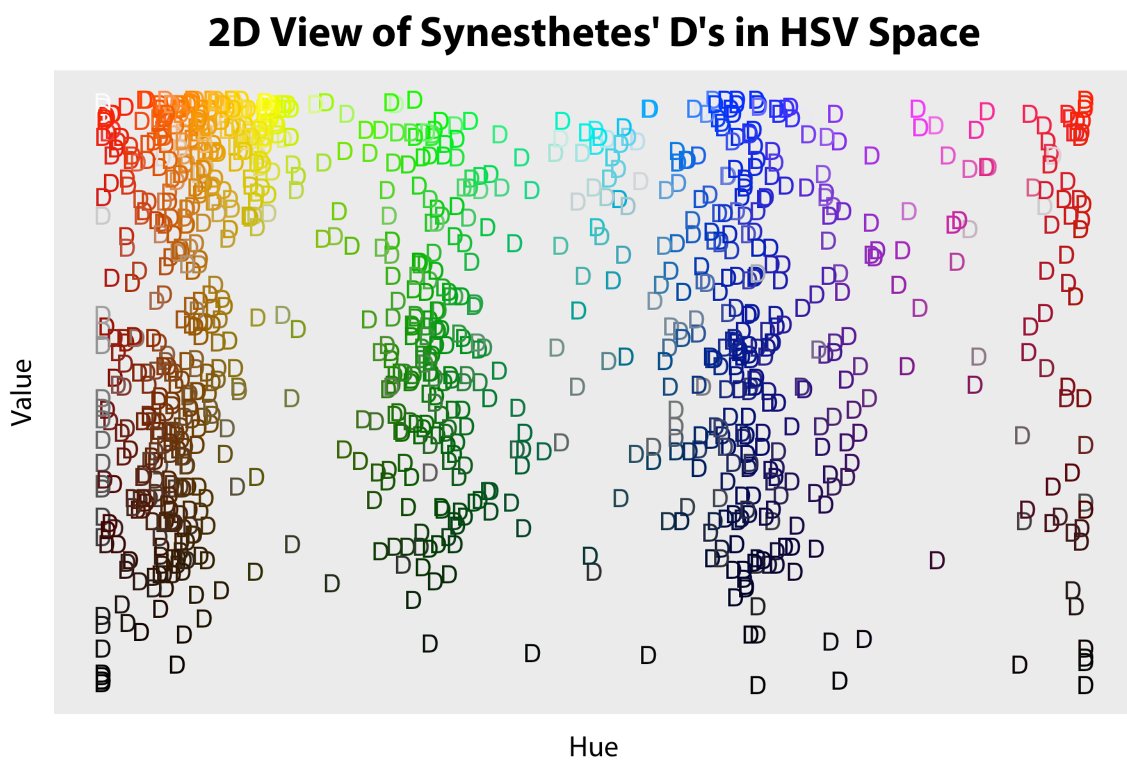
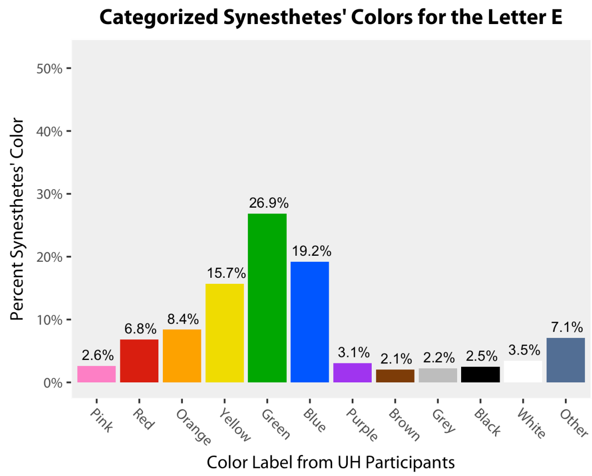
30%
20%
10%
0%
1.3%
7.0%
9.5%
8.4%
20.3%
20.6%
4.9%
12.6%
4.0%
1.8%
1.3%
8.2%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants


3D Scatterplot of Letter D in RGB Space
B
0.0 0.2 0.4 0.6 0.8 1.0
R
0.0 0.2 0.4 0.6 0.8 1.0
G
0.0 0.2 0.4 0.6 0.8 1


2D View of Synesthetes' D's in HSV Space
Value
Hue

Letter E


Categorized Synesthetes' Colors for the Letter E
Percent Synesthetes' Color
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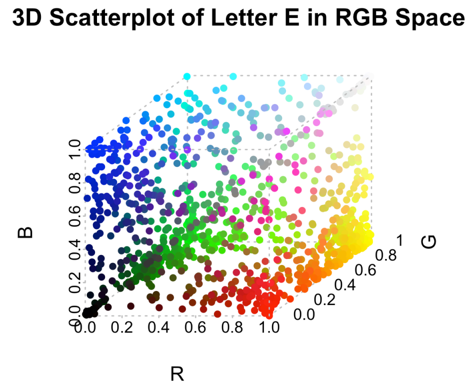
20%
10%
0%
2.6%
6.8%
8.4%
15.7%
26.9%
19.2%
3.1%
2.1%
2.2%
2.5%
3.5%
7.1%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants


3D Scatterplot of Letter E in RGB Space
B
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0.4
0.6
0.8
1.0
R
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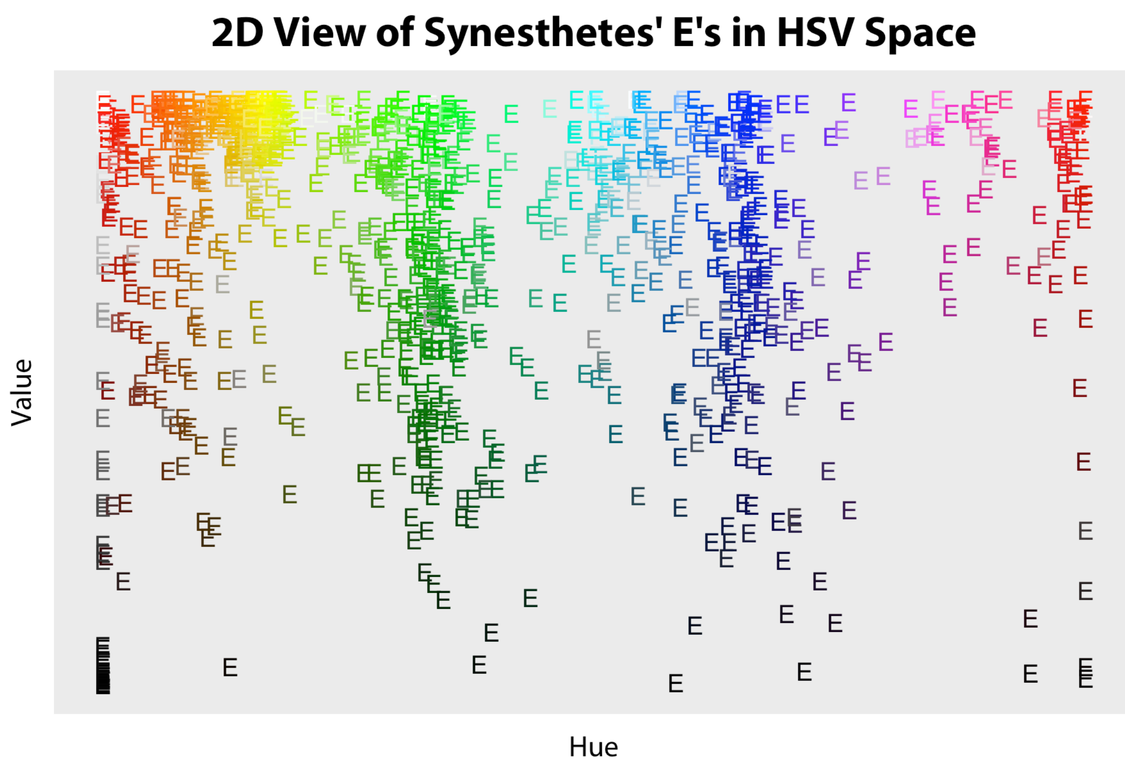
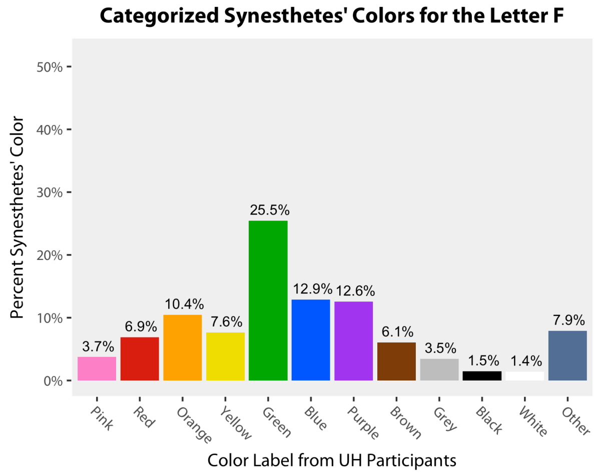
0.6
0.8
1.0
G
0.0
0.2
0.4
0.6
0.8
1


2D View of Synesthetes' E's in HSV Space
Value
Hue

Letter F


Categorized Synesthetes' Colors for the Letter F
Percent Synesthetes' Color
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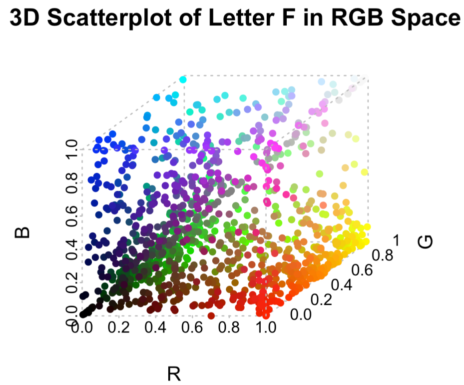
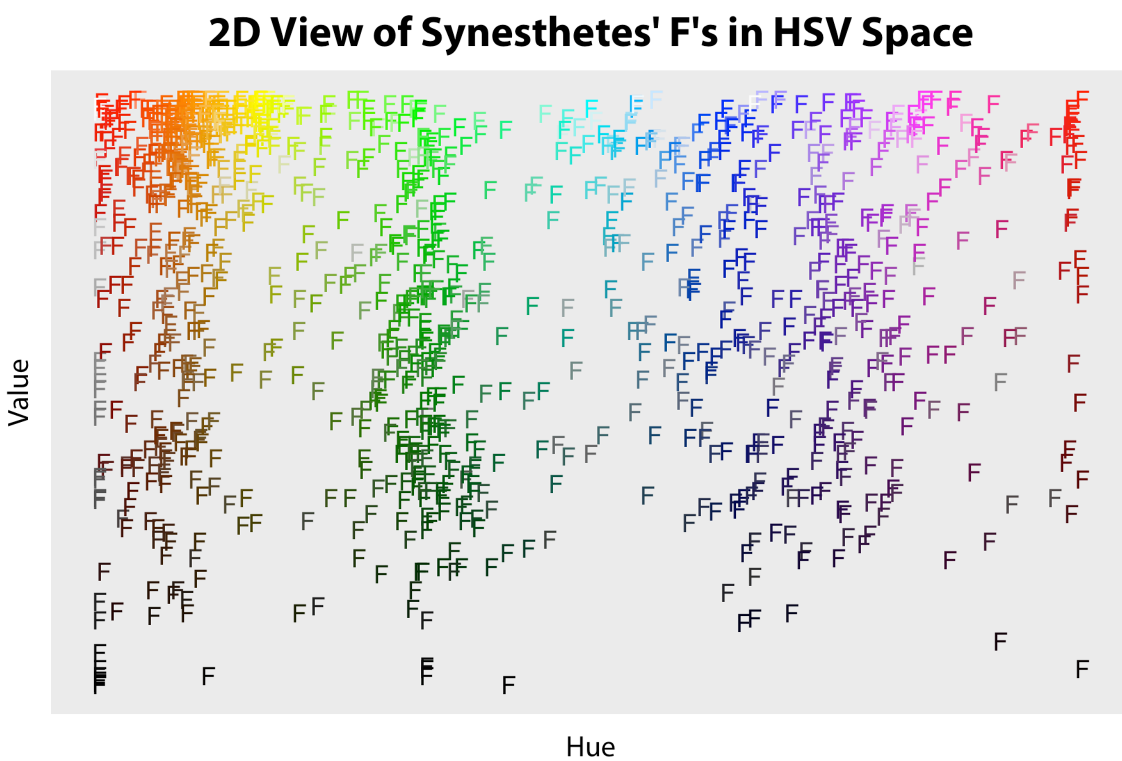
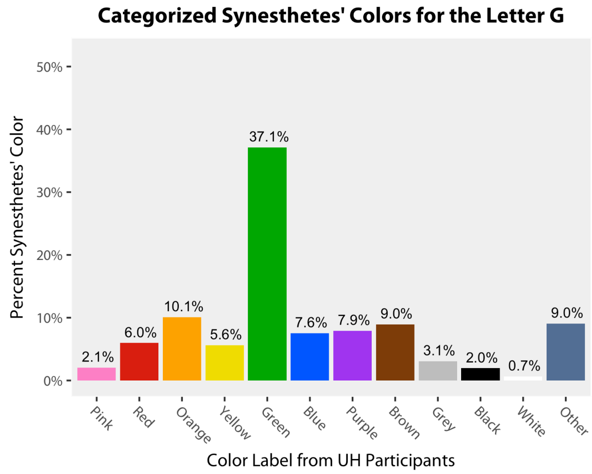
30%
20%
10%
0%
3.7%
6.9%
10.4%
7.6%
25.5%
12.9%
12.6%
6.1%
3.5%
1.5%
1.4%
7.9%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants


