Color Theory in Visualizations

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Abstract

The study of color theory is essential because it allows for visualizations to properly portray the data while appealing to the viewers ethos to make them agree with the visualization. This paper will explain what color theory is, how it applies to color deficiencies and visualizations. I used Python to understand the COVID-19 data that was used to further explain how color theory is used in practice. The main finding of this paper is that ethos is very important for portraying the right emotion tied to the visual and it will help persuade people into feeling a certain way about a topic. This is crucial for those who are interested in visualizations so they can see how to properly create strong, ethos appealing, visualizations while still being conscientious of those with color deficiencies.

1 Background

The main topics of this paper are: associating color with emotions, dealing with color-blindness, and color theory in visualizations. So, what is color theory? Color theory is the set of guidelines people use to communicate with others through appealing color schemes by using knowledge about the human optical ability, psychology, culture and more [5]. While the creator of the visualization might have a very specific color, or colors, in mind to portray a certain emotion in their visualization, they also have to keep in mind the accessibility of the visualization. Are people with color deficiencies able to see the visualization and does it still have the same, or a similar, appeal? One easy way to check this is by running the visualization through a color blindness simulator. It is also important to take geography into account. For example, red in the United States means danger and has a sexual appeal, in China it means good fortune, in South Africa it is used for mourning. So, if you know your visualization is targeting a specific region or country make sure the colors match the meanings for that location. For this paper, all color ethos information will mainly refer to the appeals in the United States.

2 Project Question

The goal of this project was to determine what emotions each color represents and how that information can be used in visualizations while still being accessible to those with color deficiencies. The ethos each color has was based first off of prior research done in the industry, then it was compared to a study I created where seventy individuals answered questions regarding the emotions they felt when looking at certain colors. Those colors being red, green, yellow, or-

ange, light blue, dark blue, purple, pink, white, and black. These specific colors were chosen for the analysis because I personally feel different emotions when looking at them. After reading about ethos in color, the paper will transition into information regarding different color blindness's and deficiencies. Then the information about color theory and color blindness will be used in COVID-19 visualizations to show how the information can be applied using real data.

3 The Data

There are two sets of data used in this project. The first being the data collected from the color ethos survey I conducted. This data was curated through a google forum, listing all the answers each individual chose regarding their emotional appeal to each color and if they thought that color was good, bad, or neither. The second being state coronavirus data to help show how color theory is used in practice [4]. This data has information for each state plus Washington D.C., although only Virginia and Maryland were used in this project. The data was cleaned in R to calculate new cases and new deaths for each day, and the analysis was done in python using the package called Altair.

4 Analysis

4.1 Ethos in Color

To determine how certain people feel when looking at different colors, I created a google forum to collect information to compare to known research. In the forum those who answered had to state what emotion they felt towards each color and if they thought the color represented a good, bad, or neutral color. In the forum the colors they had to determine between were red, green, yellow, orange, light blue, dark blue, purple, pink, black, and white. I chose these colors because I personally have different emotional appeals to each one. Due to simplicity the only emotions they could choose from were happy, sad, angry, scared, optimistic, excited, calm, anxious, and other. Through this experiment we will see how known research compares to the conducted study.

4.1.1 Red

The color red has both a mix of what would be considered positive and negative emotions attached to it. The positive emotions linked to red are love, lust, and passion. It is also known for giving energy to the wearer. The negative emotions are anger, stress, fear, and the feeling danger [9]. Red is also one of the most eye-catching colors out there, which is why it is used for stop signs and lights. It is also why red cars are easier to distinguish than others. When comparing the known research above to what was conducted in the google forum study, we see very similar results. In figure **??**, anger was the emotion most people felt when looking at red with thirty-nine votes. Followed by excited and anxious with fourteen and nine votes respectively. This does follow the previous research done on the color red as seen above. When asked if they thought the color red was a good or bad color, figure 2, thirty-nine people thought it was a bad color, twenty-one thought it was a neutral color, and ten thought it was a good color. Meaning red was only one of two colors in the list to be considered a bad color by the majority of people.

4.1.2 Green

Like any color, green has both positive and negative attributes. Green is commonly associated with envy, jealousy, and disgust. However, green is also known for its link to purity, health, growth, productivity, connection to nature and oneself, spirituality and soul searching. Additionally, green is known for having a relaxing aura [8]. Green is a color that is most commonly associated with nature as it is the most prominent color outside. So, people often feel a sense of peace or calm when seeing the color green due

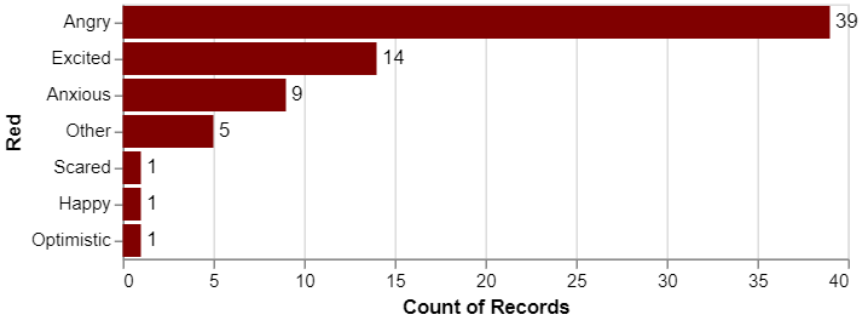

Figure 1: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color red.

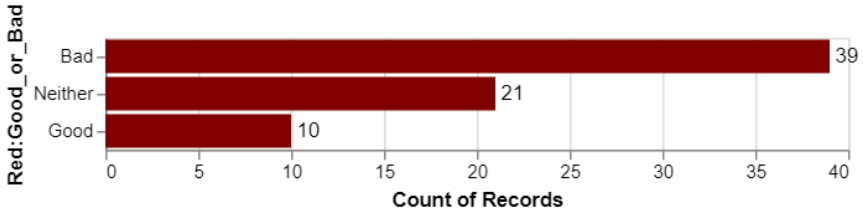

Figure 2: How people felt on if the color red was good or bad.

to their mind associating it with the peace of the outdoors. When we compare that to the google forum study, figure 3, we see that twenty-seven people associated green with calm followed by optimistic and happy with eighteen and twelve votes each. This does align with previous studies as calm is something that people often associate with the color green. Optimism could be what people feel when thinking about being optimistic about their growth in the future. Happy could be how they feel when they are in nature and calm, or it could be how they feel because they are healthy and connected to their surroundings. When asked if they thought green was positive or negative, there was an overwhelming number of people who thought green was good, figure 4. Eighty-seven percent of the people who participated associated green with good. Only six people thought it was a neutral color and three thought it was a bad color.

