Will it Blend? 2

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Abstract

Color is a phenomenon that depends heavily on human perception, however not all people perceive color the same way. In the human-computer interaction field, when it comes to represent more complex data, color blending became an alternative comparing to other similar techniques. However, there are some aspects about color blending that haven't been studied before. Our main goal is to study the influence of the Brightness component on color blending, while testing the users' perception on different color blending techniques. In order to do so, a testing interface was created to study if given two initial colors, users can perceive the Brightness of the mixed color between the two. In our study, we have focused on the analysis of the results obtained from the user study. We have found that, overall, intermediate values of Brightness were the ones users perceived better, and also that adjacent color blends are better perceived than equidistant blends in the HSV circle.
Keywords: Color, Color Blending, Perception, Brightness, InfoVis

1. Introduction

Color is a part of people's everyday lives, it can be found in nature, in city buildings and even in all objects. Color can be used to distinguish similar things, to draw attention or to stand out, to stimulate and also to label something. However, not all people have the same color perception. Cultural, geographical and genetic aspects can be the reason for this to occur. Color blindness is a color vision deficiency and it is yet another example to corroborate that not all people perceive colors the same way.

Although color is now defined in established color models, it was not always like that. It all began with members of Aristitoles' Peripatetic school in Ancient Greece studying the behaviour of color in nature. Later the studies continued with Isaac Newton discovering the colors in the light spectrum by pointing a light through a prism, leading to the first experiments with color blending.

Nowadays with the technological advancements and new extended studies, color became an important tool used to improve, for instance, the relationship between the users and the computer interface. The need for this kind of improvements has led to new levels of research regarding color, which is the case of color blending. Color blending is the technique of blending two or more colors in order to create a different one. Most of the people had their first experiments with painting and color blending in early childhood, by creating new colors, mixing the fewer ones they had in their color palette. To perform color blending, it is necessary to understand the relationships between colors, since the wrong combination of colors can influence the visual experience of the user.

Lately, color blending has been used for many different purposes, but mainly to represent more complex data in the most various fields of work.

However, some of the color blending studies performed did not reach definitive conclusions regarding color models and appropriate colors to be used in blends. One of the reasons why this happens is because not all people have the same color perception, which makes it hard to define a single color model that fits the general human perception. Alternative techniques were studied to address these problems, although the procedure is different from the technique we are studying, the outcome is similar, and in some occasions the alternative ones even perform better than color blending, which is the case of color weaving [6].

With our work, we are going to continue the studies made on color blending, through the analysis of previously studied color blending techniques and through the development of a user study focused on the Brightness component of the HSV color model.

1.1. Objectives

Our main goal is to **study the influence of the Brightness component on color blending, while testing the users' perception on**

different color blending techniques, through the analysis of the results from a user study conducted by us. In addition to our main goal, we expect to draw some conclusions relatively to the user's demographic and geographical aspects. And, also to discover which is the best Brightness level to use when performing Brightness color blending techniques.

To achieve this goal and answer the questions, it was necessary to do a research on color blending and color blending techniques and to also understand how the distinct components of color influence the human perception, in particularly, the Brightness component, since the research done on this subject has been more focused on the Hue component.

To create our study, we developed a user testing interface, so that the participants of the study could perform the tests. We opted for a presential study, so we can control the variables of the testing environment. Our user study was separated into four steps: a screen calibration, a demographic questionnaire, a color deficiency test and finally a color blending test.

2. Background

In this section, we will start by a theoretical approach, covering important color concepts for our study. Then, we will present our research by addressing the previous work done on color blending.

2.1. Color Perception

Color can generate multiple stimulus and sensations in the human brain. But the truth is that people's perception of color is subjective, which means that everyone has a different perception of color. There are cultural, geographical and genetical aspects that can be the reason for this to occur.

The human vision is one of our most important senses, it allows us to adapt to certain lights, to have a depth perception and to distinguish multiple colors. The human eye perceives light when it reaches the lens and the cornea and strikes the inner surface of the eye known as the retina. The retina is responsible for receiving the light and converting it to chemical and nervous signals with the help of photo-receptor cells: the cones and the rods. There are 3 types of cones: the S-cones, which have small wavelength sensitivity and deal with blue perception; M-cones which correspond to green color perception and have medium wavelength sensitivity and finally the L-cones, which have large wavelength sensitivity and deal with red color.

Having a color vision deficiency means that an individual lacks of one or more cones explained above. There are several types of color vision deficiencies, while most of them are genetically inherited, others can be appear with age, through the use of medication or can even be developed with diseases or injuries, since a damage in the retina or in the optic nerve can cause the loss of color recognition.

2.2. Color Basic Concepts

To fully comprehend our research and the color representations presented in the following sections of the work, it is important to understand some basic color concepts.