3D Scatterplot of Letter F in RGB Space
B
0.0 0.2 0.4 0.6 0.8 1.0
G
0.0 0.2 0.4 0.6 0.8 1
R
0.0 0.2 0.4 0.6 0.8 1.0


2D View of Synesthetes' F's in HSV Space
Value
Hue

Letter G


Categorized Synesthetes' Colors for the Letter G
Percent Synesthetes' Color
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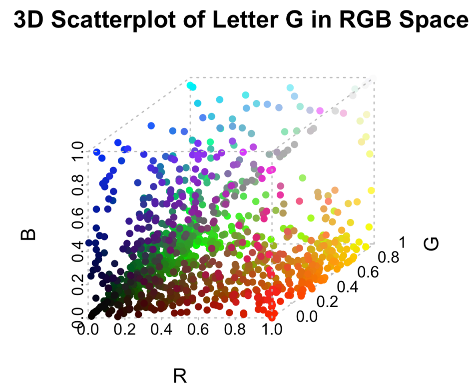
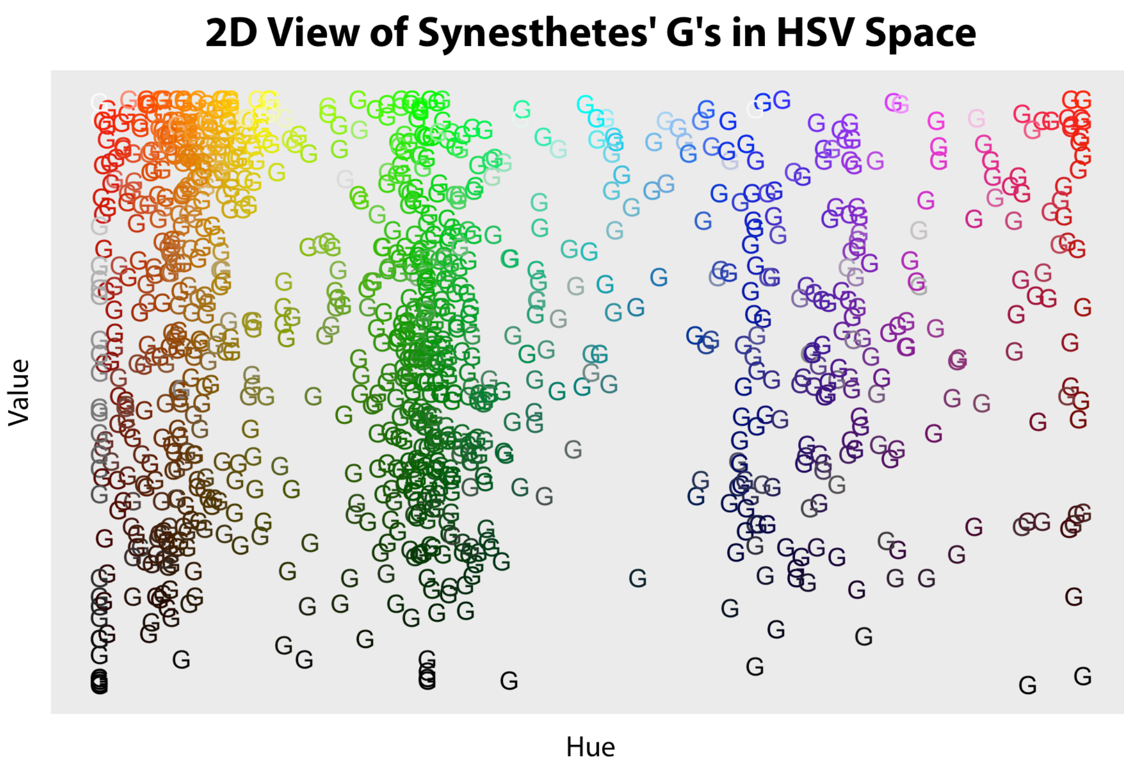
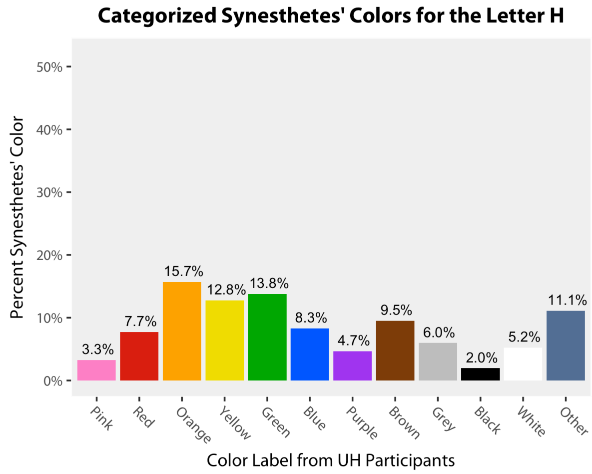
30%
20%
10%
0%
2.1%
6.0%
10.1%
5.6%
37.1%
7.6%
7.9%
9.0%
3.1%
2.0%
0.7%
9.0%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants


3D Scatterplot of Letter G in RGB Space
B
0.0 0.2 0.4 0.6 0.8 1.0
R
0.0 0.2 0.4 0.6 0.8 1.0
G
0.0 0.2 0.4 0.6 0.8 1


2D View of Synesthetes' G's in HSV Space
Value
Hue

Letter H


Categorized Synesthetes' Colors for the Letter H
Percent Synesthetes' Color
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40%
30%
20%
10%
0%
3.3%
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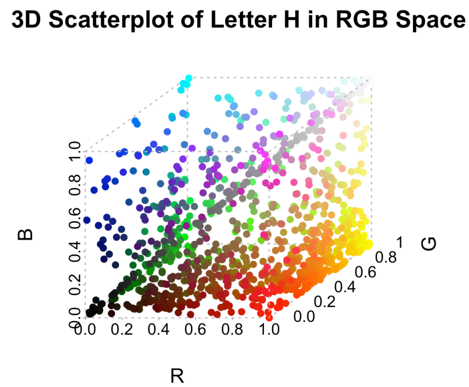
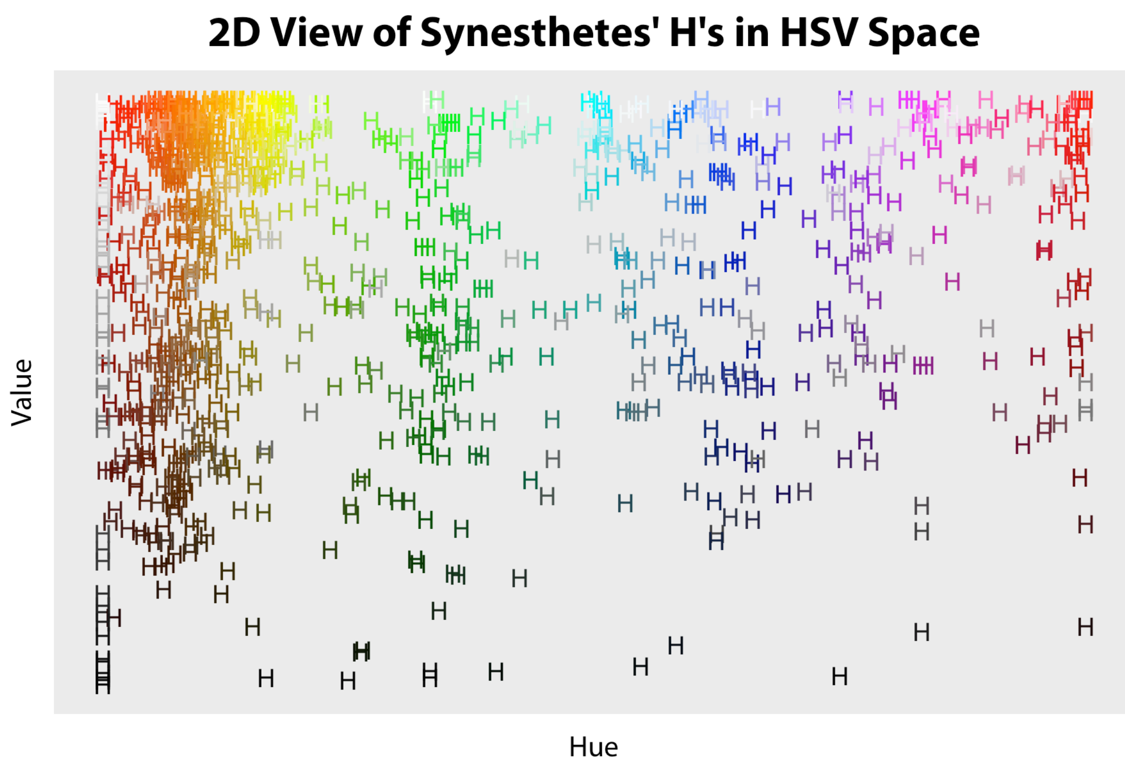
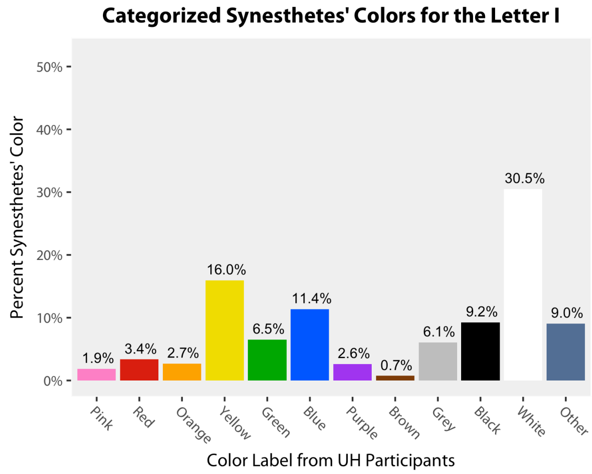
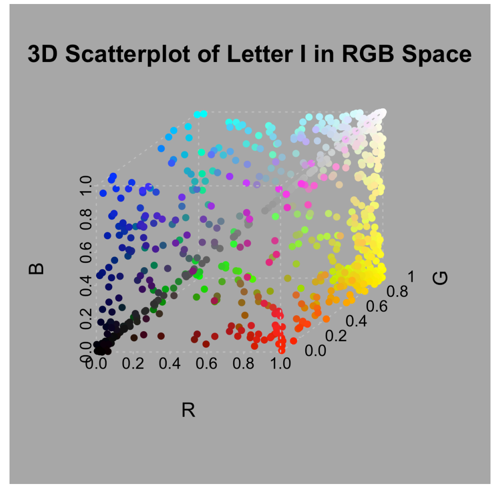
15.7%
12.8%
13.8%
8.3%
4.7%
9.5%
6.0%
2.0%
5.2%
11.1%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

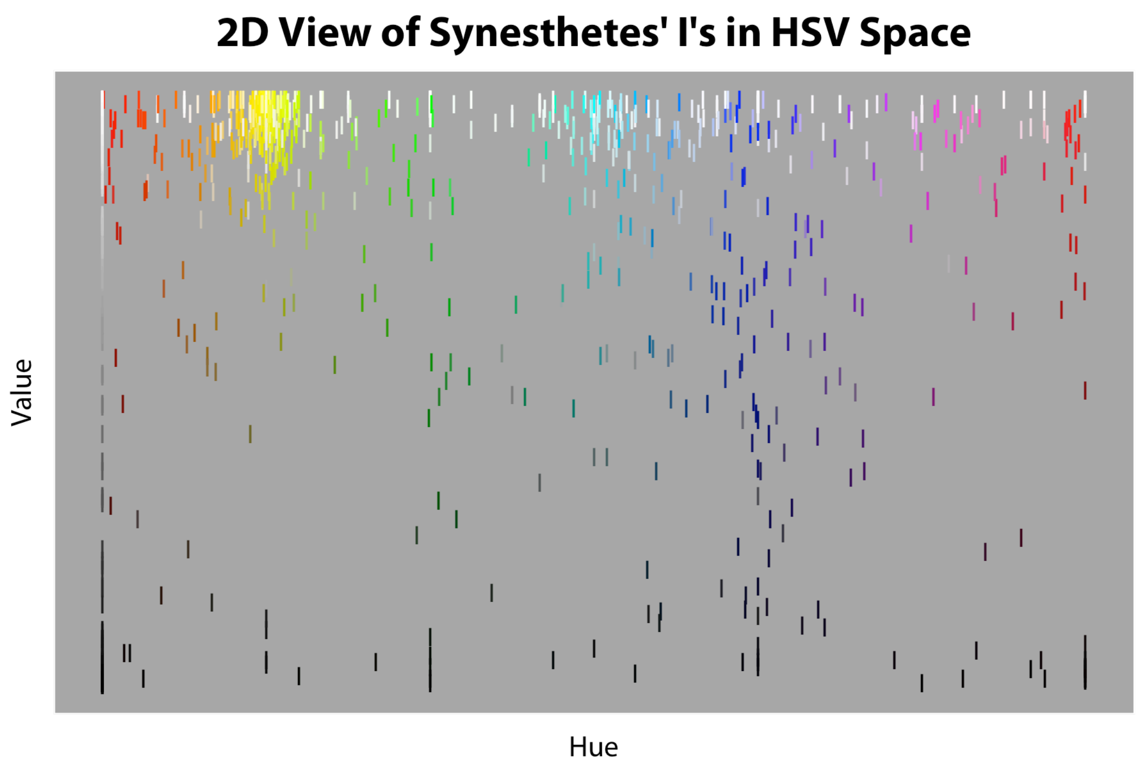

3D Scatterplot of Letter H in RGB Space
B
G
R
0.0
0.2
0.4
0.6
0.8
1.0


2D View of Synesthetes' H's in HSV Space
Value
Hue

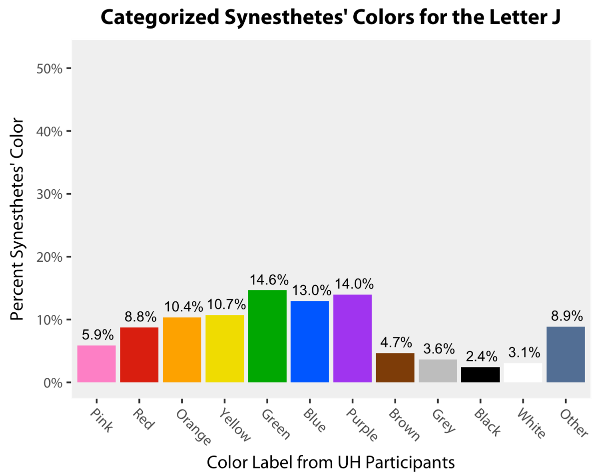
Letter I


Categorized Synesthetes' Colors for the Letter I
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
1.9%
3.4%
2.7%
16.0%
6.5%
11.4%
2.6%
0.7%
6.1%
9.2%
30.5%
9.0%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