4.1.3 Yellow

Yellow is recognized as one of the most positive colors. It is known to be linked to happiness, optimism, hope, enthusiasm, and cheerfulness. But like any color it does have negative emotions tied to it as well such as caution and anxiety. Yellow is also known for activating the left side of the brain to help with deep thinking [14]. This is why you will often see highlighters in the color yellow. In the study seen in figure 5, twenty-eight people associated yellow with happiness. Followed by optimistic and calm both with eighteen and ten votes respectively. We also see that one person voted for scared and five for anxious. All these answers tie into the previous research. Yellow is known for being happy, optimistic, and hopeful, as seen above, while also having a sense of anxiety and caution. Hopeful could be what those felt who answered with calm, and caution could be what the one person felt when answering scared. When asked about the nature of the color, seen in figure 6, fifty-

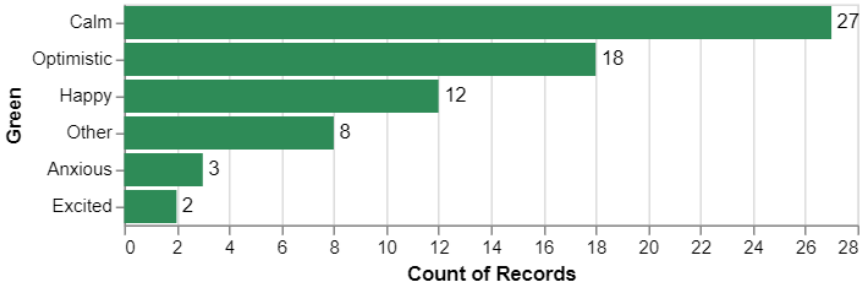

Figure 3: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color green.

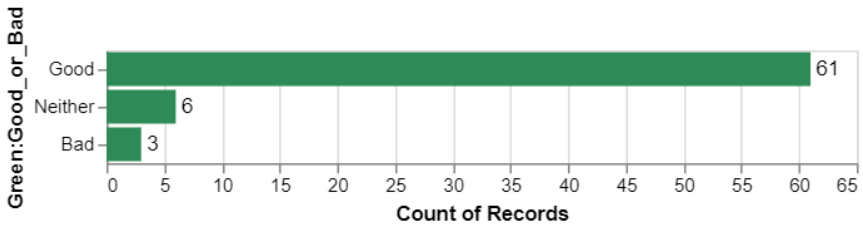

Figure 4: How people felt regarding if the color green was good or bad.

three thought yellow was a good color. Only sixteen thought it was a neutral color and one thought it was a bad color, which is the lowest number of votes for bad out of any color. This was probably the one person who associated yellow with scared. So overall, yellow is associated with happiness and other cheerful emotions, and through the study most people agree with the positive nature yellow brings.

4.1.4 Orange

Orange is a unique color because of its mix of red and yellow. Orange helps with positivity due to the yellow and excitement from the red. Orange is also the color that is commonly correlated with extroverts. Which is why introverts generally do not like the color orange and extroverts do. Introverts are likely to associate orange with its negative emotions such as aggression, pride, arrogance, and the uncomfortable feelings it brings when they are placed in extroverted situations. Extroverts likely relate orange with its positive emotions such as excitement, enthusiasm, and optimism [10]. This correlates exactly with what was found in the experiment with the two most voted answers being anxious and excited, see figure 7. So, we have the introverts leaning toward anxious with twenty-four votes and the extroverts with seventeen votes for excited. We also see that there is a mix of emotions regarding whether or not orange is a good or bad color, see figure 8, but overall orange does lean towards a good color with thirty-four votes. The other two options are not far behind with twenty-one votes for neither and fifteen for bad.

4.1.5 Light Blue

Blue in general is associated with intelligence. Light blue is known for aiding in concentration with the leading emotions being calmness and serenity [7]. Light blue is also the color of the sky which makes many people happy because it means the day will be free of rain and gloominess. This does tie into the study. As seen in figure 9, there was an overwhelming number of people who voted for calm with forty-one votes.

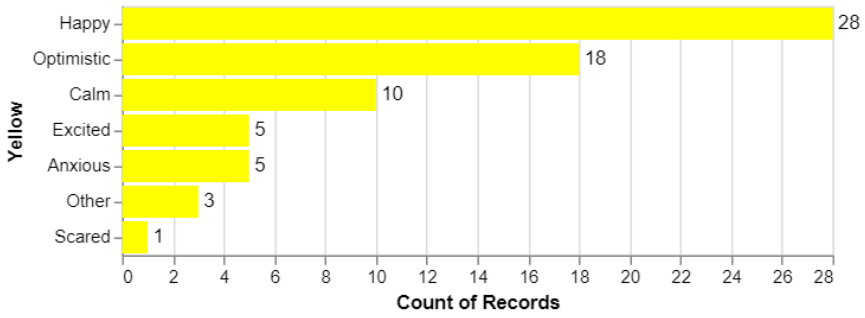

Figure 5: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color yellow.

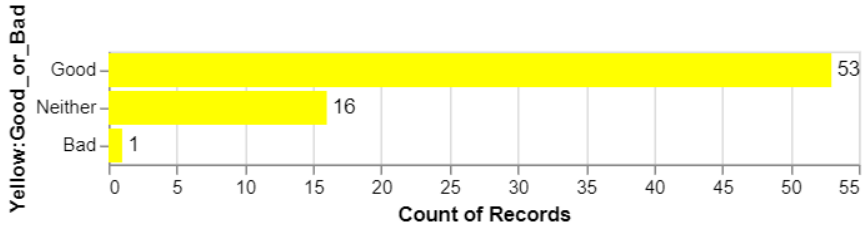

Figure 6: How people felt regarding if the color yellow was good or bad.

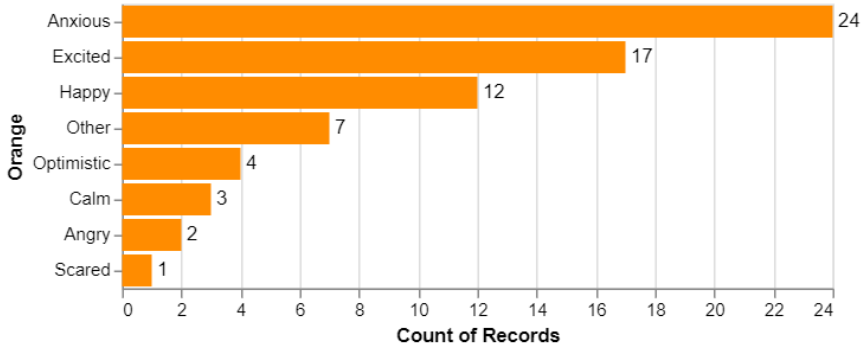

Figure 7: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color orange.

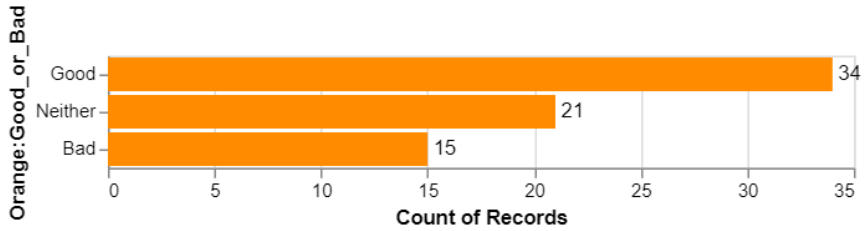

Figure 8: This figure shows how people felt regarding if orange was good or bad.

Followed by happy and optimistic with fifteen and eleven votes respectively. The happiness and optimism might be linked to the thought of a new day and the optimism you feel when you are calm and peaceful. Similarly, to green, sixty-one people voted that light blue was a good color, figure 10. Meaning the two colors people most associate with good are green and light blue.