The color wheel is a familiar diagram used to display color. The first circled diagram was created by Isaac Newton, in 1666, when he conducted his studies on the behaviour of light. By pointing light through a prism, he was able to discover the colors in the light spectrum, in which he transformed into a circle, displaying the colors with an asymmetric distance. The primary colors were first considered to be Red, Blue and Green, by German poet Wolfgang von Goethe, who created an iteration of the color wheel we often use today [4]. The secondary colors are the colors achieved by a mixture of two primary colors, which are Orange, Green and Purple. And tertiary colors are created by a mixture of primary and secondary colors.

2.3. Color Models

Color models are visual representations of the color spectrum, which can have different properties as a foothold depending on the model. But their main advantage is that it becomes easier to find and use a certain color when working with computers, for example.

Color models can be classified in two different methods: additive and subtractive color models. Addictive color models are the result of transmitted light, so white light is obtained by mixing red, green and blue light [10]. While subtractive color models are the result of reflected light, which means that when colors are mixed, the result gets darker with each mix tends to black, this method is used in paint and for printing.

The RYB is subtractive color model, where the R in the abbreviation stands for Red, Y for Yellow and B for Blue, and it was one of the first models to be created.

The RGB model is classified as additive, in which the primary colors are Red, Green and Blue. These colors mixed can produce Magenta, Cyan and Yellow and by blending all the primary colors, white is obtained. The RGB color model is often represented as a cube, with 3 dimensions in space, x, y and z axis.

CMY(K) is a four dimensional color model composed of Cyan, Magenta, Yellow and Key, which is commonly known as the value that holds the detail in images, since the mix of all of the model's colors is a color near black, there was a need to add black to the 3 origin colors.

This color model is a cylindrical or cone model, that uses Hue, Saturation and Value to define colors, differently from RGB and CMY(K) that use their base colors to create new ones. Here, the RGB primary colors are remapped into three independent dimensions of the HSV components: Hue, which is described by the color dominant wavelength and it is what determines which is the color that is represented by common color names; Saturation, which is what defines the purity of a color, from grayscale to fullest color; Value, which varies from blackness to whiteness.

The HSV model can also be called HSB, B corresponding to Brightness, as it performs in the same axis as Value. Brightness is the perception of color Lightness, in other words, is the way it appears an object is radiating or reflecting light, when the Brightness is high we get an intense color and when the Brightness is at its lowest, we get the color black.

The HSL color model is very similar to the HSV color model, after all two out of three components are the same: Hue and Saturation. The third distinct component is Lightness, which establishes how much black is mixed into a color.

2.4. Color Spaces

Color spaces are tridimensional mathematical models that represent the range of all the colors that can be perceived by humans. They are depicted as chromaticity diagrams. These diagrams illustrate the relationship between the color wavelength and the colors perceived by humans.

When the difference between two colors, perceived by the human eye, is proportional to the Euclidian distance within a given color space, it is called a perceptual uniform color space.

The CIE Color System is used nowadays to represent the range of perceivable colors and it can be expressed in several forms: CIE 1931 XYZ, the CIE-L*a*b* and the CIE-L*u*v* [7].

The CIE 1931 XYZ color space is based on the three types of cones of the human eye (S-cones, M-cones and L-cones). The axis of its diagram is represented by the abstract variables: X, Y and Z.

The The CIE-L*a*b* is a uniform color space that displays the colors scales equally in two axis: a* and b*. The a* axis contains the colors from red to green and the b* axis contains the colors from yellow to blue, all opposite colors, while the L illustrates the Lightness.

The CIE-L*u*v* is yet another uniform color space, commonly used in computer graphics and also to specify large color differences. It was created to correct the CIE 1931 XYZ distortion, since the CIE-L*u*v* distributes colors approximately proportional to their perceived color difference.

2.5. Related Work

Color is widely used to represent data artefacts in information visualization, not only because it can draw attention but also because it is a way to distinguish between elements. But when there is a need to represent more complex data, color blending becomes necessary. The study of color blending perception and color blending techniques are relevant to understand how the information can be displayed in an effective way. As such, several authors have been conducting research in this field of work.

Gama and Gonçalves did some significant studies on color blending perception. They tested if users could recognize relative amounts of color in a simple color blending [2]. They were able to conclude that some color pairs involved in the blending were more successful than others and verified that colors with the same component quantities might mislead the users. Another work done by the same authors was the study of color blending perception for data visualization [3]. From the results of this study they could conclude that color blending works better when pairs of two colors are mixed together instead of three. The users found that the CMY(K) color model was the easiest to perceive.

As for color blending techniques, Hagh-Shenas *et al.* studied strategies to display data visualization using color blending and color weaving [6]. The authors concluded that, overall color weaving is more suitable to display multivariate data than color blending, however, the number of participants in the study far from ideal.