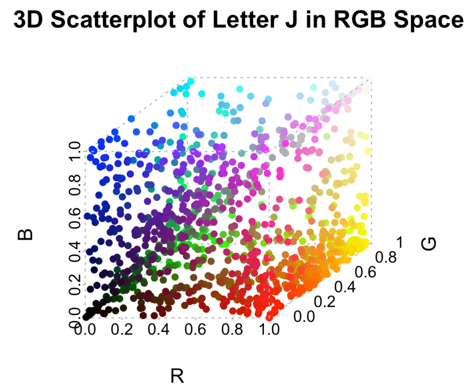

3D Scatterplot of Letter I in RGB Space
B
G
R
0.0 0.2 0.4 0.6 0.8 1.0


2D View of Synesthetes' I's in HSV Space
Value
Hue

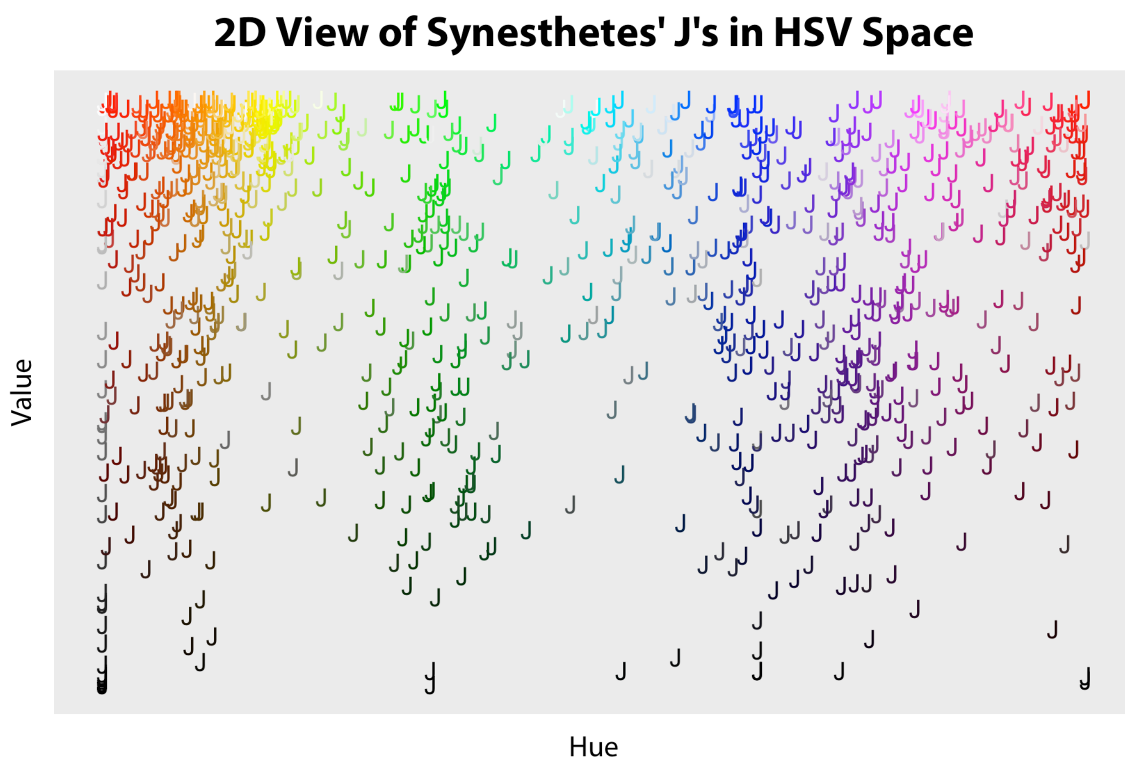
Letter J



Categorized Synesthetes' Colors for the Letter J
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
5.9%
8.8%
10.4%
10.7%
14.6%
13.0%
14.0%
4.7%
3.6%
2.4%
3.1%
8.9%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

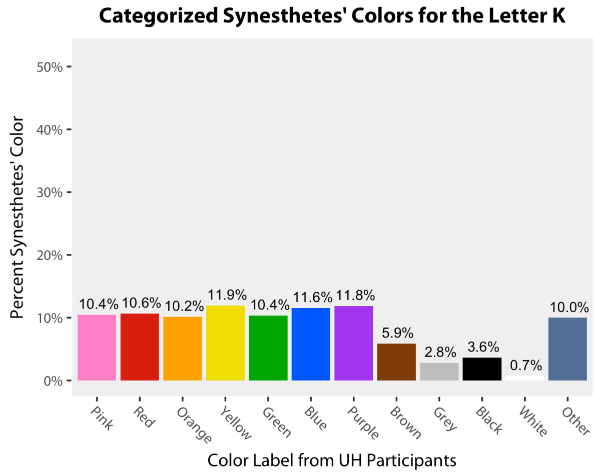


3D Scatterplot of Letter J in RGB Space
B
0.0 0.2 0.4 0.6 0.8 1.0
R
0.0 0.2 0.4 0.6 0.8 1.0
G
0.0 0.2 0.4 0.6 0.8 1

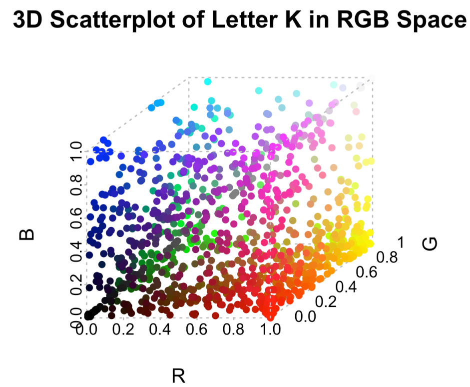


2D View of Synesthetes' J's in HSV Space
Value
Hue

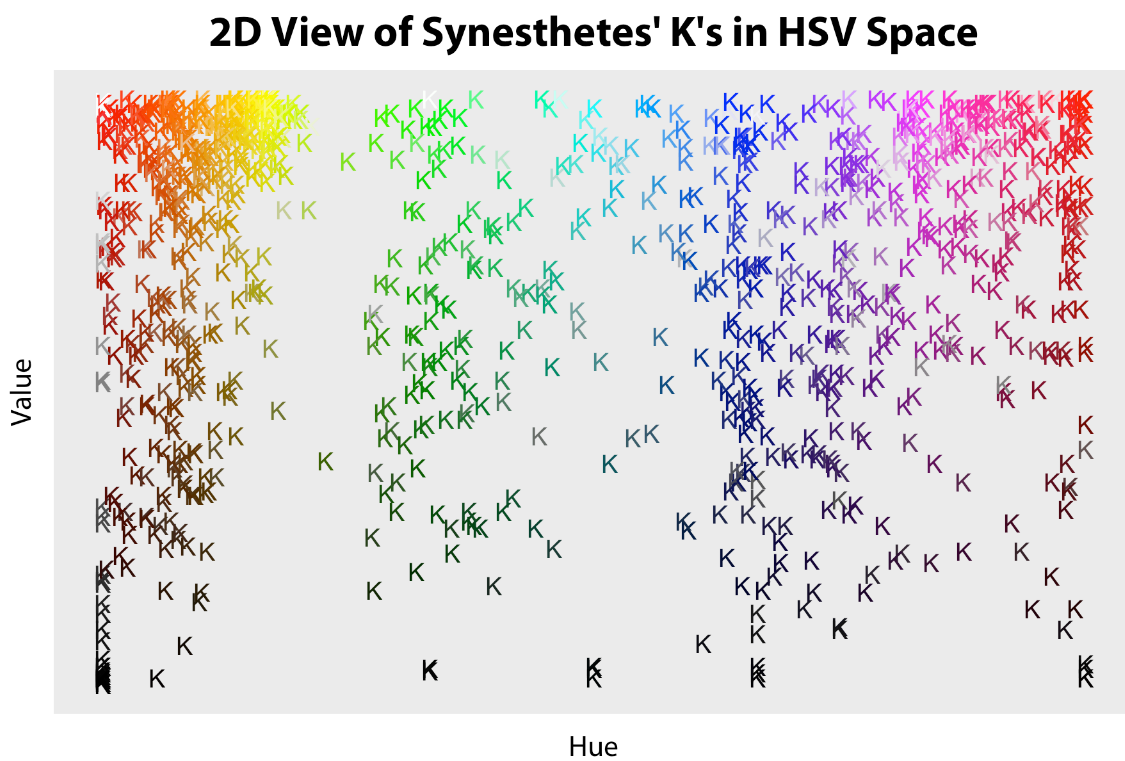
Letter K



Categorized Synesthetes' Colors for the Letter K
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
10.4%
10.6%
10.2%
11.9%
10.4%
11.6%
11.8%
5.9%
2.8%
3.6%
0.7%
10.0%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

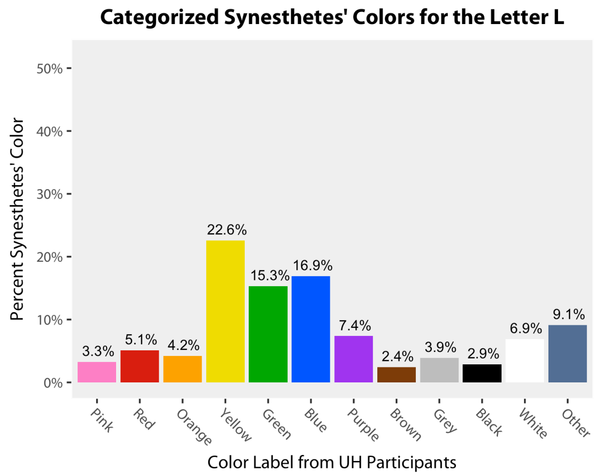


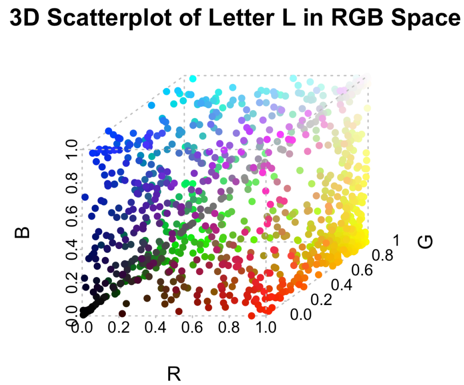
3D Scatterplot of Letter K in RGB Space
B
G
R
0.0 0.2 0.4 0.6 0.8 1.0

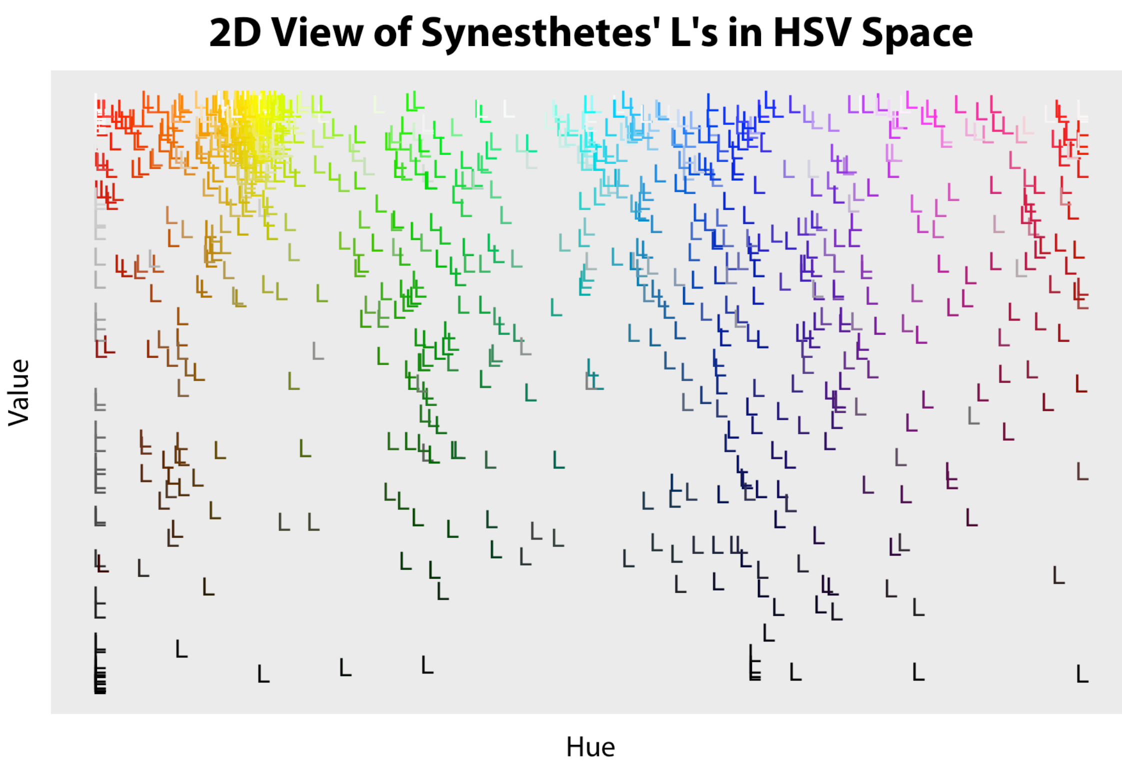


2D View of Synesthetes' K's in HSV Space
Value
Hue

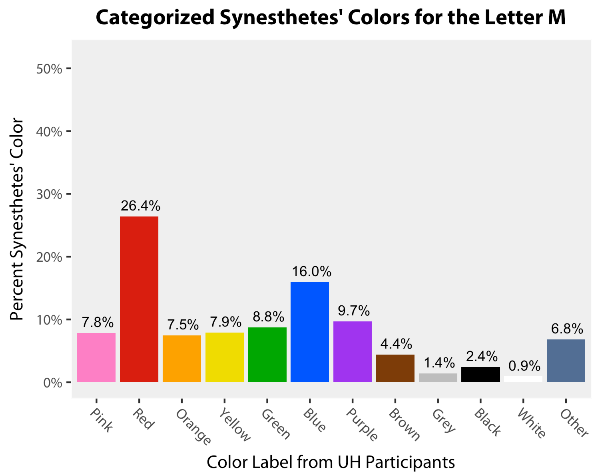
Letter L


Categorized Synesthetes' Colors for the Letter L
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
3.3%
5.1%
4.2%
22.6%
15.3%
16.9%
7.4%
2.4%
3.9%
2.9%
6.9%
9.1%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