4.1.6 Dark Blue

Dark blue, like light blue, is also associated with intelligence and is known for aiding in mental clarity. This is why when studying you are told to have a blue pen nearby, so you can write down the things in blue that you want to remember the most. The main emotions that come from dark blue are grief, sadness, and calmness. Dark blue is often linked to confidence without aggression. While red is known for being a confident color it is also associated with aggression and power. Dark blue gives the same confidence but without the aggression that red has [7]. People might associate dark blue to the ocean or the night sky, both drawing a sense of peace to them. This does match with our study with the two leading emotions being sad and calm, see figure 11 with twenty-two and twenty votes respectively. Dark blue like light blue was also seen as a good color with thirty-four votes, see figure 12. Neither and bad both had eighteen votes each.

4.1.7 Purple

Purple is often associated with luxury, power, royalty, nobility, along with mystery and magic. In history purple was one of the hardest colors to find a dye for, which is why it is associated with wealth and power. People of power throughout history were often seen wearing it as a sign of their position in society. Which is another reason why it creates a sense of wisdom. People of power were often thought of as being wise or intelligent. Like all colors it is linked to both positive and negative emotions. The positive emotions are dignity, curiosity, passion, fulfillment, and calmness. The negative emotions are sadness and frustration [12]. Because of the vast number of emotions linked to purple it makes sense that there is such a large spread of answers from the study, see figure 13. The top four being other, excited, anxious, and optimistic. These do tie into previous research because excited could be linked to passion or fulfillment, anxious could be linked to frustration, optimism could be linked to curiosity or fulfillment, and other could be related to any other emotion purple is associated with. Overall purple was thought of as a good color with thirty-nine votes, see figure 14.

4.1.8 Pink

In most of the western world, pink is thought of as a feminine color. While in Japan, pink is seen as a masculine color. Pink also has many ties to red, without the aggression and more innocence. The positive emotions are love, tenderness, intimacy, calm, innocence, and optimism. Whereas red is known for passion and lust, pink is known for love and affection. The negative aspects connected to pink are weakness, silliness, being shallow, and vulnerability. Those who like pink are thought of as shallow and childish as it is such an innocent color [11]. The emotions tied to pink do correlate to the study, see figure 15, as the two most voted for emotions were happy and optimism with twenty-four and sixteen votes correspondingly. Interestingly, pink had the second most votes for good after light blue and green with fifty-six votes, see figure 16. Only fourteen total people voted that pink was either a neutral color or a bad color.

4.1.9 Black

Black evokes a sense of power, mystery, calmness, and sophistication. It is known for making people feel powerful. Which is why men often wear black suits and women talk about a “little black dress”. Black makes the wearer feel seductive while still feeling comfort and strength in themselves. The negative emotions associated

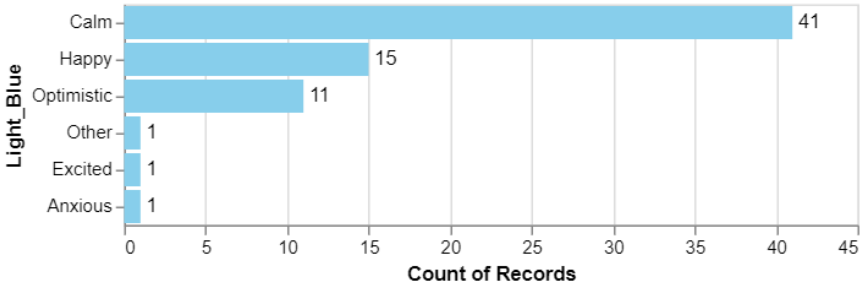

Figure 9: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color light blue.

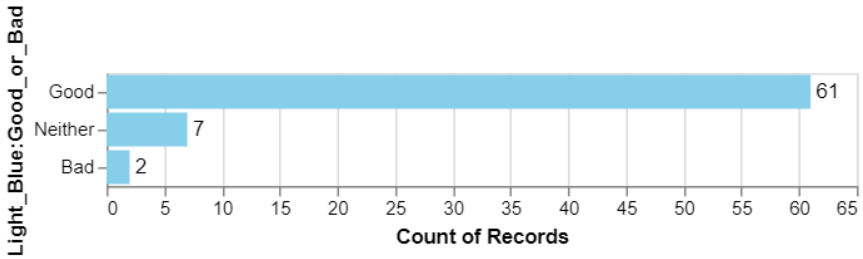

Figure 10: This figure shows how people felt regarding if light blue was good or bad.

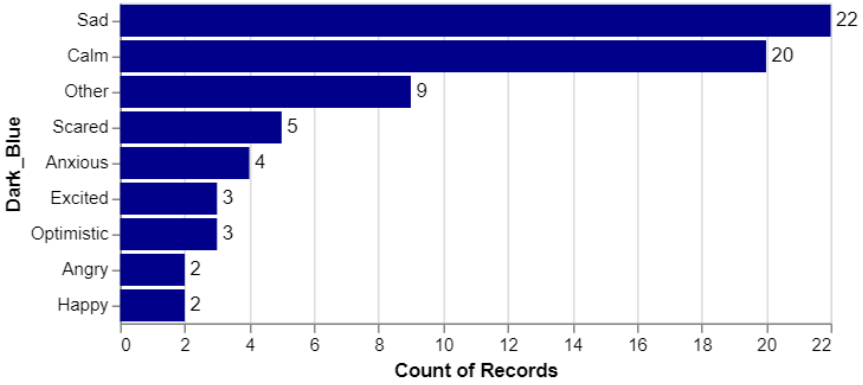

Figure 11: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color dark blue.

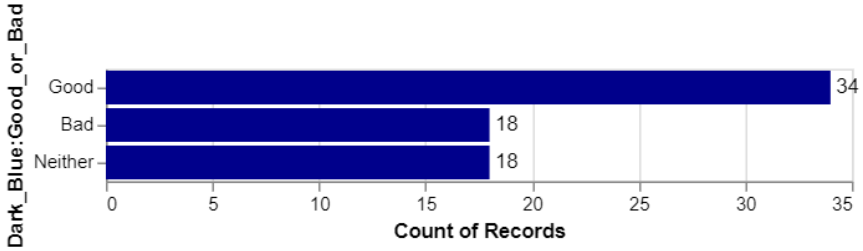

Figure 12: figure shows how people felt regarding if dark blue was a good or bad color.

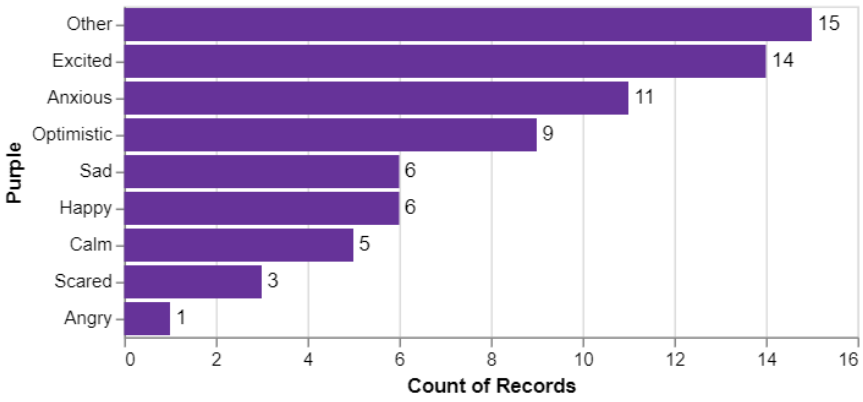

Figure 13: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color purple.

