

Experiments on Effective Color Combinations in Map-Based Information Visualization

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ABSTRACT

The effect of harmonious versus non-harmonious color combinations in one aspect of information visualization effectiveness is considered. One focus is the relative suitability of two competing paradigms for determining color combinations that are harmonious. A second focus is the suitability of using opposing (i.e., opponent) colors for feature presentation in information visualization. The effects are considered for color item overlays on crowded and non-crowded displays. A statistical analysis of human responses is also presented.

Keywords: Color harmony, Color Opponent theory, Information Visualization

1. INTRODUCTION

Color is often used as a cue in the visualizing of many types of information. One concern in using color is which color combinations create effective impressions of different types (or levels) of information for users. Recently, there has been interest in the visualization community in the relationship between color combinations that have harmony, which is defined as a set of colors that are aesthetically pleasing together to the human perceptual system, and aspects of visualization effectiveness. Here, we report findings that extend insights into which color combinations are suitable choices in information visualization. We explore the effect of color harmony and color opponency on a feature's noticability (visibility).

Color opponency, which is a color theory based on the human visual system, is based on the notion that there are three separate opponency channels in the vision system. The opponency channels are red versus green, blue versus yellow, and white versus black. In each opponency channel, the two main colors of the channel are antagonistic to each other. Opponent color theory was proposed by Hering [2]. The concept of hue cancellation, which is based on opponent theory and was proposed by Hurvich and Jameson [4], says that the mixture of red and green light produces yellow and the mixture of yellow and blue light produces white (i.e., the red and green hues cancel each other as do yellow and blue since each combination produces a color of another opponency channel).

One early theory about color harmony, attributed to Goethe, is based on Goethe's hue circle. Using the hue circle, colors are categorized as positive or negative depending on where they lie in the hue circle. Each location in the hue circle is associated with one color. Colors in the Goethe's hue circle are harmonic if they are opposite one another. Har-

monic colors, used together, can create a beautiful effect [1]. Another theory of color harmony was proposed by Ostwald [3]. In that theory, color is a spinning mixture of three sensations: full color (the most chromatic color), ideal white, and ideal black. Colors are harmonic if they have properties that satisfy a particular simple relationship called the color-order relationship. Ostwald claimed that he could find all harmonic colors by analyzing all the orders of color which his color solid and the double-cone would allow, and that he could do this according to the rules of geometry.

Munsell [5] proposed that the key factor determining harmony was the balance between the strength and the color display area. By strength, Munsell means the product of its value and chroma. Colors in Munsell theory are based on three dimensions: hue, value, and chroma. In this dimensional arrangement, perceptual difference between two neighboring colors is almost constant in each dimension (i.e., physical distance between colors in the system is strongly correlated to the perceptual response difference between the colors). Colors with higher values and chroma in the Munsell system appear “stronger.” Itten [6] proposed that colors are harmonic if their mixture creates a neutral grey.

Nemcsics [7] proposed several properties describing color harmony in another color system, the ColorOid system. He claimed that colors are harmonic only when they have a contrast relationship in at least one of the three attributes of the system: hue, saturation, and lightness. He believed that color pairs whose hue angle is between 25 and 43 degrees or between 121 and 139 degrees are harmonic [4].

In the rest of this paper, we describe experiments we have done to determine if harmonious colors are advantageous over disharmonious colors in map-based information visualization. The paper is organized as follows. First, related work is discussed. Then, in Section 3, the experimental setup is described. Experimental results and analyses are then presented in Section 4.

2. Background And Related Work

Next, some background about color theory and harmony is discussed.

2.1 Color and Human Vision

Grayscale displays of information are readily discerned since the human visual system is sensitive to variations in brightness. However, the number of gray levels that can be perceived as distinct by the human eye is limited. Thus, using color can allow more total levels or values to be utilized in a visual presentation. Also, using color in visualization of information could make the presentation more appealing to end users. Presentation of a feature or structure in a distinct color can make it easier to distinguish it from background and other features or structures.

Human experience of color depends on the reflectivity of the object and the visual system’s processing. Objects themselves appear in color because they reflect light of particular wavelengths of the visible spectrum. The human eye can sense light at wavelengths from 380 nm to 740 nm. The visual system is able to distinguish thousands of colors from one another.

Color can be viewed as being made up of three properties or qualities: hue, brightness, and saturation. Hue is one of the best-known properties of color. Many hues have names (such as red, blue, etc.); some colors are well distinguished by name. Brightness refers to intensity. Saturation refers to a combination of light intensity and how the wavelengths of the color are distributed across the spectrum. Different sets of light energy that produce an identical color

sensation are called *metameric* sets. Two colors of light are called *complementary* if they produce white when combined together. Since the color of sunlight varies over the span of a day (e.g., late afternoon light contains more long wavelengths than does noon-time light) in outdoor scenes, the light reflected by outdoor objects will vary from time to time. Surfaces containing different pigments reflect light in differing distributions of wavelengths and therefore appear to be different colors. The light reflected from a surface depends on the pigments in the surface and the type of illuminating light [8].