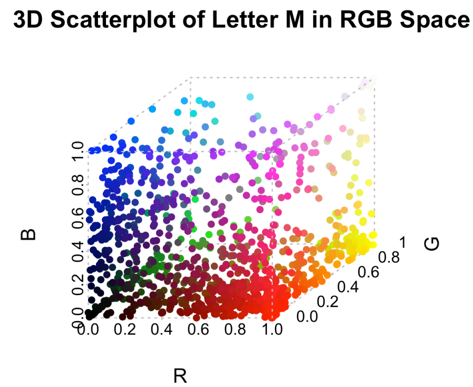

3D Scatterplot of Letter L in RGB Space
B
G
R


2D View of Synesthetes' L's in HSV Space
Value
Hue

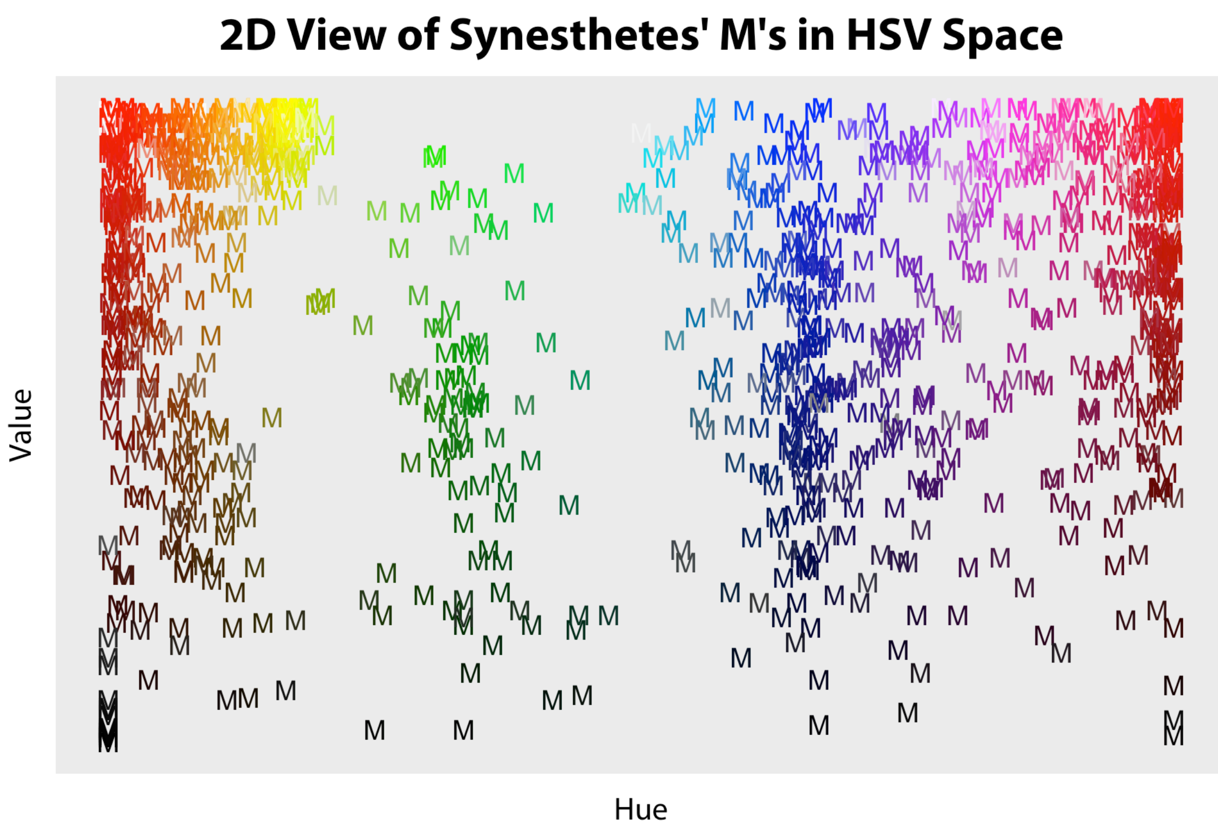
Letter M



Categorized Synesthetes' Colors for the Letter M
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
7.8%
26.4%
7.5%
7.9%
8.8%
16.0%
9.7%
4.4%
1.4%
2.4%
0.9%
6.8%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

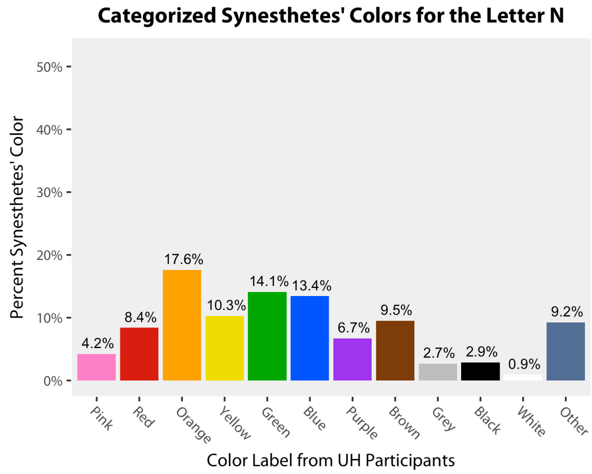


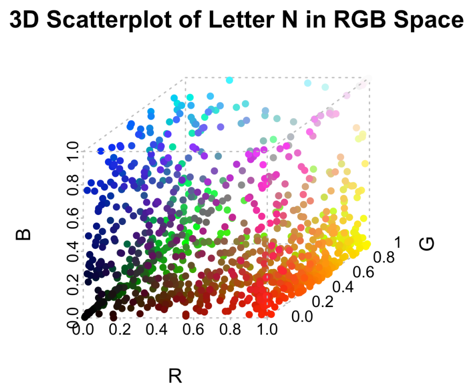
3D Scatterplot of Letter M in RGB Space
B
R
G

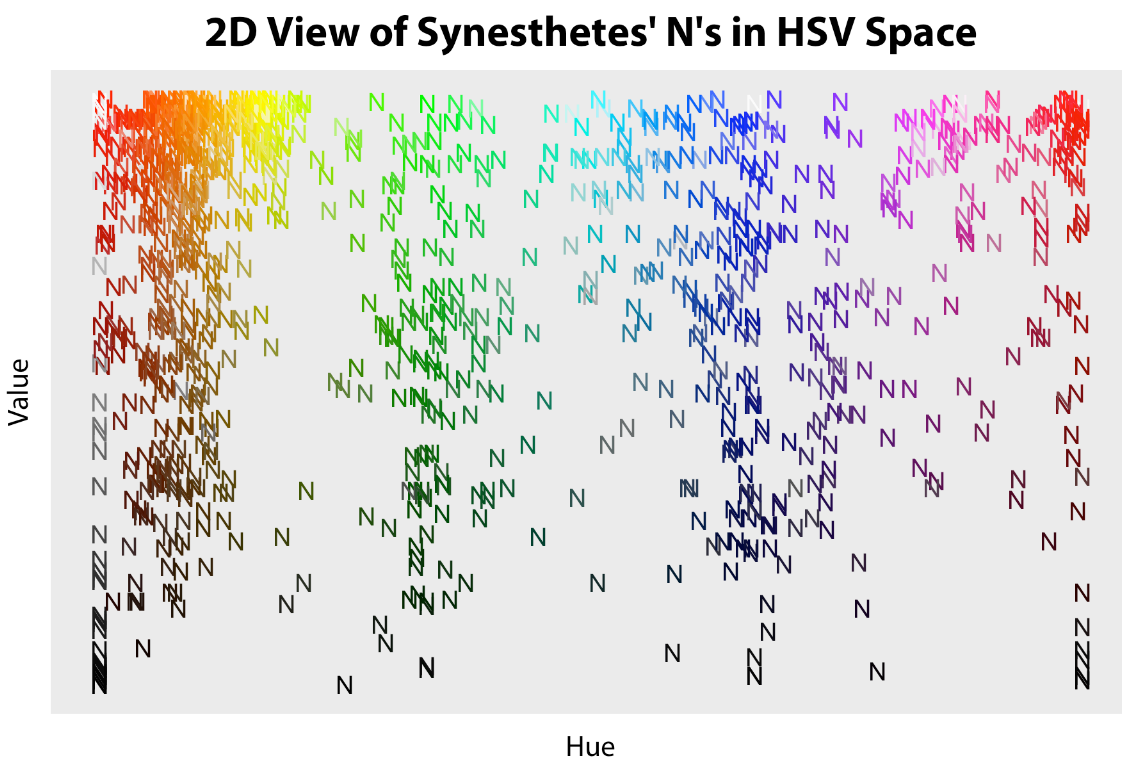


2D View of Synesthetes' M's in HSV Space
Value
Hue

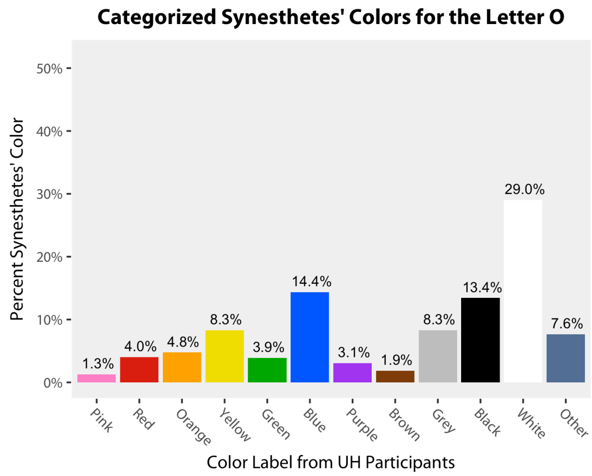
Letter N

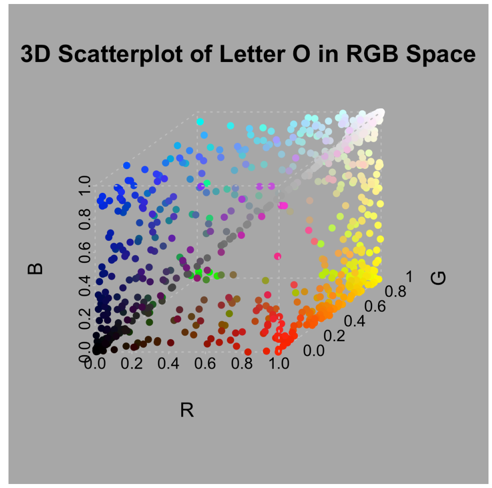

Categorized Synesthetes' Colors for the Letter N
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
4.2%
8.4%
17.6%
10.3%
14.1%
13.4%
6.7%
9.5%
2.7%
2.9%
0.9%
9.2%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