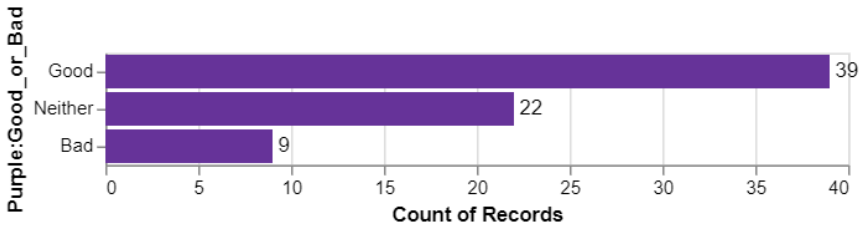

Figure 14: This figure shows how people felt regarding if purple was a good or bad color.

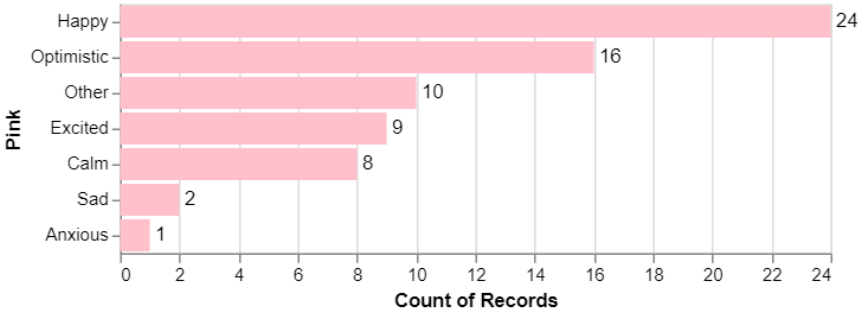

Figure 15: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color pink.

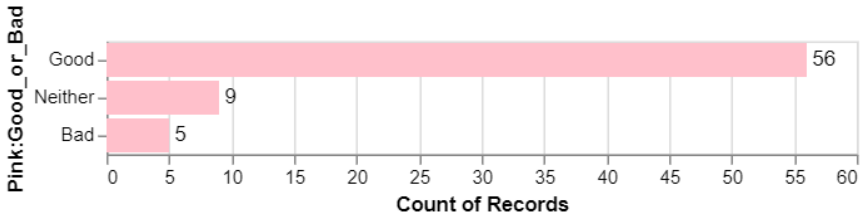

Figure 16: This figure shows how people felt regarding if pink was a good or bad color.

with black are depression, disappointment, pessimism, and secretive. The positive emotions are protection, strength, comfort, and seduction [6]. As seen in figure 17, the majority of people were unsure of what to choose based on the given answers, causing eighteen people choosing other. Seventeen people picked sad, and fourteen people picked scared. These emotions do correlate with the negative emotions linked to black and those who said other probably feel the positive emotions black brings. Interestingly other than red, black was the only other color to be voted as a bad color with thirty-one votes, see figure 18. Which makes sense because black is often associated with darkness which causes people to be afraid of what might lurk in the shadows.

4.1.10 White

While black represents the transition between the end and the beginning. White represents new beginnings. It is also associated with purity, innocence, and integrity. Which is why in the western world brides wear white, to show off their innocence and purity and to signify the start of the rest of their life. The positive emotions white brings are neutrality, hope, optimism, clarity, and its refreshing appeal. The negative emotions are indecision, coldness, and unfriendliness [13]. Again, it makes sense why the majority of people picked other, because the options did not one hundred percent fit with the main emotions of white, see figure 19. The next two highest emotions people chose were calm and optimism with nineteen and ten votes respectively. The calm emotion might be tied to the refreshing feeling people get with seeing white and optimism is an emotion linked to white. Unsurprisingly, based on the prior research done on white, it was the only color where most people thought it was a neutral color, see figure 20. This makes sense because as stated previously, white is known for having a neutral emotion. So, thirty-six people voted for neutral, followed by thirty for good and only four for bad.

4.1.11 Conclusions

In conclusion, every color has a different aura such as concentration, helping with studying, energy, or confidence. Darker colors are often seen as being serious, wise, or sad due to having a lower frequency. Lighter colors are often associated with happiness, optimism, and hopefulness due to their higher frequencies. From the google forum study and prior research done on color theory, we now know how important the meanings are behind each color and how they are able to influence the emotions of the viewers.

4.2 Color Blindness

4.2.1 Red-Green Color Blindness

Red-Green color blindness is the most common form of color blindness. It is apparent in around eight percent of the male population and zero point four percent of females. Which is equal to about one in twelve males and one in one thousand females. The reason why men are more likely to have this form of colorblindness is because this form of color blindness is X-chromosome linked. So, because men have two X-chromosomes and females only have one they are more likely to have this type of deficiency [2]. There are four different types of red-green color deficiencies: deuteranomaly, protanomaly, protanopia, and deuteranopia [3]. Deuteranomaly is the most common, found in five percent of males. It is known as a mild color deficiency. Making green look redder, figure 21 shows how those with deuteranomaly see the colors red and green. Protanomaly is the other form of minor color deficiency in the red-green color blindness family. Making reds look more green and less bright [3]. Protanomaly is found in one percent of males. Figure 21 shows what green and red look like to those who have protanomaly. Protanopia, also known as being red-blind, is the more severe version of protanomaly. Those with protanopia are unable to tell the difference between red and green at all because red looks green to them [3]. Protanopia is found in one

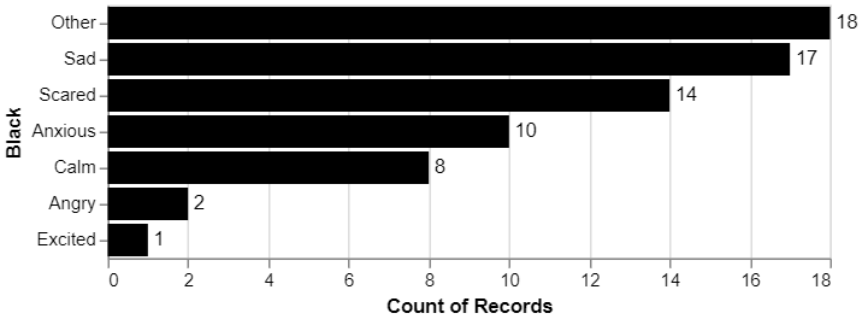

Figure 17: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color black.

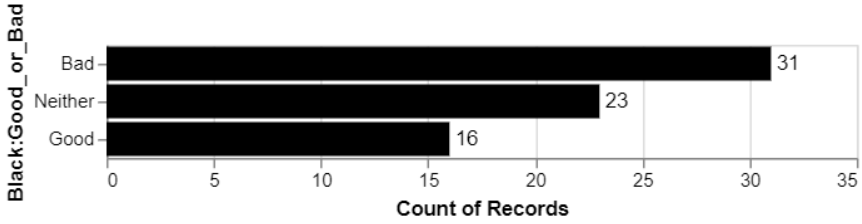

Figure 18: This figure shows how people felt regarding if black was a good or bad color.