In the human eye, the cones enable distinguishing colors. They also provide input to other perceptual processes at normal levels of light. There are three types of cones, the short-wavelength or S-cones, the middle-wavelength or M-cones, and the long-wavelength or L-cones. The eye is called trichromatic since it has three cone types.

Each cone type is sensitive to light of a particular wavelength. The S-cone is sensitive to light between 400 and 500 nm. Its peak wavelength is 420-440 nm. The M-cone is sensitive to light between 450 and 630 nm. Its peak wavelength is 534-545 nm. Finally, the L-cone is sensitive to light between 500 and 700 nm. Its peak wavelength is 564-580 nm. There is a large separation between S cones, which helps to explain the inferior ability (i.e., to other colors) to resolve fine details of blue objects [8].

2.2 Opponent Color Theory

Opponent color theory is based on the psychological relationship between certain hues. As a result of the opponency in the three opponency channels, we never experience red and green or blue and yellow simultaneously since they are opponent colors. Hering theorized that opponent colors exist because the sensations of two opponent channels (red-green and blue-yellow) are encoded in a single visual pathway. The excitation of the pathway causes the sensing of one opponent color and inhibition of the other opponent color [9]; opponent color works based on the process of excitatory and inhibitory responses. For example, red creates a positive (or excitatory) response while green creates negative (or inhibitory) response. These responses are controlled by opponent neurons that have excitatory responses to some wavelengths and inhibitory responses to others [9].

In data visualization, color will ideally be used in effective ways. One approach to gain more control over color is to choose colors using a perceptual based color model, like the CIELUV, CIELab or Munsell models. CIELUV color system is based on luminance and chromaticity [10]. The Munsell color system is a color space that specifies color based on three dimensions: hue, value (or lightness), and saturation [10, 11]. Using these systems, color properties, such as distance or separation between colors or color categories, could be used in formal ways to select color combinations for information visualization. While the Munsell model is perceptually based, it should be noted that color spacing in it is not aesthetically (i.e., perceptually) uniform [23].

2.3 Color Harmony Theory

Harmonic colors are ones that produce an aesthetically pleasing perception when viewed together. Historically, study of color harmony has been related to study of the physical nature of light and color. In many color spaces, harmony is related to relative position of the colors in color space. One key work of modern color theory was Itten's introduction of a color wheel based on hue in which harmony is determined by the relative position of hues on the color wheel. Itten's hue wheel included 12 named colors, with primary colors of cyan, magenta, and yellow. In Itten's scheme, com-

plementary colors are called *two-color harmonies*. If three colors are harmonious together, they will form an equilateral triangle in his hue space. If four colors are harmonious together, they will form a square. If six colors are harmonious together, they will form a hexagon, etc. [6, 13].

There are several other forms, schemes, and relations in color spaces that describe harmonious colors [13]. For example, Matsuda and Tokumaru [14] have defined a color scheme with eight hue and ten tone types. Thus, the hue and tone type combinations yield 80 color combinations.

Some color harmony principals for two-color combinations have been developed. For example, equality in hue strongly supports colors to have harmony. Combinations of lighter colors also tend to have more harmony. The lightness differences between colors must also be neither too small nor large for the color combinations to be harmonious. Also, blue colors have a tendency to be harmonic with other colors [15].

2.3.1 ColorOid

An alternative color space to Itten's color wheel is the ColorOid Color System developed by Nemesics. It assumes illumination by sunlight and an observer with normal color vision. The system aims to space colors evenly in terms of their perceptual effect. ColorOid can categorize colors that exist in nature that cannot be displayed on a computer screen. Some high preferred hue-differences can be recognized by analyzing the curve of the harmonic saturation, with maximal harmony occurring for colors separated by $\pm 12, 35, 130, 180$ degrees [16, 17, 22].

Using ColorOid a set of two or more colors are harmonic if:

- a) They have the same hue (A) and saturation (T), but their luminosity (V) color characteristic represents an arithmetical or geometrical sequence, or
- b) They have the same A and V characteristics, but their T color characteristic represents an arithmetical or geometrical sequence, or
- c) The color characteristics of two above cases are same but their T and V color characteristics change jointly on one straight line.