In the remaining research on color blending techniques, Gossett concluded that paint inspired color blending using the RYB color model was indeed more intuitive to inexperienced users [5]. Also, Chuang *et al.* stated some important regards on their Hue-preserving color blending study [1], for instance, the fact that grey colors become less perceiving in color blending, because they can come from diverse blended Hues.

3. Studying Color Blending

Some of the theoretical research previously made on color blending techniques focused on which was the best color model to perform color blending, or if subjects could perceive relative amounts of color components in blended colors, among others. Although meaningful conclusions were reached, we noticed that none of them was focusing on a color model's Brightness component. So, we opted to study how a color component can influence the human perception on color blending, in particularly the Brightness parameter.

We opted to study the Brightness component instead of Saturation because of the known problem that low Saturation colors are difficult to distinguish [12], which would constitute a difficulty for the users participating in the test.

We used the HSV color model. But since we want to assess the Brightness, we must focus on the HSV's Value, because it gives us the intensity of the color by working in combination with the Saturation value, thus the Brightness [11]. Since our main goal is to **study the influence of the Brightness component on color blending, while testing the users' perception on different color blending techniques**, we elaborated several questions which we intend to answer at the end of our study:

- **Q1** - When blending colors with the same Brightness, which is the Brightness value to choose?
- **Q2** - When blending colors with different Brightness, which Brightness value to choose?
- **Q3** - Between darker colors and lighter colors, which one performs better?
- **Q4** - When blending colors with the same Hue, which is the Brightness and Hue to choose?
- **Q5** - Does the distance between Hues in the HSV color model have an influence on the results?
- **Q6** - Does gender and age have an influence on the human color blending perception?

Our user tests were composed by 4 steps: a screen calibration, a demographic questionnaire, a color deficiency test and finally a set of color blending tests.

3.1. Designing the User Study

We decided to use the Primary colors: Red (R), Green (G) and Blue (B), and the Secondary colors: Cyan (C), Magenta (M) and Yellow (Y) to create the blended colors. We chose these six colors because they are reasonably far apart in the color circle. And together with Black, White, Grey, Brown, Orange and Purple, are considered distinguishable for the human perception [12]. Then, after choosing the colors to be used in the study, we opted to mix the six selected colors between each other and between themselves in pairs of two, originating 21 possible blends (Figure 1).

We decided it was interesting to create combinations between the same color because we are going to vary the Brightness level of each color, making the blend slightly more difficult to identify. And we also decided to keep the pairs with opposed colors in the HSV color circle (R-C, B-Y and G-M), even though when interpolating the two Hue values it results in two distinct Hue outcomes, because we want to assess how equidistant and adjacent color pairs perform in a color blending.

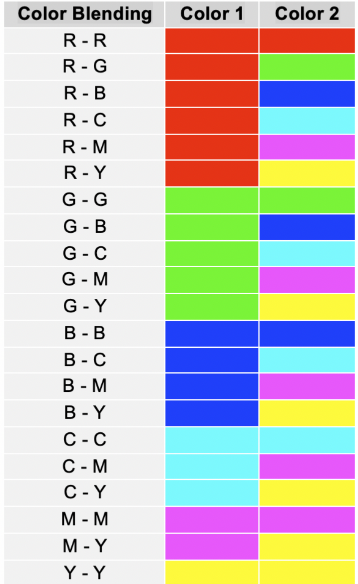

Figure 1: Color Blending Pairs.

As for the Brightness levels, originally thought of having five levels of Brightness, but that would lead us to 525 color combinations, resulting in a lot color blends and consequently user tests. So, we decided that three distributed levels would be a more suited option for our user study, resulting in less color combinations: 189. Since the Brightness component varies from 0% to 100%, we established the following levels: 30%, 60% and 90%, these values are not evenly distributed because darker levels of Brightness, for instance below 30%, become almost imperceptible to distinguish.

For each of the 21 color combinations, we had to do 9 Brightness combinations, such as: 30%-30%, 30%-60%, 30%-90%, 60%-30%, 60%-60%, 60%-90%, 90%-30%, 90%-60% and 90%-90%, apart from the color blends between the same colors because it only made sense mixing 30%-60%, 30%-90% and 60%-90%, otherwise we would obtain replicated or even evident color blends, since the result would be the exact same as the two initial colors. By applying the levels of Brightness described above to each color pair, we obtained 153 distinct color blends.