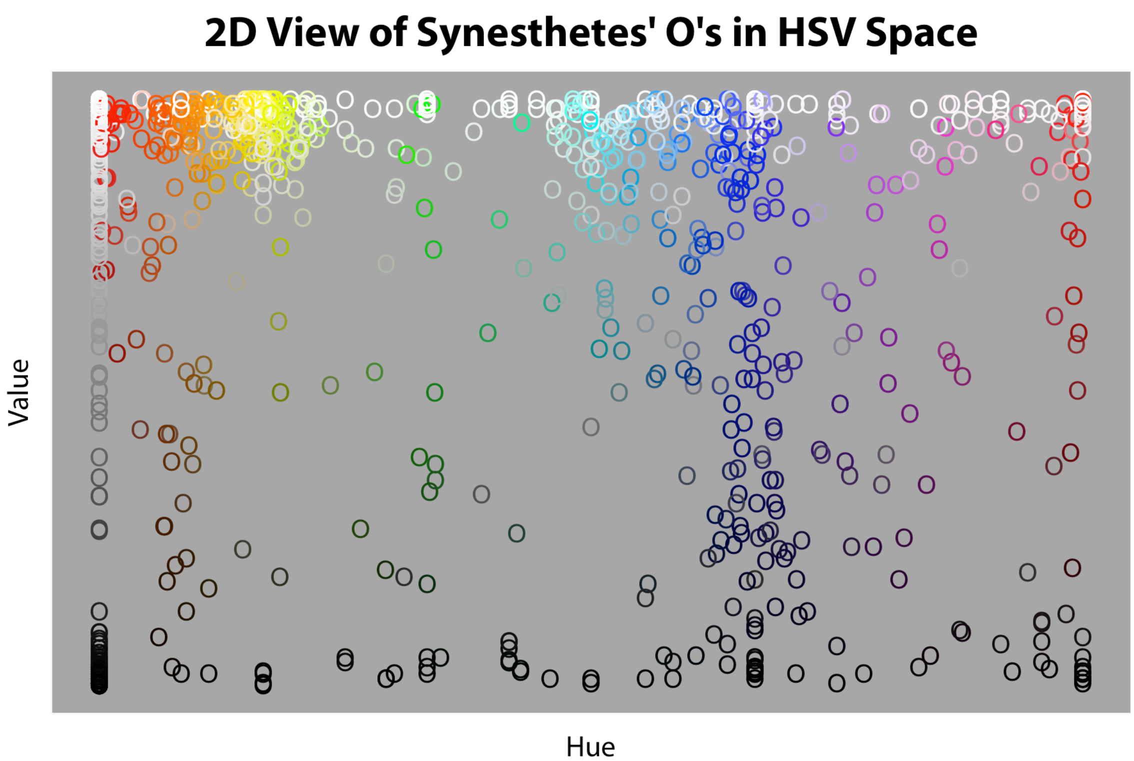

3D Scatterplot of Letter N in RGB Space
B
0.0 0.2 0.4 0.6 0.8 1.0
G
R


2D View of Synesthetes' N's in HSV Space
Value
Hue

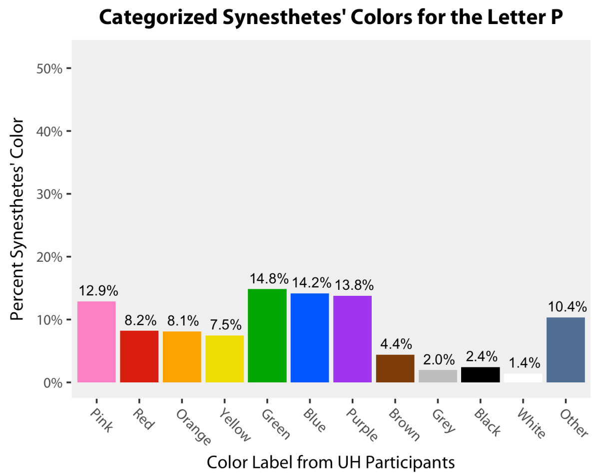
Letter O


Categorized Synesthetes' Colors for the Letter O
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
1.3%
4.0%
4.8%
8.3%
3.9%
14.4%
3.1%
1.9%
8.3%
13.4%
29.0%
7.6%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

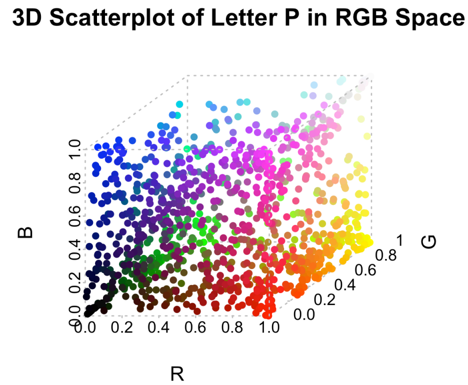

3D Scatterplot of Letter O in RGB Space
B
G
R


2D View of Synesthetes' O's in HSV Space
Value
Hue

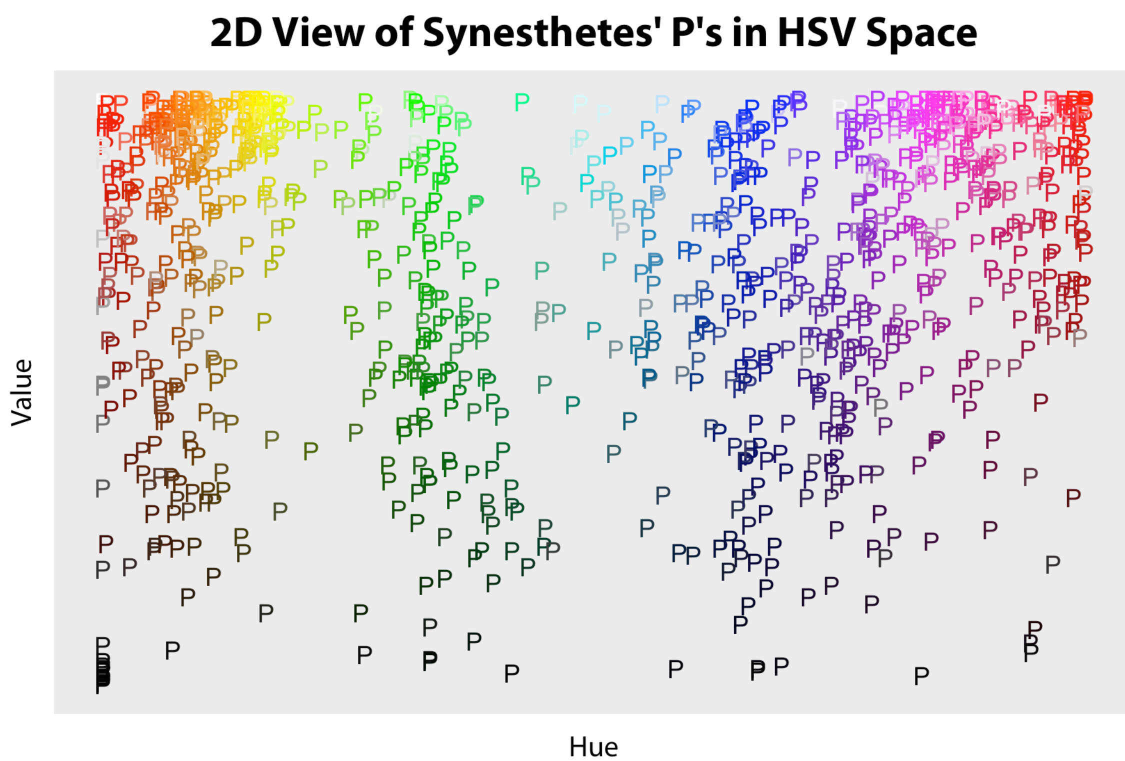
Letter P



Categorized Synesthetes' Colors for the Letter P
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
12.9%
8.2%
8.1%
7.5%
14.8%
14.2%
13.8%
4.4%
2.0%
2.4%
1.4%
10.4%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

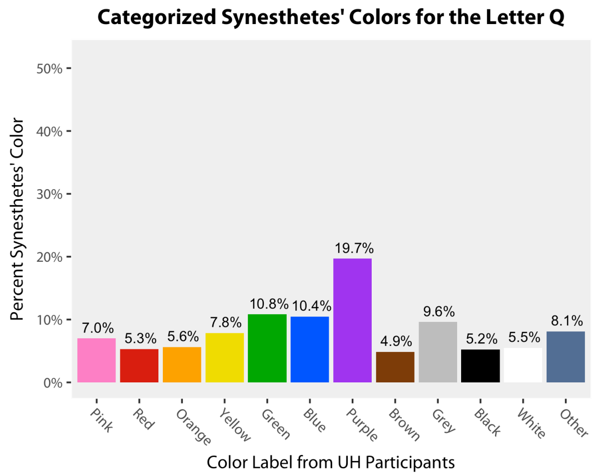


3D Scatterplot of Letter P in RGB Space
B
G
R
0.0 0.2 0.4 0.6 0.8 1.0

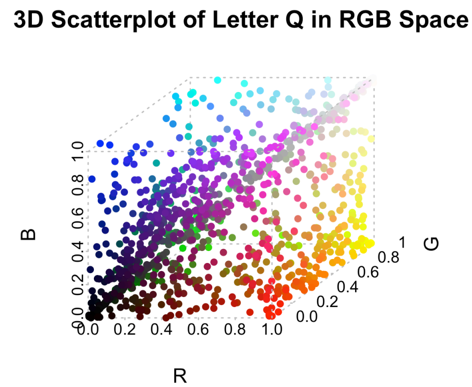


2D View of Synesthetes' P's in HSV Space
Value
Hue

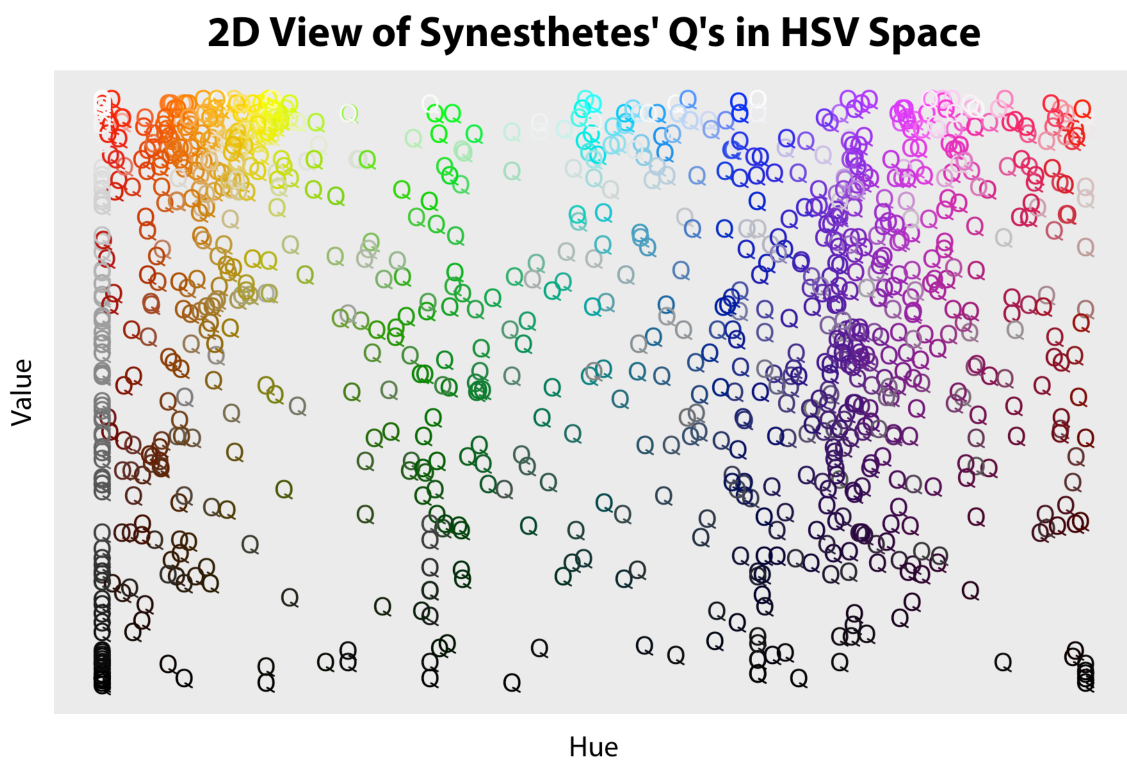
Letter Q



Categorized Synesthetes' Colors for the Letter Q
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
7.0%
5.3%
5.6%
7.8%
10.8%
10.4%
19.7%
4.9%
9.6%
5.2%
5.5%
8.1%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

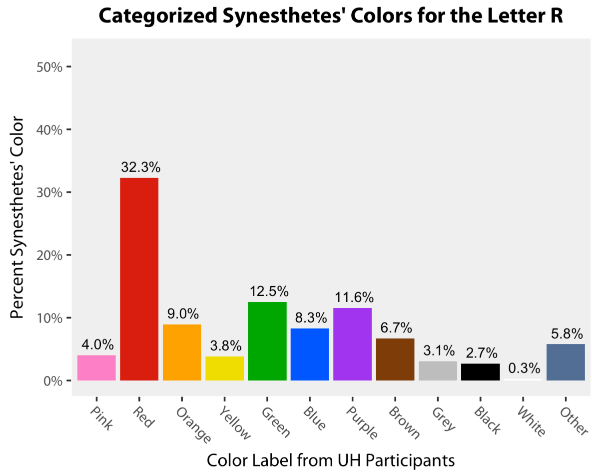


3D Scatterplot of Letter Q in RGB Space
B
G
R

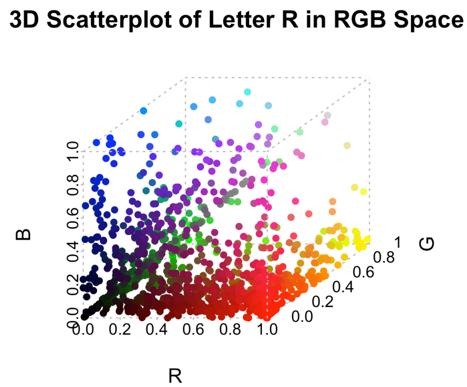


2D View of Synesthetes' Q's in HSV Space
Value
Hue

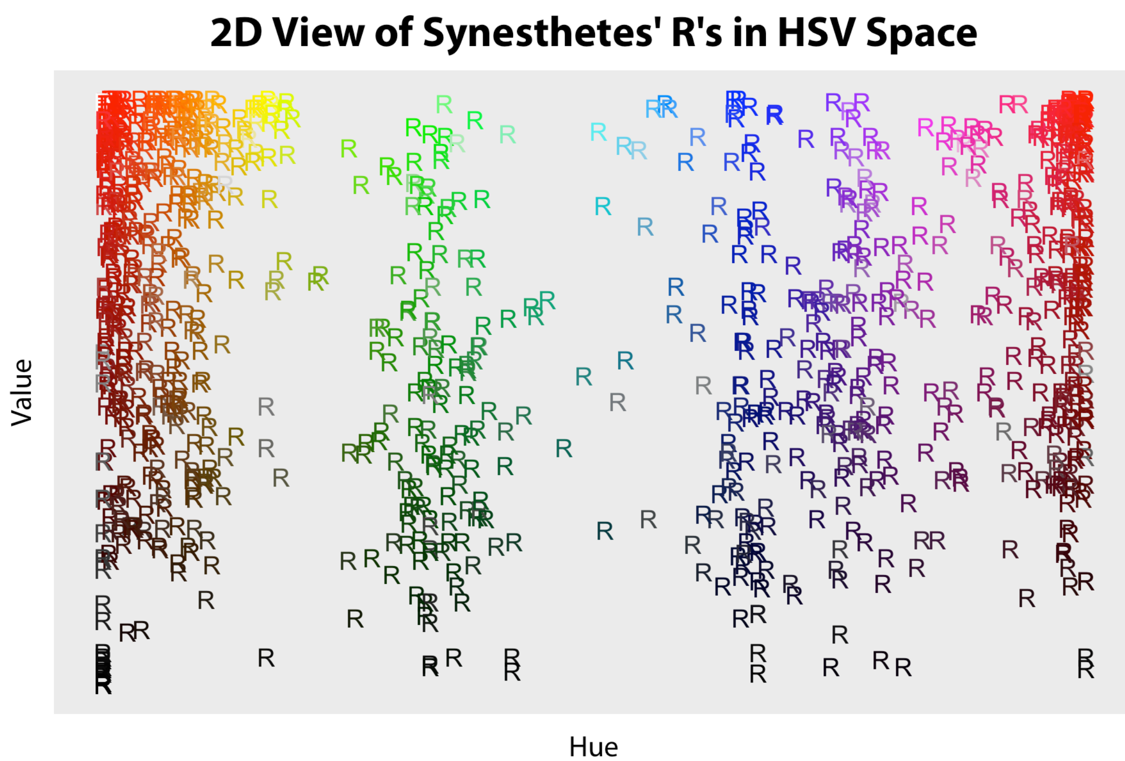
Letter R



Categorized Synesthetes' Colors for the Letter R
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
4.0%
32.3%
9.0%
3.8%
12.5%
8.3%
11.6%
6.7%
3.1%
2.7%
0.3%
5.8%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