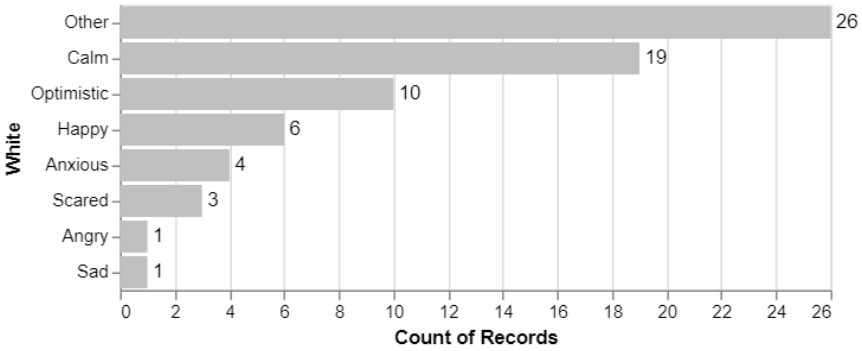

Figure 19: This figure represents the different answers chosen by the seventy people conducted in the survey, regarding the emotion they felt when looking at the color white.

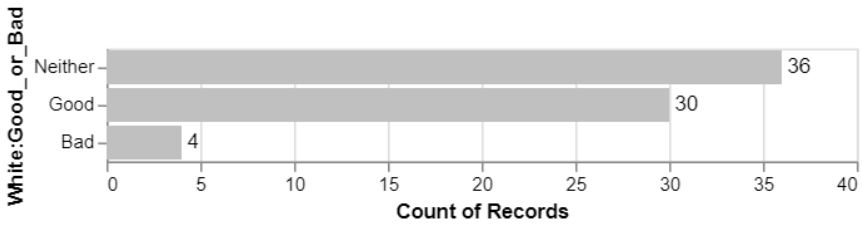

Figure 20: This figure shows how people felt regarding if white was a good or bad color.

percent of males. Figure 21 shows what those who have protanopia see when looking at red and green. The last form of red-green color blindness is deuteranopia, also known as being green-blind. Like protanopia, those with deuteranopia are unable to tell the difference between red and green [3]. Instead of having red look green as it does for those with protanopia, those with deuteranopia see green appearing as red. Figure 21 shows what green and red look like for those with deuteranopia.

4.2.2 Blue-Yellow Color Blindness

The next set of color deficiencies lies under the Blue-Yellow color blindness spectrum. These color blindness's are much less common. With only zero point zero one percent of men and women being likely to have it [2]. The first type of color blindness is tritanomaly. Tritanomaly makes it hard to tell the difference between blue and green as well as the difference between yellow and red. Tritanomaly is the mild form of blue-yellow color blindness [3]. Figure 22, shows how each color, red, yellow, green, and blue look for those with tritanomaly compared to those with no visual impairment. The second type of blue-yellow color blindness is tritanopia. Tritanopia is the more severe version of blue-yellow color blindness. Making those who have it unable to tell the difference between blue and green, purple and red, and yellow and pink. Tritanopia also makes colors appear duller and less bright [3]. From figure 23, those with tritanopia see yellow as pink blue looking more green, and purple looking red with less vibrancy.

4.2.3 Complete Color Blindness

Those with complete color blindness, also known as monochromacy, are unable to see any colors. Monochromacy is not linked to sex and is very uncommon with 0.003 percent of people having this form of color blindness [2]. Those with monochromacy could also have trouble seeing clearly and may be sensitive to light [3]. Figure 24 shows what each color looks like for those with monochromacy. From the figure 24, those with monochromacy are only able to see different shades of gray instead of the different colors.

4.2.4 Blue Cone Monochromacy

Blue cone monochromacy, also known as BCM, is a rare genetic disease. Where one in one hundred thousand people have it. Blue cone monochromacy also almost exclusively affects males and it is hereditary. So those with family members with this genetic disease are likely going to have it as well. Blue cone monochromacy causes impaired vision, intolerance to light, and the poor ability to distinguish colors [1]. From figure 25, those who have blue cone monochromacy see colors with a gray tinge to them, making the colors less vibrant and dull.

4.3 Color Theory in Visualizations

When creating visuals, it is very important to keep in mind both the emotion of the colors you want to use and how they will look to those with color deficiencies. The most common color dificiencies you have to be careful of are the red-green color blindness's as they are the most common, but you should still be considerate of the other color blindness's as well. For this paper we will be looking at applying the above information to the Coronavirus state data. If you want to make the coronavirus look more deadly, try using a dark red color to signify the seriousness of the topic and how lethal the virus is, figure 26. A visualization that would not be as good, is one using yellow and blue, figure 27. While blue can be a serios color when used with yellow it appears brighter and calm, due to yellow being such a happy and optimistic color. So, if you want to make it seem like there is optimism in the virus maybe yellow is the color you want to use. But if you are going for a more serious visualization then yellow is not the way to go. One way to fix figure 27, is to change the blue for deaths to dark red and change the yellow to

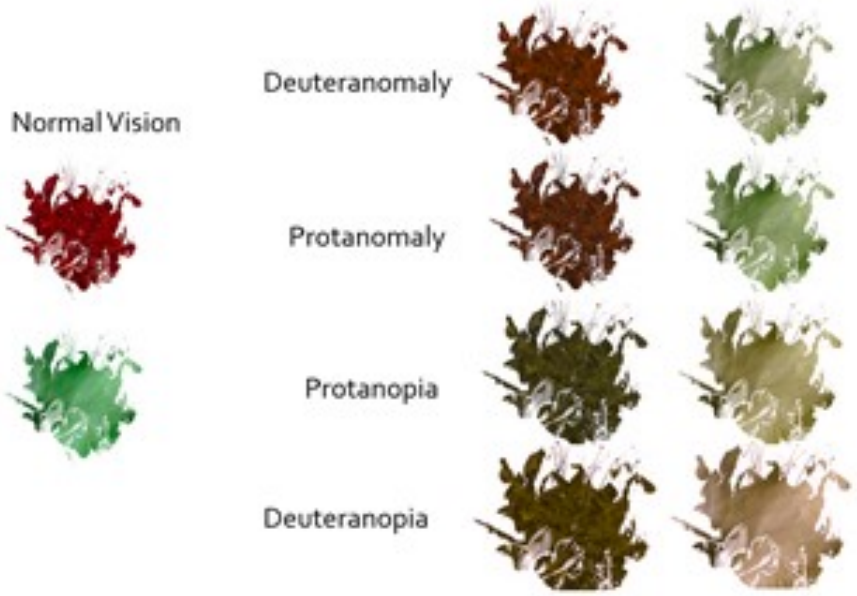

Figure 21: This image shows what those who have any of the four types of red-green color blindness see in comparison to those with no color deficiencies.

Figure 22: This image shows what those who have tritanomaly see in comparison to those with no color deficiencies.