As we stated before, the HSV color model has three components: Hue, Saturation and Value. As for the Hue, it varies from 0 to 360 and we already selected the colors that will take part in the study: Red (Hue = 0), Yellow (Hue = 60), Green (Hue = 120), Cyan (Hue = 180), Blue (Hue = 240) and Magenta (Hue = 300). Regarding the Saturation, since we are only studying the Brightness component, we decided to set it to its maximum (100%), this way it could not interfere with the study results. Regarding the Brightness, as we previously explained, a nine Brightness combination was achieved for each color pair, therefore producing the following Brightness results: 30%, 45%, 60%, 75% and 90%.

In order to create the color blends in HSV, since the Hue is radial and the Value is linear, we had to apply an interpolation equation to get the blended Hue. The Brightness values obtained from a color blend are just the mean values of the two colors. To do so, we used the formula below, which allows us to obtain the correct Hue resultant from the blend in the HSV circle. In equation 1, Hue_1 represents the Hue of the first color and Hue_2 the Hue of the second color involved in the blend. The Hue_3 is the angle that is obtained from the interpolation of the first two Hues.

$$Hue_3 = Hue_1 + \frac{Hue_2 - Hue_1}{2}. \tag{1}$$

As for the equidistant colors in the HSV circle, by using of the formula above, it could give us two different results, so, two opposed Hues. We decided to choose only one of the two resultant Hues, for the three cases where that happened (G-M, R-C and B-Y). Since the options were either to choose between a smaller and a larger angle in the HSV color circle we opted to randomly choose one of the two Hues - the one with a larger angle in the HSV circle.

The user study was developed from scratch using web-technologies such as HTML5, CSS and Javascript and it was conducted locally, in a Google Chrome web browser.

Considering the user study was being developed in web-technologies, we had to perform the interpolation before the HSV colors were converted to RGB, in order to display the colors in the web page. Since our study was to be performed in person, we did not feel the need to create a database, so each time a user finished a test, a csv file was saved with a user identifier.

3.2. Environment and Screen Calibration

The testing environment was supposed to be the same for all users, but due to the large number of users, we could not perform all the tests in the same Laboratory environment, since we had to dislocate to some users in order for them to perform the test. However, we always had the preoccupation to find a windowless room with similar lighting conditions as the one we performed most of the tests, to provide almost identical testing and lighting conditions among the users. The tests were always performed in the same laptop computer (MacBook Pro 2017) and we decided to perform the tests on Google Chrome web browser. Since we did not want the participants to have any distractions on the screen, we always set the window to full screen and we also hid Google Chrome's toolbar. So that the users could perform the test more accurately, we provided them with a computer mouse and a mat. The computer mouse was at set at normal tracking speed.

Before starting the user tests, the computer screen was calibrated accordingly with the use of Datacolor Spyder® 5ELITE, a computer software combined with a colorimeter that calibrates the color of the screen based on the lighting in the environment and also based on the properties of the screen in use. The colorimeter was then used before starting each individual test or each set of consecutive user tests.

3.3. Demographic Questionnaire

The demographic questionnaire is the first part of the user study, and it is where we collected demographic information about the study participants. The questionnaire presented to the participants contained questions about Age, Gender, Education, Nationality, Country of Residence and lastly if they were familiar with the concept of color blending. The answers to these questions will help us correlate the results of the color blending tests with demographic aspects of the users, helping us reach some conclusions related to the gender and age influence on color blending.

3.4. Color Deficiency Test

The color deficiency test is the second part of our user study and it is supposed to determine if the subjects bear any visual deficiencies. This part of the test consists of showing to the users a carefully selected set of six pseudoisochromatic plates, taking into account Ishihara's simplified version of a color blindness test [8], that will allow us to determine if the participants bear any visual deficiencies and which type of condition the study participant has. We used the following plates: No.1 (containing the number 12), No.2 (number 8), No.5 (number 3), No.9 (number 45), No.11 (number 7) and No.15 (which does not contain any number for normal color vision users).

3.5. Color Blending Test

The final stage of our user study is the color blending test, which is composed by a set of different color blending combinations. For each combination, the user is shown two colors and has to decide which is the resultant color, by adjusting the Brightness.

We obtained 153 distinct color blends and we wanted to obtain at least 20 user responses for each color blend, in order to get a reasonable sample amount. To be able to cover all the blends the times we established, we would need at least 100 users. So, we decided that each user tests would be composed of 31 randomized color blends.

When creating the prototype, we took into consideration previously made studies on color and color blending. Regarding that this is a study involving color and the perception of a certain color is affected by its neighbouring colors, we opted for a white background for our interface [9]. We also decided that we would not insert any visual distracting elements in the color blending test pages.

Eventually, we designed a prototype of the study that consisted in three squares, two colored squares and a third in blank, represented in a sum: the first two combined will equal the third one (Figure 2). We opted to create a slider below the third blank square, where the users could click and drag through the different levels of Brightness, ranging from 0% to 100%, and while doing that, the Brightness of the initial blank square would change accordingly. The Hue presented in the third square does not change, as it is given to the users the first time they click and drag the slider. The resultant Hue is calculated by formula 1.