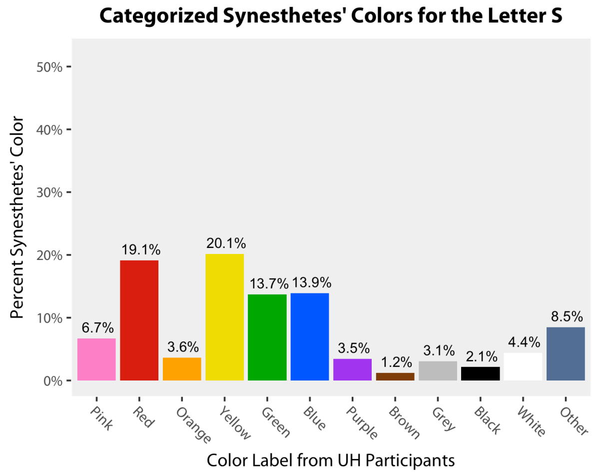


3D Scatterplot of Letter R in RGB Space
B
0.0
0.2
0.4
0.6
0.8
1.0
R
0.0
0.2
0.4
0.6
0.8
1.0
G
0.0
0.2
0.4
0.6
0.8
1



2D View of Synesthetes' R's in HSV Space
Value
Hue

Letter S



Categorized Synesthetes' Colors for the Letter S
Percent Synesthetes' Color
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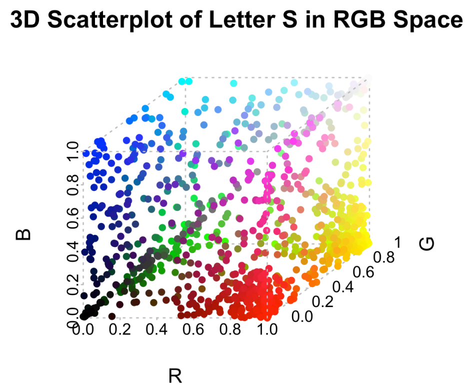
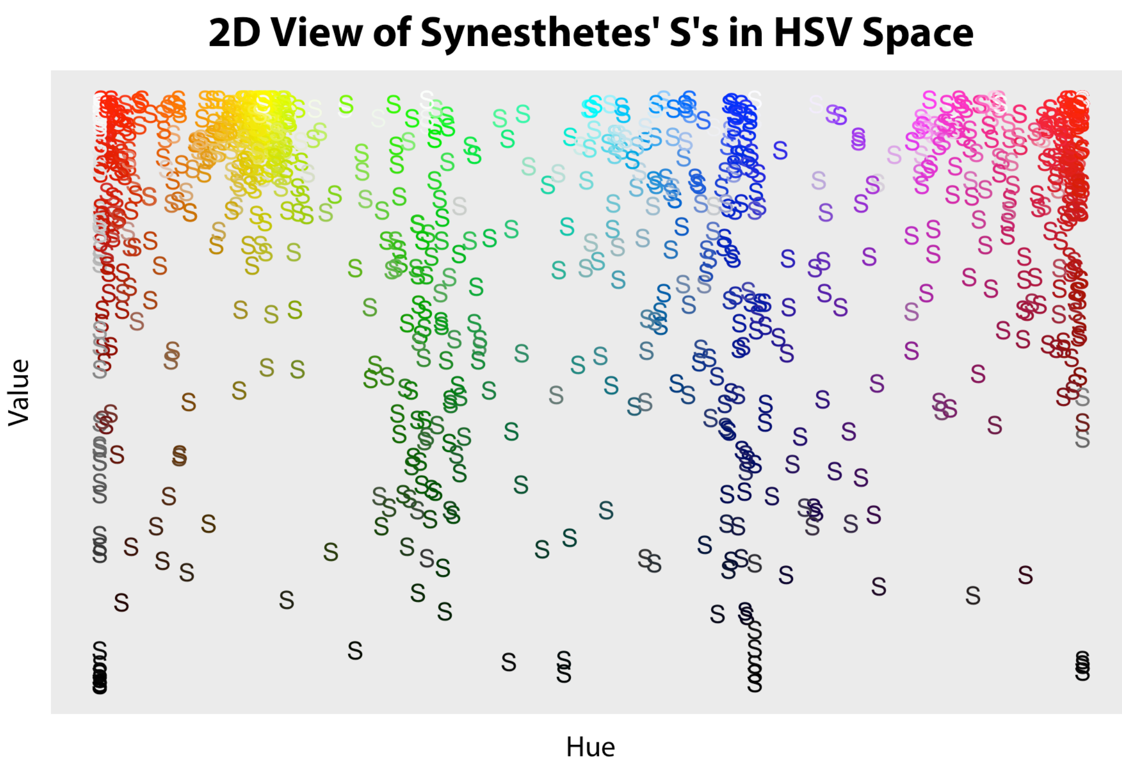
40%
30%
20%
10%
0%
6.7%
19.1%
3.6%
20.1%
13.7%
13.9%
3.5%
1.2%
3.1%
2.1%
4.4%
8.5%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

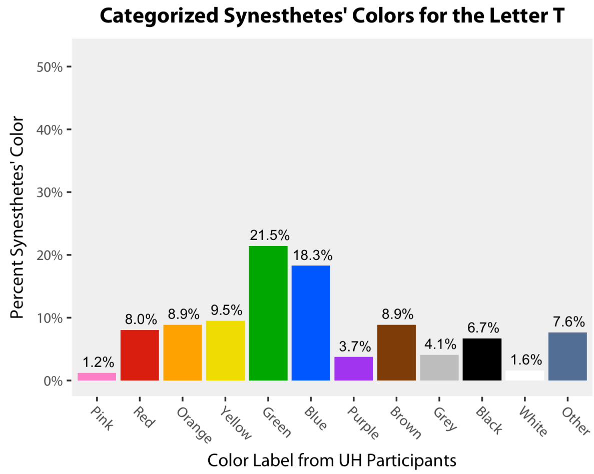


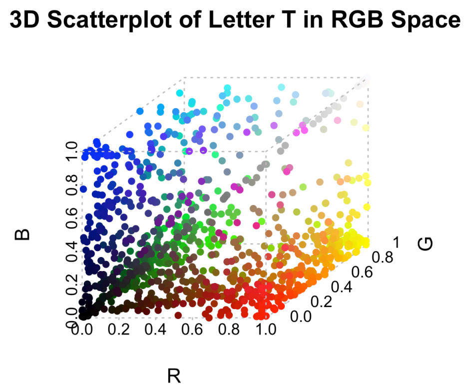
3D Scatterplot of Letter S in RGB Space
B
R
G
0.0 0.2 0.4 0.6 0.8 1.0

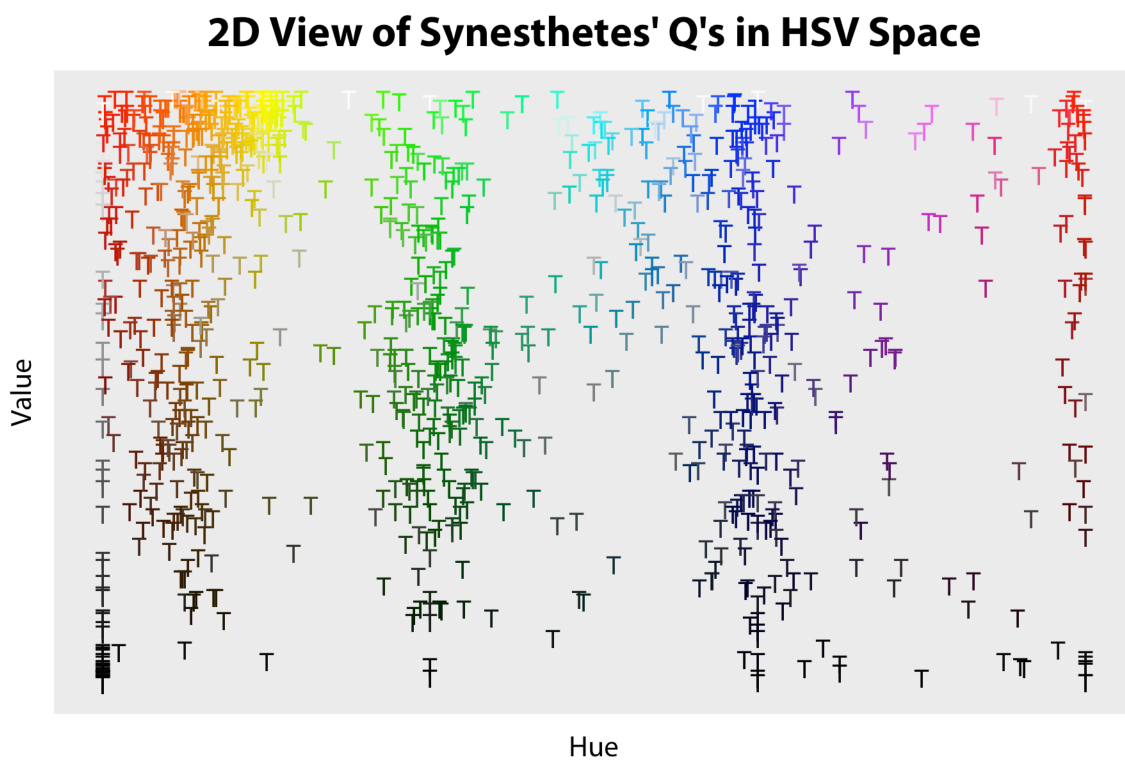


2D View of Synesthetes' S's in HSV Space
Value
Hue

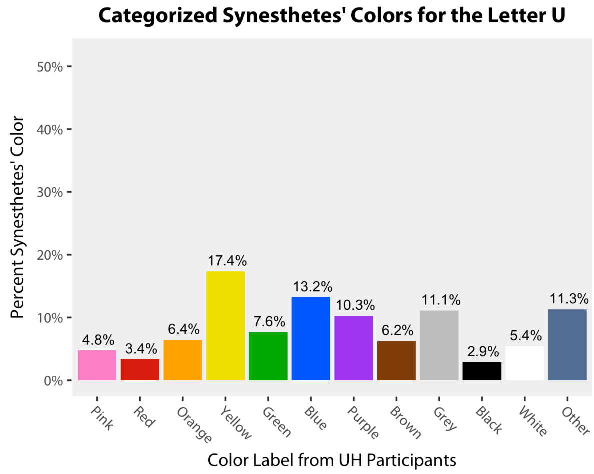
Letter T


Categorized Synesthetes' Colors for the Letter T
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
1.2%
8.0%
8.9%
9.5%
21.5%
18.3%
3.7%
8.9%
4.1%
6.7%
1.6%
7.6%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