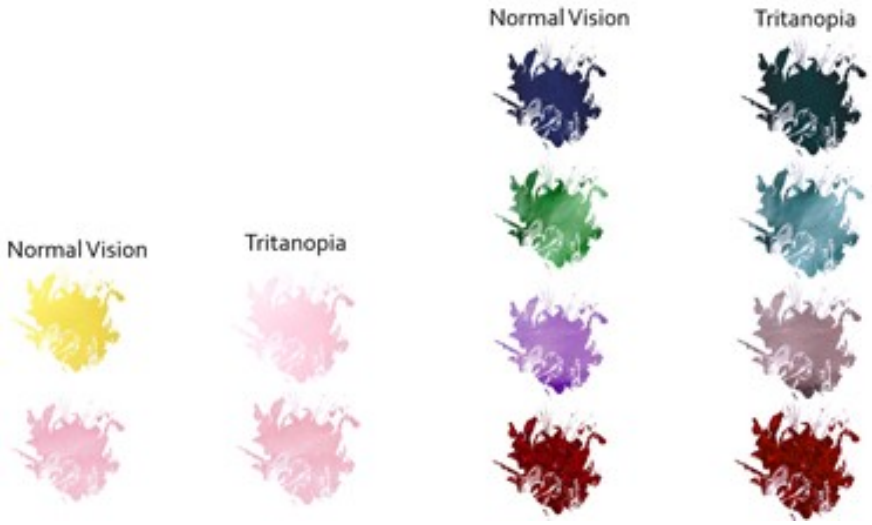

Figure 23: This image shows what those who have tritanopia see in comparison to those who have no color deficiencies.

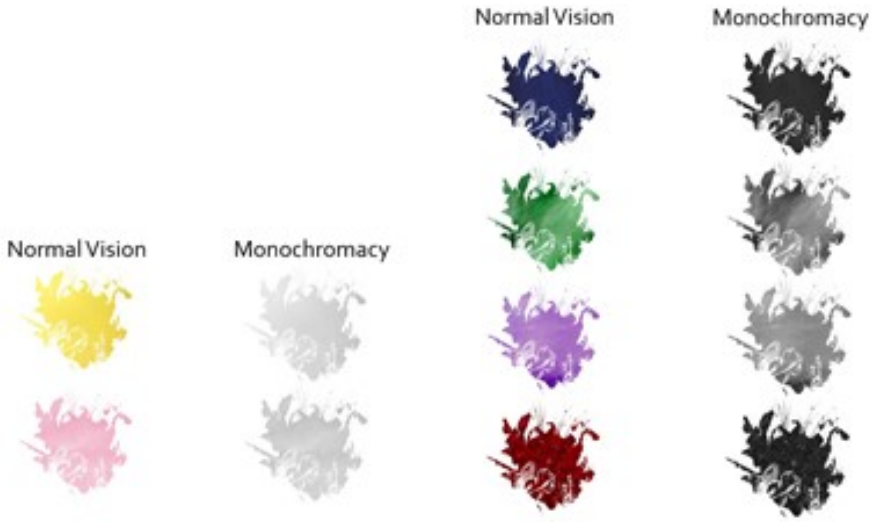

Figure 24: This image shows what those who have monochromacy see in comparison to those who have no color deficiencies.

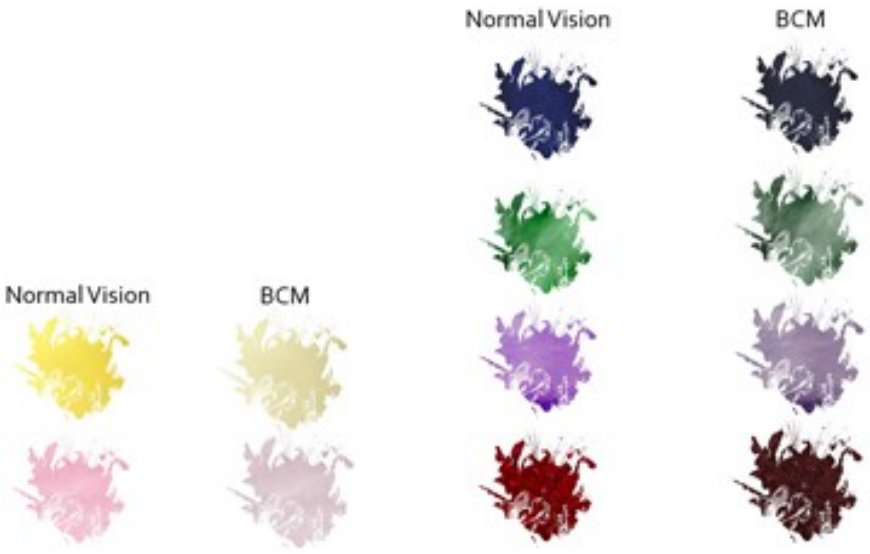

Figure 25: This image shows what those who have BCM see in comparison to those who have no color deficiencies.

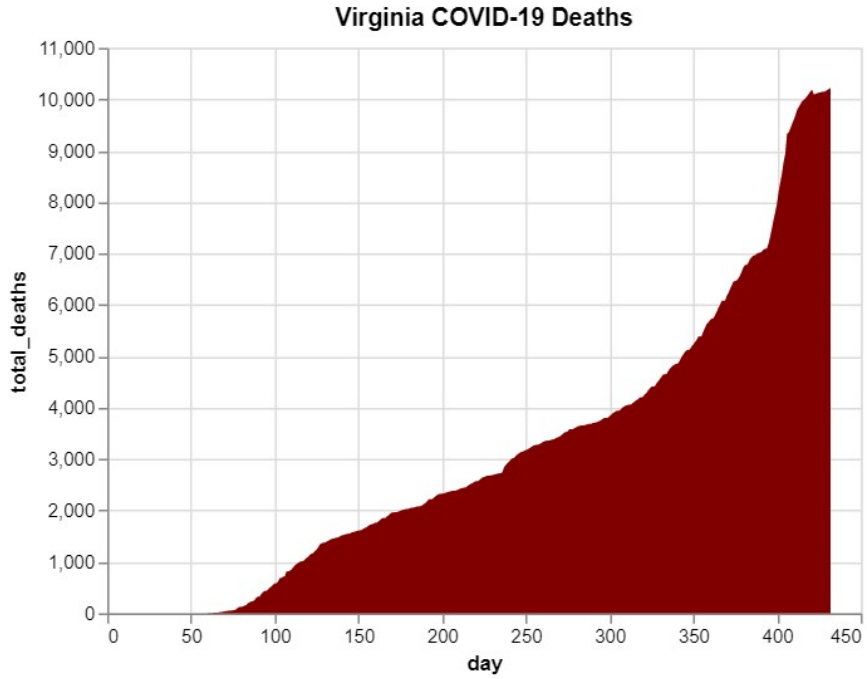

Figure 26: This figure shows a visualization marking the total number of deaths each day for Virginia.