Figure 2: Final Prototype of the Color Blending Test.

Each color blending test page would contain the two blended colors, the resultant color, a "What the hell...?" button and a right arrow, so that the user could skip to the next page. The button idea arose from the fact we had equidistant colors in our user study and we thought it would be interesting to find out if the users could perceive whether the resultant Hue from the blend did not correspond to the one they were expecting to see.

After each color blending page, we used a Likert scale (1 to 5 scale, 1 corresponding to "very hard" and 5 to "very easy") to assess the user's difficulty or the easiness after each mix. The users were asked if they found easy to identify the colors involved in the mix.

4. Analysis on Brightness' Influence on Color Blending

With the results obtained from the user study, we can answer the questions asked in the previous section, and make an analysis on the results obtained from the user study.

In this section we will perform an analysis of each of the color blending Brightness techniques, in order to get different perspectives on how Brightness influences the users' perception.

4.1. Blending Colors with the Same Brightness

To study color blending by blending two colors with the same Brightness, we selected and divided the blends into three groups. The first group containing the blends with 30%-30% Brightness, which are the perceptually darkest blends and originate consequently darker colors. The second group has the 60%-60% Brightness color blends. And the third group contains the lighter blends, with 90%-90% color blends.

We calculated the mean of the Brightness results given by the participants for each color blend and the respective standard deviation. Then for each Brightness group we calculated the distance to the correct Brightness value (Distance = |User's Brightness value - correct Brightness value|). And replicated this procedure for the remaining techniques.

Considering the mean of the distance values for each group, we could conclude that the **60% Brightness group was closest to the correct Brightness value** ($\overline{x} = 10.61, std = 8.417$), then the 30% Brightness group had close values as well ($\overline{x} = 10.79, std = 9.654$), and finally the 90% Brightness group, which contains the brightest color blends was the one that had worse results ($\overline{x} = 13.82, std = 11.385$). By performing a one-way ANOVA test between each groups' distance, we could conclude that there are statistically significant differences between color blends with the same Brightness values, so we reject the null hypothesis ($F(2, 897) = 8.972, p = 0.000139$). Post hoc comparisons using the Tukey HSD test revealed significant differences between 90% and 60% Brightness color blends and between 90% and 30% Brightness color blends ($p \leq 0.05$). But the color blending with 60% Brightness was not significantly different from the 30% Brightness.

Regarding the Likert Scale answers we had distinct results, the study **participants found that the easiest group was the 90% Brightness group**, which contains the lighter blends.

4.2. Blending Colors with Different Brightness

We separated the blends into three groups: the first group with 30% - 60% / 60% - 30% Brightness color blends, creating a color with 45% Brightness; the second group with 30% - 90% / 90% - 30% Brightness values, which originates a blended color with 60% Brightness; and a third group with 60% - 90% / 90% - 60% Brightness values, generating a color with 75% Brightness. To simplify the reading, we will call the groups by 30% - 60%, 30% - 90% and 60% - 90%, respectively.

We proceeded to calculate the mean of the participant results for each color blend, the standard deviation and the distance, as we described above.

By observing the results of the distance mean, for **30% - 60% Brightness group we get the closest mean to the correct Brightness value** ($\overline{x} = 10.06, std = 8.857$), succeeded by the 30% - 90% group ($\overline{x} = 10.68, std = 8.763$) and finally by the 60% - 90% group which had the worst distance results ($\overline{x} = 12.70, std = 10.427$).

According to a one-way ANOVA test, the results showed that there are statistically significant differences between color blends with different brightness values, so we reject the null hypothesis ($F(2, 216) = 15.592, p = 1.892E - 07$). And by performing a Post hoc Tukey HSD test, were revealed significant differences between 30% - 90% and 60% - 90% Brightness color blends and between 30% - 60% and 60% - 90% Brightness color blends ($p \leq 0.05$). But color blends with 30% - 60% Brightness was not significantly different from the 30% - 90% Brightness group.

As for the Likert Scale users' responses, they were all very similar.

4.3. Blending Darker and Lighter Colors

We will study the results from blends with 45% (30% - 60%) and 75% (60% - 90%) Brightness resultant colors, which correspond to the darker and lighter Brightness color blending results.

Starting with the mean of the distance values in the 45% and the 75% Brightness group, we concluded that the **45% group mean** and standard deviation ($\overline{x} = 10.06, std = 8.857$) **is lower than in the 75% Brightness group** ($\overline{x} = 12.70, std = 10.427$) (Figure 3).