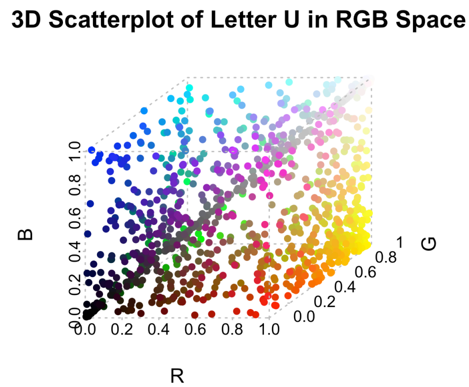

3D Scatterplot of Letter T in RGB Space
B
G
R
0.0
0.2
0.4
0.6
0.8
1.0


2D View of Synesthetes' Q's in HSV Space
Value
Hue

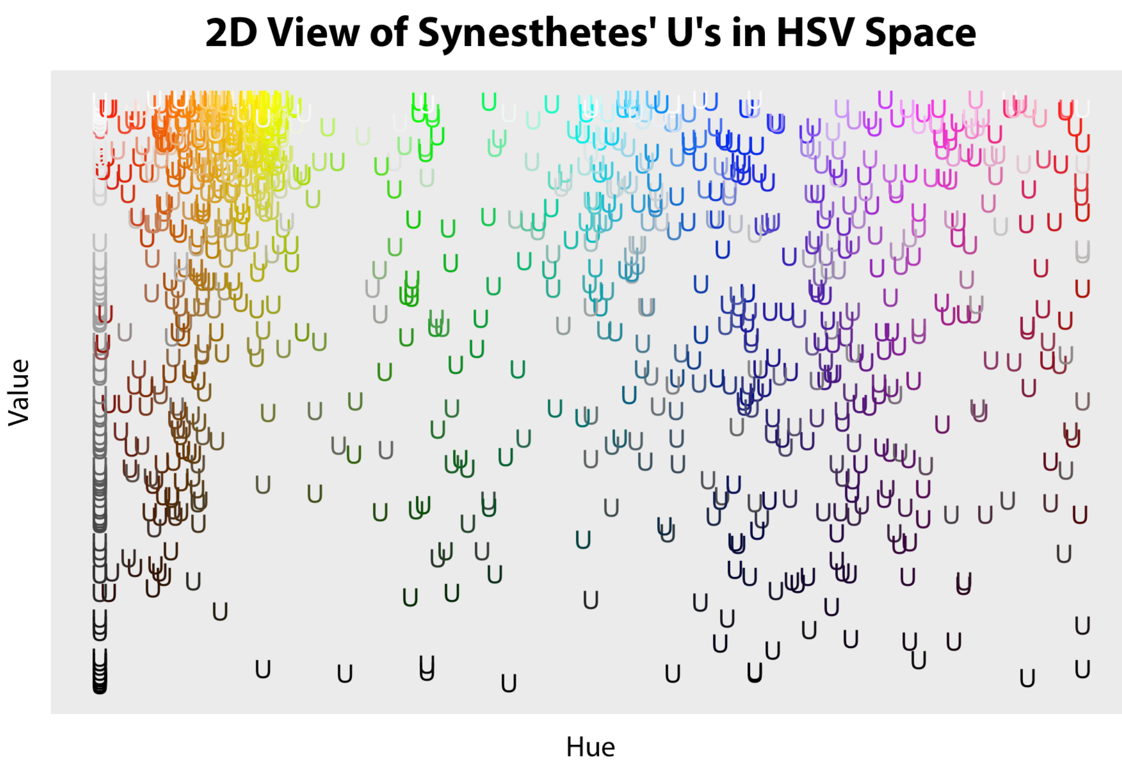
Letter U



Categorized Synesthetes' Colors for the Letter U
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
4.8%
3.4%
6.4%
17.4%
7.6%
13.2%
10.3%
6.2%
11.1%
2.9%
5.4%
11.3%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

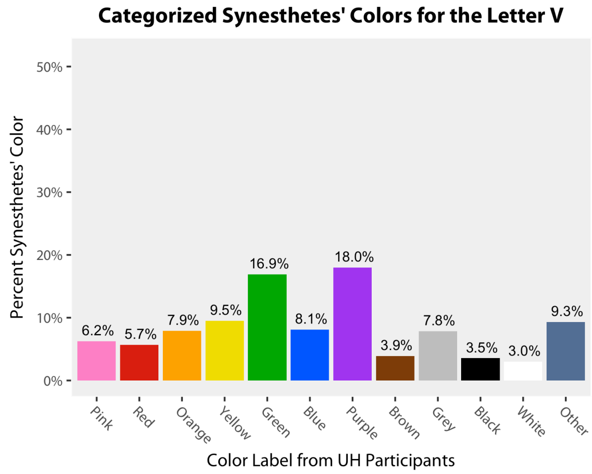


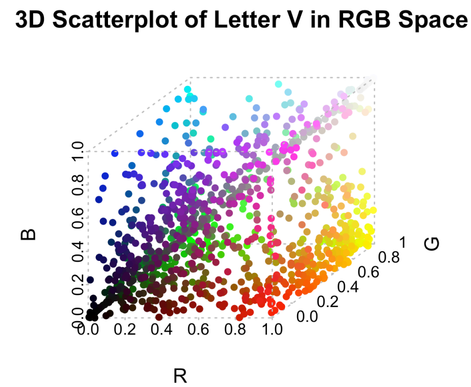
3D Scatterplot of Letter U in RGB Space
B
G
R
0.0 0.2 0.4 0.6 0.8 1.0

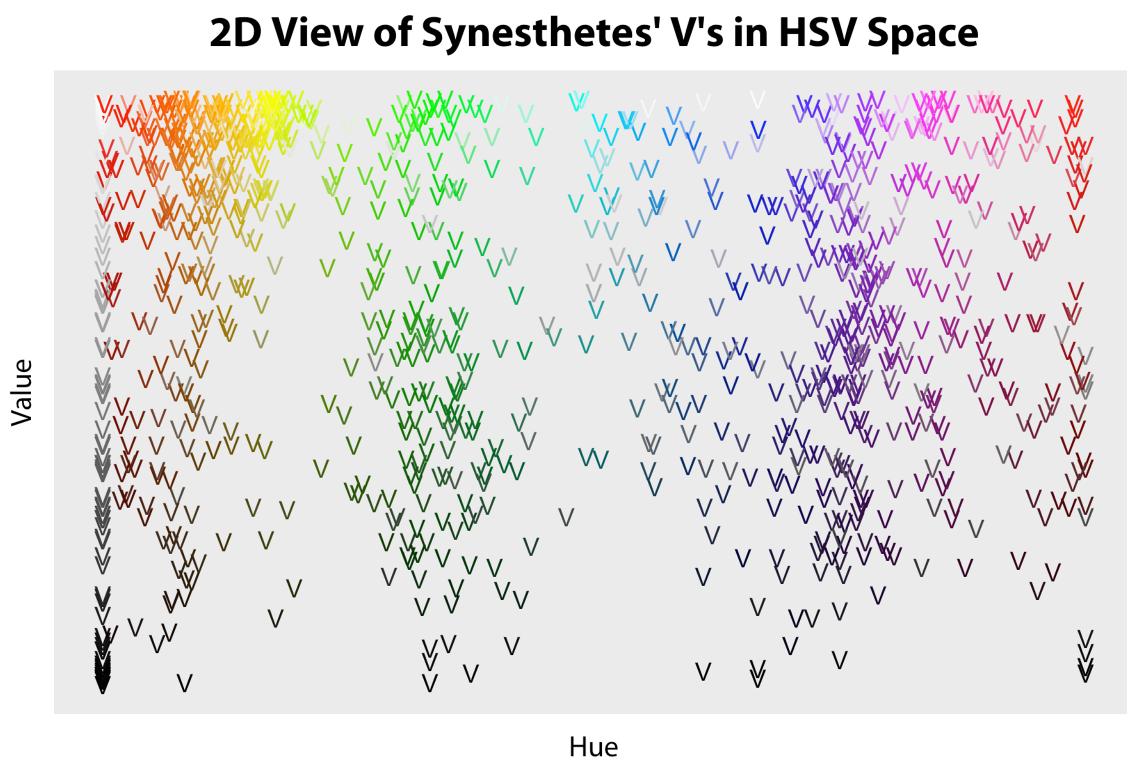


2D View of Synesthetes' U's in HSV Space
Value
Hue

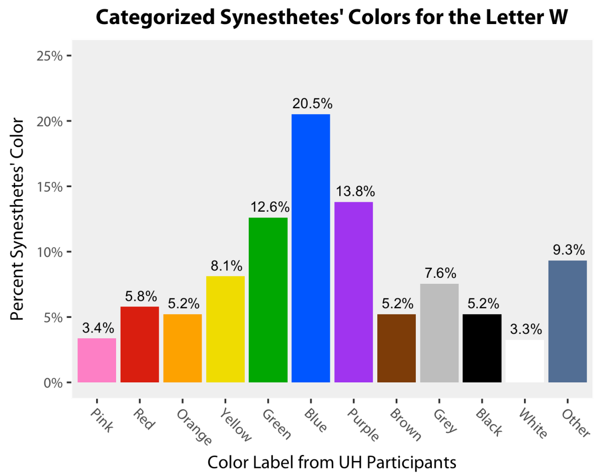
Letter V


Categorized Synesthetes' Colors for the Letter V
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
6.2%
5.7%
7.9%
9.5%
16.9%
8.1%
18.0%
3.9%
7.8%
3.5%
3.0%
9.3%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

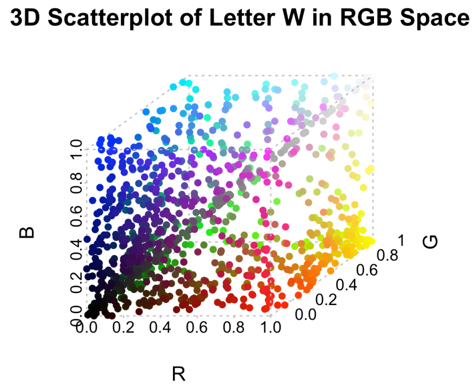

3D Scatterplot of Letter V in RGB Space
B
G
R
0.0
0.2
0.4
0.6
0.8
1.0


2D View of Synesthetes' V's in HSV Space
Value
Hue

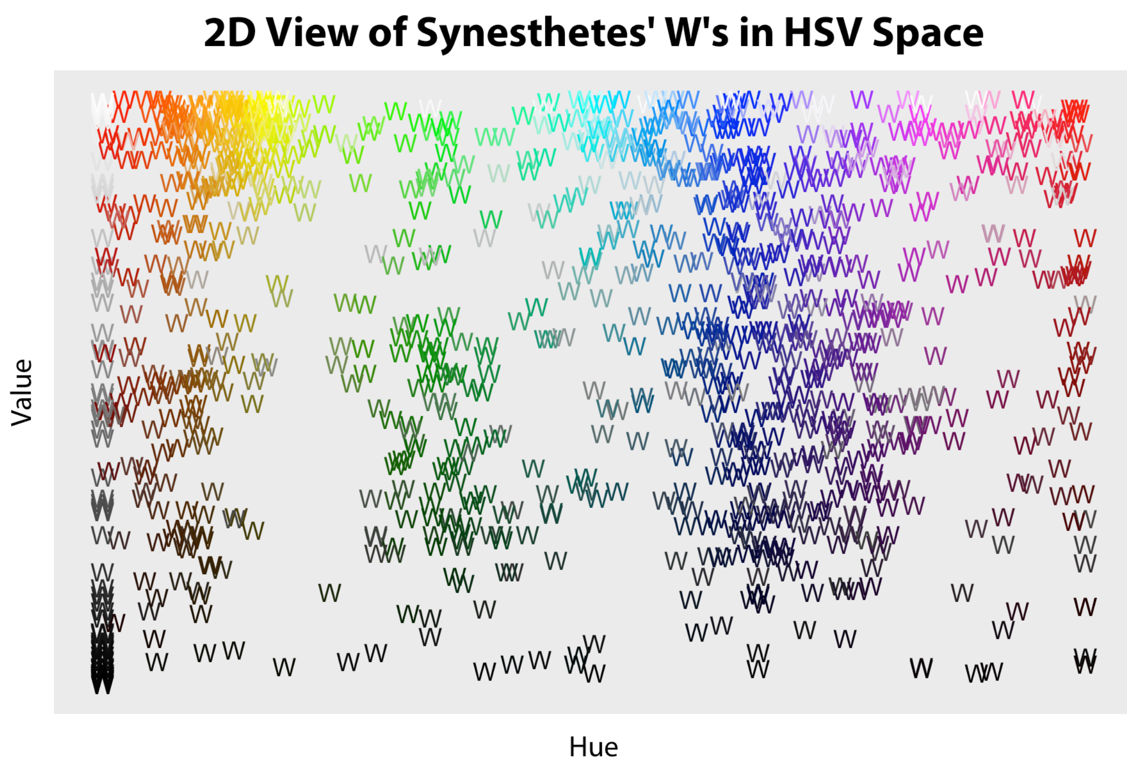
Letter W



Categorized Synesthetes' Colors for the Letter W
Percent Synesthetes' Color
25%
20%
15%
10%
5%
0%
3.4%
5.8%
5.2%
8.1%
12.6%
20.5%
13.8%
5.2%
7.6%
5.2%
3.3%
9.3%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

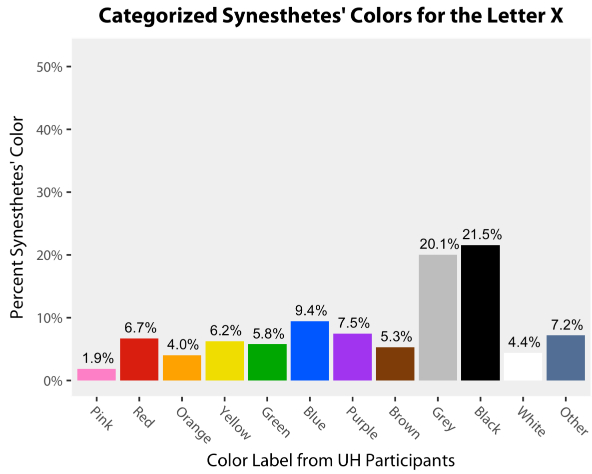


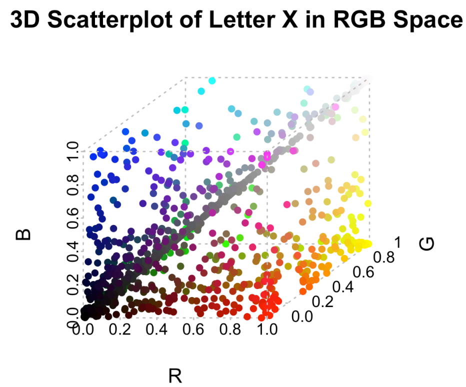
3D Scatterplot of Letter W in RGB Space
B
0.0 0.2 0.4 0.6 0.8 1.0
R
G
0.0 0.2 0.4 0.6 0.8 1