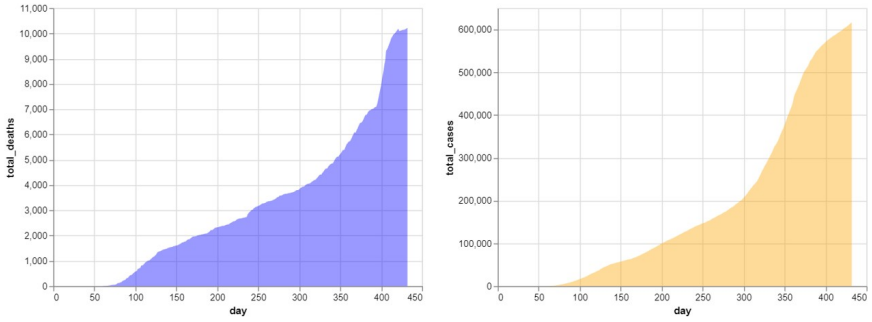

Figure 27: This figure shows a good visualization with bad, unmeaningful color choices that do not benefit the visualization.

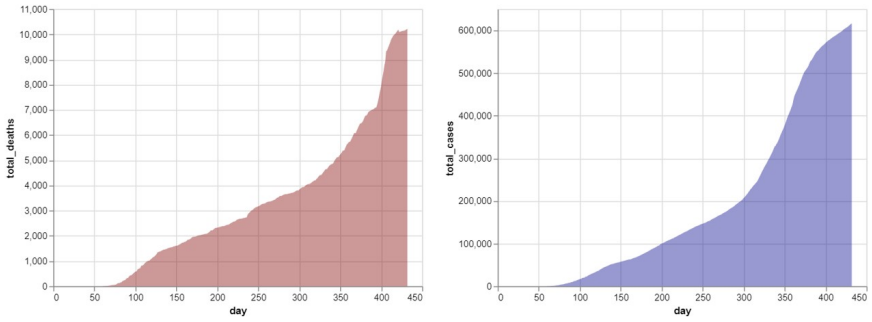

Figure 28: This visualization fixes the previous visualization, making the tone of the image appear somber and serious

dark blue, as seen in figure 28. The mix of dark blue and red will make the visualization appear more serious and somber.

Another good way of visualizing the coronavirus data between two states is to plot them on top of each other. In figure 29, we see how the total cases has increased each day in both Maryland, seen in blue, and Virginia, in orange. This visual was also made more significant by creating a tool tip that gives more information for each data point. For the example in figure 29, Virginia on day three-hundred-and-fifty-seven, January 12th, 2021 there were over four hundred thousand total cases and over fifty-five hundred total deaths.

There are also good and misleading visualizations, as seen in figure 30. In figure 30, the visual on the right is very misleading because it makes it look like Maryland has twice the number of deaths that Virginia does. When in reality, from the image on the left of figure 30, we see that while Maryland does have more deaths than Virginia for the majority of the duration of the virus. Virginia surpasses Maryland in the last fifty days spiking much higher than the Maryland deaths. So, the better visualization would be the one on the left, showing the real comparison between the two states. If for some reason you really wanted to use a stacked area plot. A better version would be to normalize the stacked area plot creating a better, more accurate visualization, figure 31.

Now using the normalized stacked area chart, it is also important to remember what colors work best for each visualization. So, in figure 32, we see that there is a good color choice on the left and a bad color choice on the right. Not only do the colors on the right have no meaning to deaths and the coronavirus, but they also are hard to see for both people with normal vision as well as those with red-green color deficiencies. When run through a color blindness simulator [15], we see that even with the two red-green deficiencies, the visual on the right is much harder to read than the one on the left, figure 33. When looking at the two red-green color blindness's, it becomes almost impossible to tell the difference between Maryland and Virginia, figure 34. While the visualizations on the left are still easily distinguishable for all four color deficiencies.

5 Conclusion

In conclusion, color theory in visualizations is important, as is the location on where you are sharing your visualization as each country might have a different emotional attachment to every color. With color theory we were able to determine how color can change the meaning behind a visualization. We also learned that colors do have emotional appeals. Where darker colors are more serious, lighter colors are usually happier and optimistic. The paper also discussed how important it is to keep in mind the different color deficiencies when creating your visualization, so it is accessible to everyone. We also learned that red-green color deficiencies are the most common with around eight percent of all males having one of the four different types of red-green color blindness. In this paper, we also learned how to properly apply color theory into visualizations to portray the meaning you want the viewer to agree with, as the color is the first thing people notice when looking at a visualization and it sets the tone for the rest of the visual.

6 References

References

[1] BCM – blue cone monochromacy.

[2] Color blindness. Page Version ID: 1021358238.

[3] Types of color blindness | national eye institute.

[4] United states COVID-19 cases and deaths by state over time | socrata API foundry.

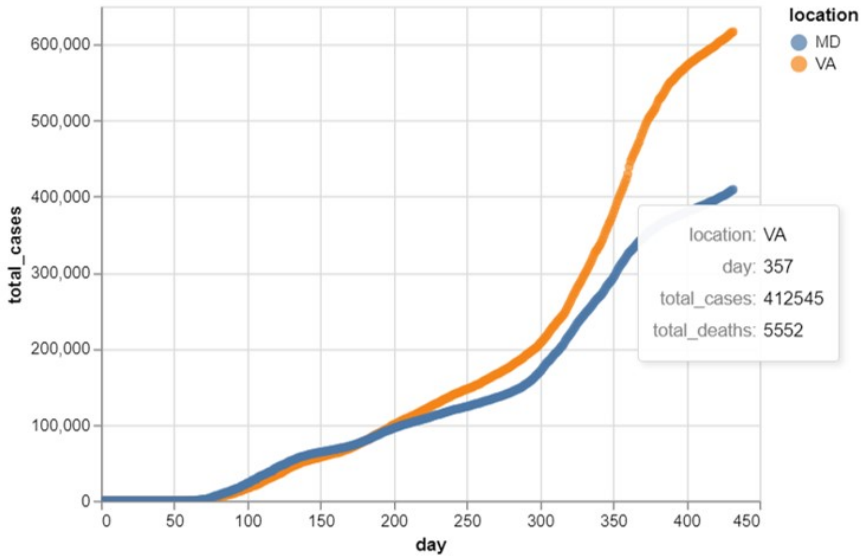

Figure 29: This is a good, meaningful visualization that shows important data by hovering over a point on the plot. Each point gives the information regarding the state, day, total cases, and total deaths.

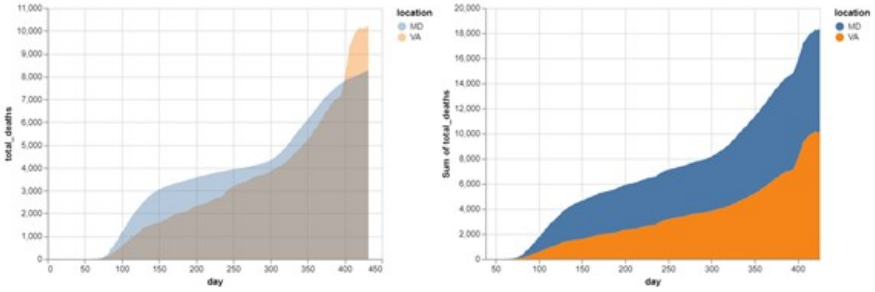

Figure 30: The figure on the left shows a good visualization, accurately depicting the total deaths in both Virginia and Maryland for comparison between the two states. The figure on the right shows a bad visualization that makes it look like Maryland has had twice the number of deaths that Virginia had due to the two state plots being stacked on top of each other.