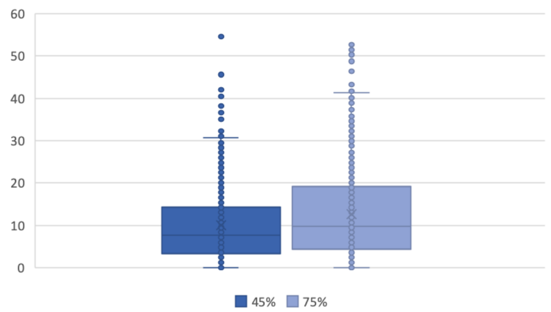

Figure 3: Boxplot Chart representing the distances for Darker (45%) and Lighter (75%) blends.

With a one-way ANOVA test between each groups' distance, the results showed that there are statistically significant differences between color blends with darker and lighter results, so we reject the null hypothesis ($F(1, 144) = 26.820, p = 2.550E - 07$). By performing post hoc comparisons using the Tukey HSD test, we concluded that there are statistically significant differences between darker and lighter results from color blends for ($p \leq 0.05$). Concerning the Likert Scale responses, the 45% Brightness group had better results.

4.4. Blending Colors with the Same Hue

In this section, we will focus on the Brightness component but we will also be considering the Hue involved in the color blend.

We selected the color blends between colors with the same Hue, then separated them into six groups, one for every Hue (Green, Red, Blue, Yellow, Magenta and Cyan), obtaining three color blends for each group. The Hue groups contain each 3 different Brightness color blends, the first with 30% - 60% combination, the second with 30% - 90% and lastly with 60% - 90%, which we'll refer to as 45%, 60% and 75% Brightness respectively, for a better understanding.

For the 45% Brightness group, we calculated the mean of the distance ($\overline{x} = 6.91, std = 7.544$) and conducted a one-way ANOVA test, that showed that there are no statistically significant differences between the means of the results ($F(5, 114) = 0.667, p = 0.649$). Then for the 60% Brightness group, the mean of the distance was calculated as well ($\overline{x} = 7.74, std = 7.207$), and the one-way ANOVA test indicates that there are no statistically significant differences between the means ($F(5, 114) = 1.091, p = 0.370$). Finally, for the 75% Brightness group, like the other two Brightness groups, the mean of the distance was calculated ($\overline{x} = 6.87, std = 6.910$) and a one-way ANOVA statistical test performed, showing that **there are no statistically significant differences** between the means of the results ($F(5, 114) = 0.220, p = 0.954$), $p \leq 0.05$.

In addition to the prior study analysis, we also wanted to reach some conclusions on the performance of the Hues. So, we grouped the color blends by Hue, obtaining six groups and calculated the distance mean for each Hue. **Red was the one that had the lowest distance** mean ($\overline{x} = 6.80, std = 6.111$), then accompanied by Yellow ($\overline{x} = 6.82, std = 7.803$), Green ($\overline{x} = 7.07, std = 6.572$) and Cyan ($\overline{x} = 7.08, std = 7.916$), this implies that Red is the most appropriate color to use when blending colors with the same Hue.

Since we were dealing with blends between colors with the same Hue, as we expected, the Likert Scale results were overall very positive, which suggests that the color blends were relatively easy.

4.5. Blending Equidistant and Adjacent Colors in HSV Color Circle

In this section we will continue by examining the Brightness depending on the Hue, but this time we will focus on the Hue proximity of the two colors in the HSV color circle used in the color blend.

We created two distinct groups of color blends: the group that contains equidistant colors and the group that contains adjacent colors involved in the blend. The equidistant group includes the following color blends: Red + Cyan, Blue + Yellow and Green + Magenta. While the adjacent group contains: Red + Yellow, Green + Yellow, Green + Cyan,Blue + Cyan, Blue + Magenta and Red + Magenta. After establishing the groups, we must separate, within each group (equidistant and adjacent), the Brightness values we want to evaluate. We then obtained five groups, one for each resultant Brightness of the blend: 30%, 45%, 60%, 75% and 90%.

Starting by the equidistant colors, the **45% Brightness level was the one to have a lower distance mean** therefore, performed better ($\overline{x} = 10.53, std = 10.489$), followed by 60% ($\overline{x} = 13.25, std = 10.912$) and 75% ($\overline{x} = 13.67, std = 10.012$) Brightness levels. The worst results were from the 30% ($\overline{x} = 14.39, std = 13.583$) and 90% ($\overline{x} = 15.69, std = 10.697$) groups.