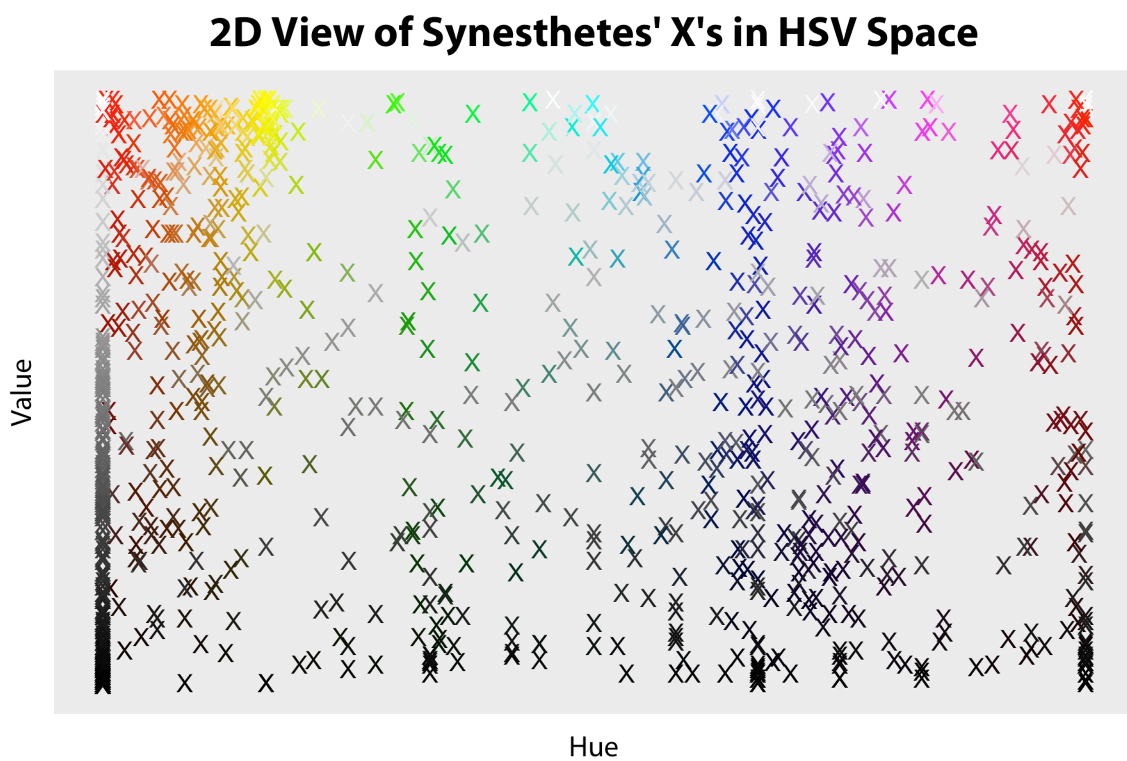


2D View of Synesthetes' W's in HSV Space
Value
Hue

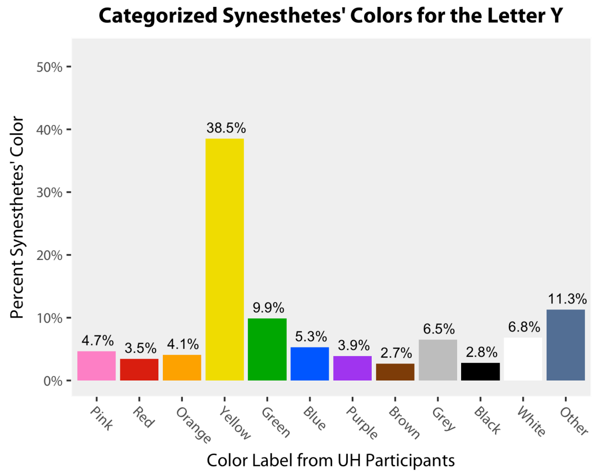
Letter X

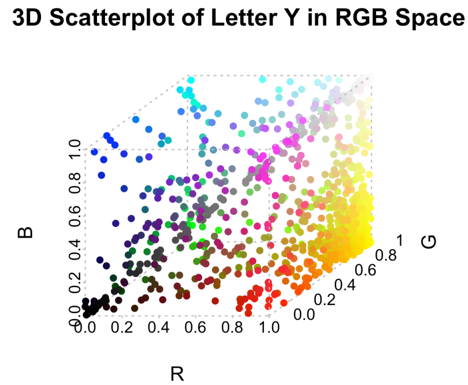

Categorized Synesthetes' Colors for the Letter X
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
1.9%
6.7%
4.0%
6.2%
5.8%
9.4%
7.5%
5.3%
20.1%
21.5%
4.4%
7.2%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

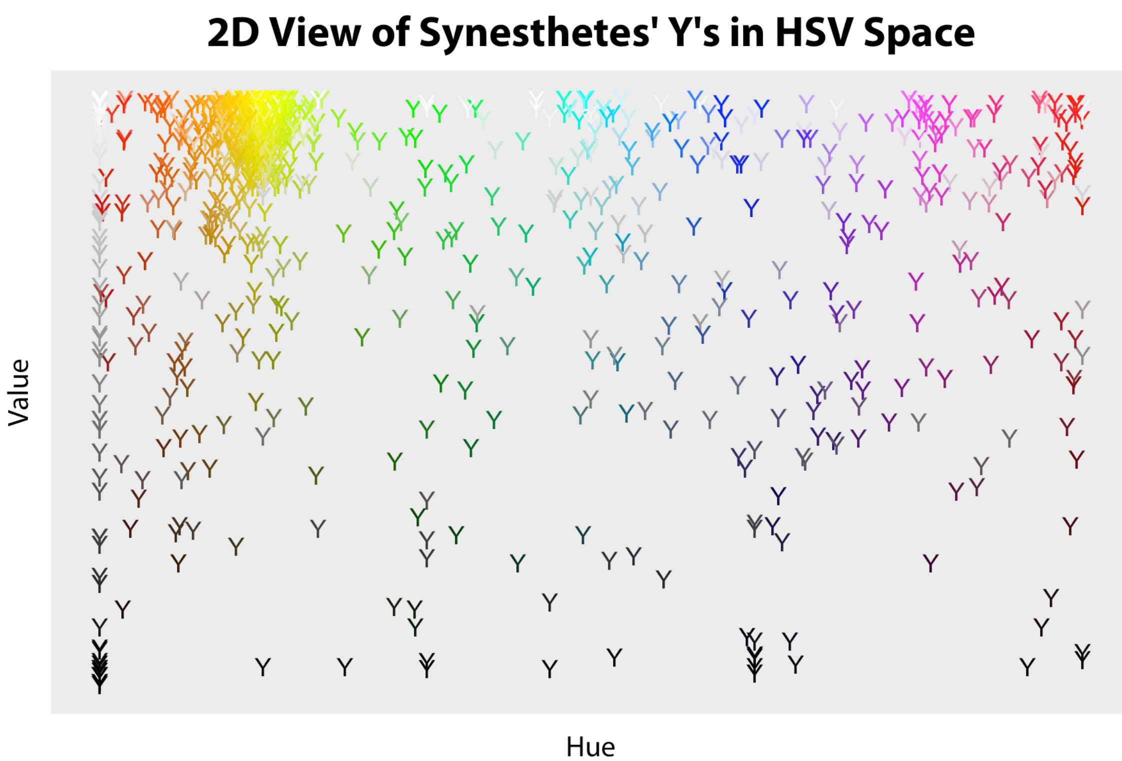

3D Scatterplot of Letter X in RGB Space
B
0.0
0.2
0.4
0.6
0.8
1.0
R
0.0
0.2
0.4
0.6
0.8
1.0
G
0.0
0.2
0.4
0.6
0.8
1


2D View of Synesthetes' X's in HSV Space
Value
Hue

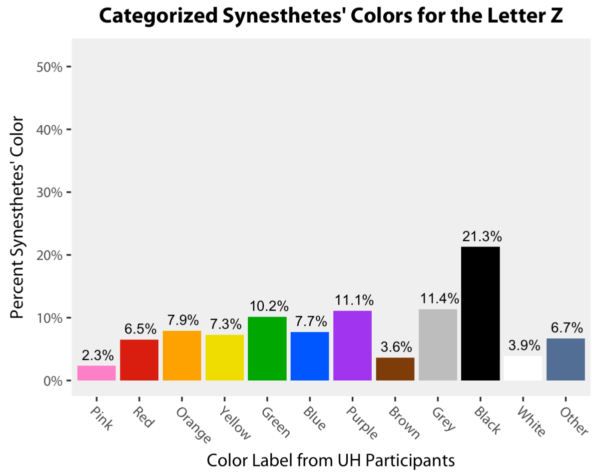
Letter Y

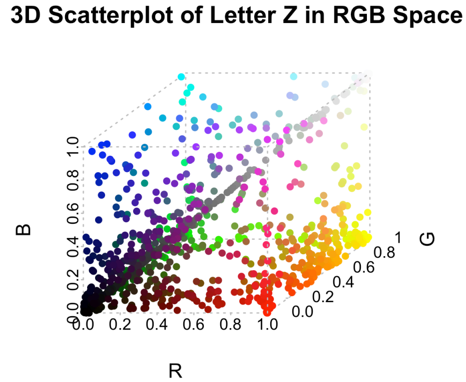

Categorized Synesthetes' Colors for the Letter Y
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
4.7%
3.5%
4.1%
38.5%
9.9%
5.3%
3.9%
2.7%
6.5%
2.8%
6.8%
11.3%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants

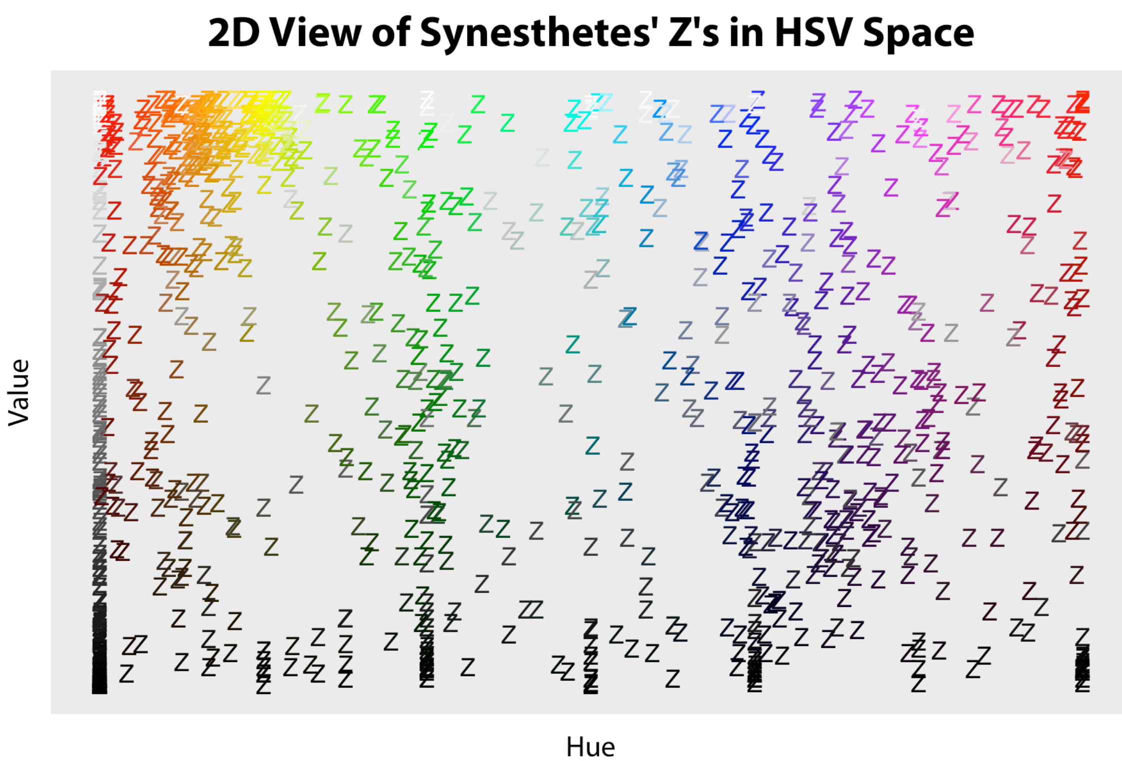

3D Scatterplot of Letter Y in RGB Space
B
0.0 0.2 0.4 0.6 0.8 1.0
R
0.0 0.2 0.4 0.6 0.8 1.0
G
0.0 0.2 0.4 0.6 0.8 1


2D View of Synesthetes' Y's in HSV Space
Value
Hue

Letter Z


Categorized Synesthetes' Colors for the Letter Z
Percent Synesthetes' Color
50%
40%
30%
20%
10%
0%
2.3%
6.5%
7.9%
7.3%
10.2%
7.7%
11.1%
3.6%
11.4%
21.3%
3.9%
6.7%
Pink
Red
Orange
Yellow
Green
Blue
Purple
Brown
Grey
Black
White
Other
Color Label from UH Participants


3D Scatterplot of Letter Z in RGB Space
B
0.0 0.2 0.4 0.6 0.8 1.0
R
G
0.0 0.2 0.4 0.6 0.8 1


2D View of Synesthetes' Z's in HSV Space
Value
Hue

Exit Questionnaire

Thank you for participating in this study! Before you leave if you could please give us a few comments about your experience we would greatly appreciate it.

1. How difficult was it for you to decide if the colors matched the words?

Easy Medium Difficult

2. Do you believe you have any experiences or conditions that might have had a significant impact on your responses?

3. Is there anything else the researchers could have done to make the experience more comfortable or enjoyable for you?

4. Do you have any other comments that might be useful to the researcher?

If you think of any other feedback after leaving the study, please feel free to contact us at mvwarner@uh.edu

This project has been reviewed by the University of Houston Committee for the Protection of Human Subjects (713) 743-9204

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