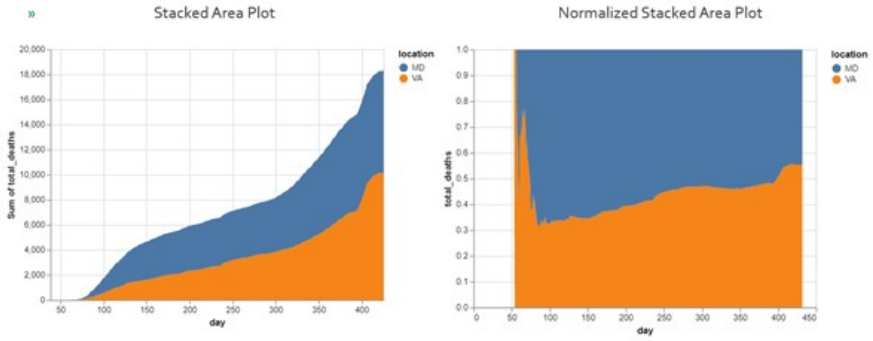

Figure 31: The figure on the left is the same stacked area plot that was shown on the right in figure 30. The plot on the right is a more accurate depiction for the two states, showing a normalized stacked area plot.

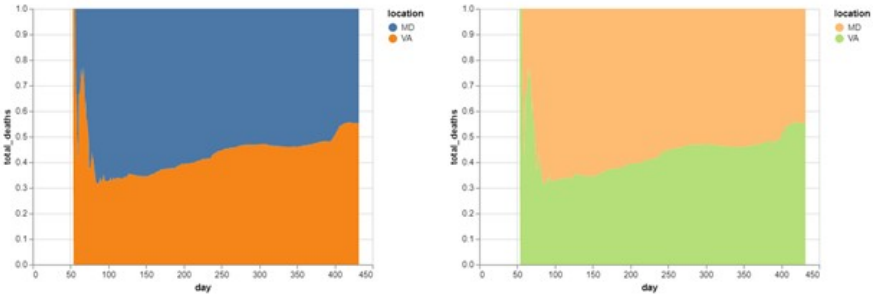

Figure 32: This figure uses the same plot from the right side of figure 31, but it has a bad color choice of the same visualization on the right that has no color meaning to deaths or the coronavirus. This figure will be used to show color blindness comparisons.

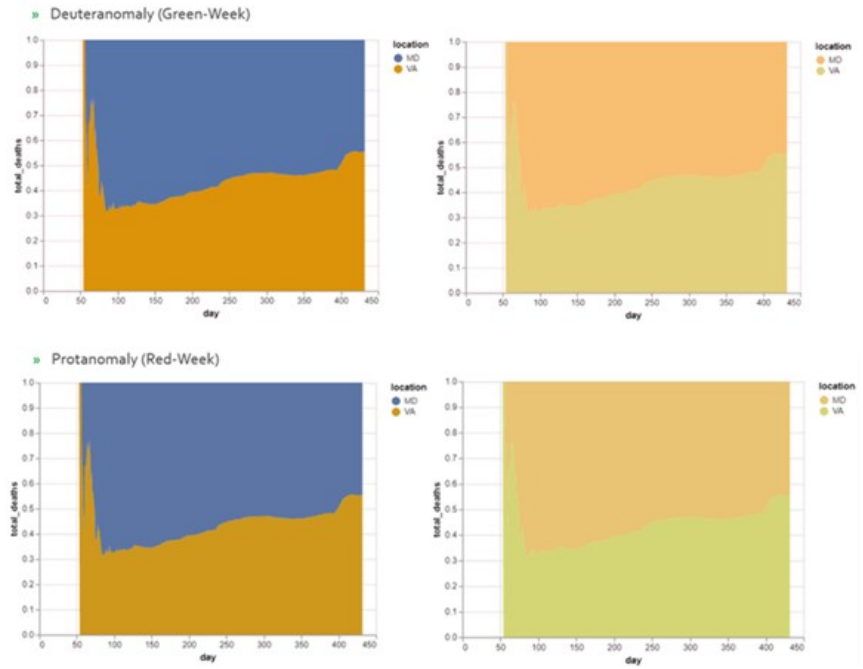

Figure 33: This figure shows a color blindness check for those with deuteranomaly (green-week) and protanomaly (red-week).

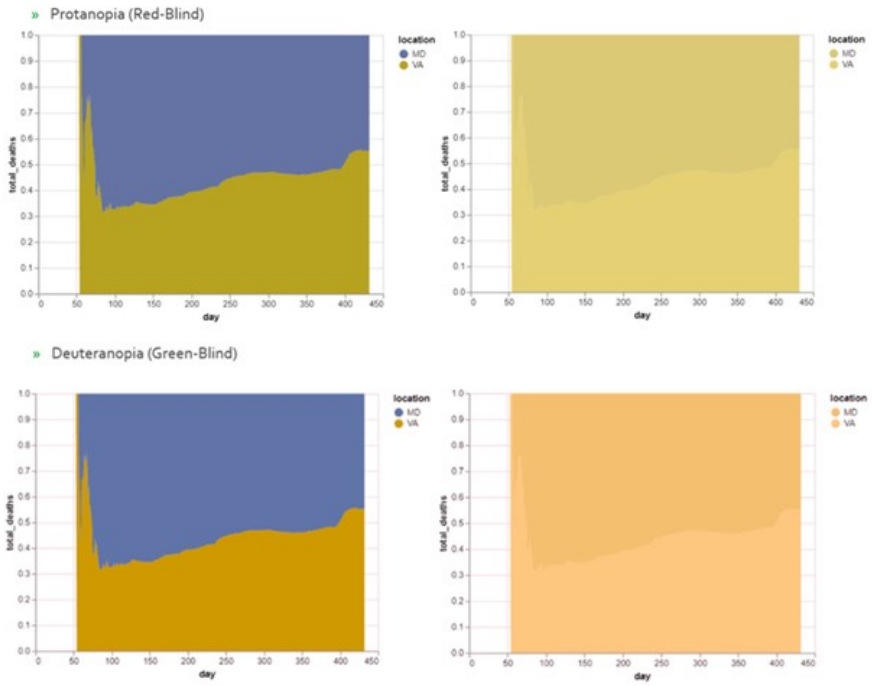

Figure 34: This figure shows a color blindness check for those with Protanopia (red-blind) and deuteranopia (green-blind).

[5] What is color theory?

[6] Hailey van Braam. Black color psychology - black meaning & personality.

[7] Hailey van Braam. The color psychology of blue.

[8] Hailey van Braam. The color psychology of green.

[9] Hailey van Braam. The color psychology of red.

[10] Hailey van Braam. Orange color psychology - orange meaning & personality.

[11] Hailey van Braam. Pink color psychology - pink meaning & personality.

[12] Hailey van Braam. Purple color psychology.

[13] Hailey van Braam. White color psychology - white meaning & personality.

[14] Hailey van Braam. Yellow color psychology - yellow meaning & personality.

[15] Matthew Wickline. Coblis — color blindness simulator – colblindor.