We proceeded to do the same regarding the adjacent set of color blends. In this case, the results were significantly better, meaning that the means of the distances were lower than in the equidistant colors group The **60% Brightness level was the one with lower distance mean** ($\overline{x} = 9.4, std = 7.783$), accompanied with the 30% group ($\overline{x} = 9.91, std = 7.548$). Then followed by the 45% ($\overline{x} = 10.72, std = 8.723$) and 75% level ($\overline{x} = 11.35, std = 9.323$), 90% being the Brightness level with the worst results and with the highest number of outliers ($\overline{x} = 12.36, std = 11.124$). Analyzing the results from both groups, equidistant and adjacent color blends, we can conclude that the 90% Brightness value is not a good option for both types of blends. And although 30% might be suitable for adjacent blends it is definitely not for equidistant color blends.

To support the results gathered, we decided to compare the distance means between equidistant and adjacent color blends for each level of Brightness. For the 30% Brightness level, with a one-way ANOVA test, we could conclude that there are statistically significant differences between equidistant and adjacent color blends, so we reject the null hypothesis ($F(1, 238) = 9.908, p = 0.002$), $p \leq 0.05$. By performing a one-way ANOVA to the remaining Brightness levels, the same happens for the 60% Brightness value ($F(1, 718) = 29.569, p = 7.404E-08$), the 75% Brightness group ($F(1, 478) = 6.852, p = 0.009$) and the 90% group ($F(1, 238) = 5.549, p = 0.019$), after all they had statistically significant differences between equidistant and adjacent color blends, so the null hypothesis must be rejected ($p \leq 0.05$). The only exception was the 45% Brightness level, when performing a one-way ANOVA, the results showed that were no statistically significant differences between equidistant and adjacent distance means, so we fail to reject the null hypothesis ($F(1, 478) = 0.081, p = 0.775$), ($p \leq 0.05$).

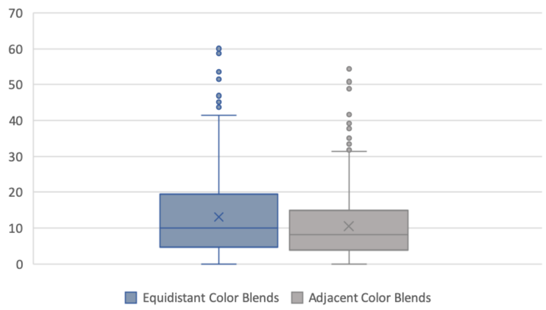

Figure 4: Boxplot Chart representing the distance results of Equidistant and Adjacent Color Blends.

To conclude our analysis, we decided to gather all the distance results from each group and perform an additional statistical test. By calculating each group's distance mean, the results show, once again, that the **adjacent color blends** ($\overline{x} = 10.41, std = 8.664$) **have a better performance than the equidistant blends** ($\overline{x} = 13.12, std = 11.04$), as it can be observed in Figure 4.

We conducted a one-way ANOVA test between the distance means of each group and the results showed that there are statistically significant differences between equidistant and adjacent color blends, so we reject the null hypothesis ($F(1, 2158) = 36.815, p = 1.529E-09$). Post hoc comparisons using the Tukey HSD test revealed statistically significant differences between equidistant and adjacent color blends ($p \leq 0.05$).

In addition to our previous analysis, we decided to study the Brightness for each of the color combinations used in both types of blends, equidistant and adjacent color blends.

The equidistant group has three sets of color blends: Red + Cyan, Blue + Yellow and Green + Magenta. Although the mean of the Brightness distance was quite high for all pairs, the color pair with better results was the Green + Magenta, since the mean was the lowest of the three ($\overline{x} = 13.26, std = 11.284$). As for the adjacent group, it contains six pairs: Red + Yellow, Green + Yellow, Green + Cyan, Blue + Cyan, Blue + Magenta and Red + Magenta. We found that the best adjacent pair is the Green + Yellow with the lowest distance mean ($\overline{x} = 8.57, std = 5.343$).

4.6. Demographic Results

We conducted the tests to a total of 100 users, in which 62% were Male users and 38% Female users. Their age varied between 17 and 72 years old. The users were mostly of Portuguese nationality (98%) and the remaining had British and Spanish nationality (2%). Out of the 100 total users, 29 had secondary education, 45 had a Bachelor's Degree, 25 had a Master's Degree and 1 user had a Doctorate Degree. Concerning the user's familiarity with color blending, 45% were familiar with the concept of color blending, while 55% were not familiar with it.

To find a connection between the answers given and the demographic date, we decided to analyze the results by gender and by age.

As for the gender groups, in order to perform a statistic analysis, we had to divide the Male from the Female users' results. Then, we had to organize the data in the same way as we did in the previous sections: by the same Brightness value, by different Brightness values, by darker and lighter colors, by the same Hue and by equidistant and adjacent colors, for each gender group.

We performed a two-sample t-Test to compare the Female and Male distance results and determine if there were statistically significant differences between them ($p \leq 0.05$). But we could not reach a definitive conclusion whether if there is a difference between Female and Male user results, since we did not find any statistically significant differences on every analysis made on gender. We did find small differences based on the mean of the distance results, but we did not discover any pattern between them, therefore, they are not enough to substantiate a formal conclusion. This could be due to the lack of a more diverse and significant user sample, since we only had 62 Male and 38 Female users.

As for the age groups, we realized that we had a considerable discrepancy on the number of users on each age group. Therefore, it would be difficult to reach any conclusion with such user sample. So, instead of dividing the users' results by the age groups mentioned above, we decided to separate them in two groups: younger than 25 (including the 25-year-old users) and older than 25 (excluding the 25-year-old users). Resulting in a total of 65 users under 25 years and 35 users over 25 years old.

After the division, we organized the data exactly like the gender groups. Then, we analyzed both groups by calculating the mean of the distances and conducting a two-sample t-Test to compare the $\leq$ 25 and $>$ 25 group distance results and determine if there were statistically significant differences between them ($p \leq 0.05$). In similarity as gender groups, we could not reach any definitive conclusion whether if there is a difference between $\leq$ 25 and $>$ 25 user results. We did find a few statistically significant differences on our analysis between the results of younger and older users, such as the 90% - 90% and 60% - 90% color blends. These two groups have something in common: they both involve lighter colors in the mix, which consequently, generates a lighter color from the blend, 90% and 75%, respectively. However, there is not sufficient information to substantiate a formal conclusion.

4.7. Design Implications

With the results obtained from the user study, we have learned valuable outcomes on how to use Brightness correctly with different color blending techniques, using the HSV color model. This allowed us to identify and present the following set of implications, not only concerning the Brightness component, but also color blending techniques:

- From all the Brightness values tested, we have found that, **intermediate Brightness levels** (between 45% and 60%) are the most appropriate levels to use in most of the color blending techniques studied.
- When choosing between darker and lighter colors, **darker colors** seem to correspond to the users' expectations better than lighter colors.
- **Blending colors with the same Hue** was proved to have the best performance comparing to the other studied Brightness color blending techniques.
- When choosing between equidistant and adjacent color blends, the **adjacent color blends** are preferred.
- When it is necessary to use equidistant color blends, it is advisable to provide the resultant Hue, since there are two possible Hues that can be obtained from the blend. This may constitute an additional difficulty in perceiving the resultant blend.
- When it is necessary to use equidistant color blends, it is also advisable to choose the resultant color from the blend that corresponds better to the users' expectations.
- In HSV color blends, when the **color Blue** is included, overall, it performs better than color blends that don't involve Blue.
- When creating a color blend and Brightness is component to be altered, it is advisable not to vary the Saturation, since it can affect the intended color result.

5. Conclusions

In order to answer the questions asked in section 3, an analysis was made with the results obtained from the study. We were able to answer the questions and draw conclusions regarding the Brightness component of the HSV color model, except for Q6.

From all the color blending techniques we have tried, such as blending colors with the same Brightness, blending colors with different Brightness, blending colors with the same Hue and blending equidistant and adjacent colors, we could conclude that, overall, intermediate values of Brightness (ranging from 45% to 60%) are best to work with when using the color blending techniques that we described above, since the resultant blends are according to the users' expectations. We have also found that adjacent color blends are better perceived than equidistant blends. As for our studies regarding the Hue component, the Red + Yellow pair stood out from the rest when it comes to blending colors with the same Hue, and the pairs Green + Magenta and Green + Yellow were the ones that the users perceived better when blending equidistant and adjacent colors, respectively.

We could not draw any definitive conclusions for gender and age, although we have found a few differences between age groups in some color blending techniques, it was not enough evidence to substantiate a formal conclusion on this subject.

The conclusions we could extract from our study will help to display information using Brightness derived color blending techniques, and how the choice of Brightness in a color blending can influence the perception of the user.

5.1. Future Work

The research we conducted can be extended in order to cover and improve more aspects of color blending and consequently study the users' color perception. One of the most evident way to do so, is to expand the user sample, obtaining a more diverse and larger number of participants.

With that criteria met, it would be interesting to focus more on the demographic study of the results, it could be determined if the nationality or the educational level of users have an influence on color blending perception. And also, to study if there is a relation between age and gender results, in order to understand how gender's perception develops through age. It would be also interesting to study if the users who were familiarized with the concept of color blending had better results than the rest.

Similar studies could be performed regarding different color components, such as: Saturation, Lightness or even solely focused on the Hue component, to access the relationship between colors. Future studies can be performed using different color models. Taking this into account, the color that the user has to determine could be switched, for example, the missing color could be part of the mix.

Performing the test on an online environment could be the key to find a more diverse user sample, but there are some implications that would have to be studied, such as the calibration of the screen.

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