3. Experimental Results

Next, we present our experiments of color harmony in information visualization. Our aim is to test the relationship between color harmony and one aspect of a presentation's effectiveness: visual attentiveness to (noticeability of) certain visual information. While we focus on foreground and background coloring, other issues in the use of various visual metaphors remain. In particular, we note that other parameters (which are beyond our scope here) are also involved in noticeability, including the size of the item of interest, its position with respect to other items, and item style (e.g., size or style of glyph or other visual cue). (Recent work by Ziemkiewicz and Kosara [24] may interest readers keen on some other issues in the use of visual metaphors.) In this work, we use color label overlays on maps to test noticeability. Two experiments were conducted and are described next.

3.1. Software and Tools

We used certain software and tools in our experiments. The background color and harmonious foreground color were chosen according to the Color Wheel system (of Itten) using the ColorWheel expert software package. For finding

harmonic combination of colors according to the ColorOid color system, we used the ColorOid Professional software package was used. Then, new overlays were made on the maps in the determined foreground color using OpenGL.

3.2. First Experiment

In the first experiment we explored the reported noticeability of a visual cue rendered in a harmonious color. The experiment involved overlay of symbology on four visualizations of the spatial distribution of political information for regions of a U.S. state (Alabama). The overlays each were done over a different background color for the major information with the tested cue overlaid as foreground on this background. The colors of the overlaid cues were harmonic with the background in three cases. Using the ColorWheel system, there are certain known "templates" of harmonious color combinations. Each template is named after a particular "shape" defined by the harmonious color positions it defines in the color space. The templates used were the i-Type, T-Type, and X-type harmonies. In each case, we selected the foreground color to be harmonious with the background color; the foreground color satisfied the template relation with the background. For comparison, a foreground color that was non-harmonious according to all templates was tested, too. The colors were chosen using the ColorWheel Expert software to ensure color correctness. Thirty persons participated in the experiment, viewing the visualization on a laptop with a moderate resolution monitor.

3.3. Second Experiment

In the second experiment, we investigated the reported noticeability of a visual cue rendered in colors chosen from the opponency ColorOid versus the Color Wheel color space. Five visualizations were utilized. Two classes of tests were done, as described later. The experiment involved overlay of symbology on visualizations of political information for various geographic regions. The symbology was crowded on two of the visualizations (as shown in Figures 1 and 2). The symbology was not crowded on three other visualizations (as shown in Figures 3, 4, and 5).

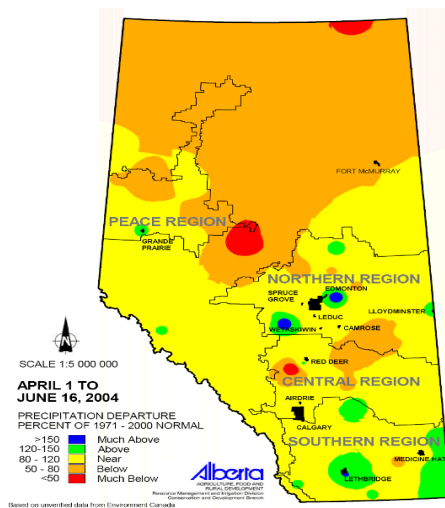


Figure 1: Crowded Symbology #1



Figure 2: Crowded Symbology #2



Figure 3: Non-Crowded Symbology #1

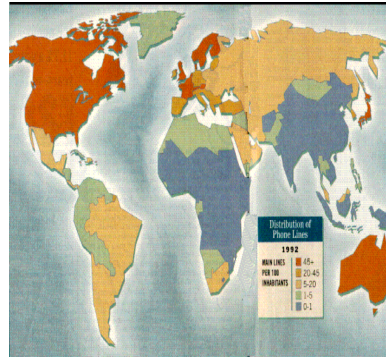


Figure 4: Non-Crowded Symbology #2



Figure 5: Non-Crowded Symbology #3

Color selection from two color spaces were tested in the experiment. The ColorWheel Expert and ColorOid Professional software package were used to select color from ColorWheel and ColorOid space, respectively. Thus, ten maps' overlays were used. For finding the color value of the harmonious and non-harmonious color overlay in each color space, we determined the RGB value of the background color and then found color combinations that were harmonious and non-harmonious with this color in both the ColorWheel and ColorOid color systems. The non-harmonious overlay color was chosen by selecting an opposing, non-harmonious color in the ColorWheel space. Only two visualizations were used for that testing. We tested colors from both the ColorWheel and ColorOid systems to find some evidence of the effect that a strong perceptual basis for a color system has on noticeability of harmonious colors. Figures 8 and 9 show two of the visualizations of political information with the harmonious overlays that we used in the experiment. Forty persons participated in the experiment.



Figure 8: Crowded #1 with new Symbology



Figure 9: Non-Crowded #3 with new Symbology

A common environment was maintained through the experiments. For example, the same monitor was viewed by all participants. A randomized order of presenting the visualizations was also used to limit biases potentially introduced by presentation order. The overlays in the experiment were labels of place names. To minimize personal knowledge biases, relatively unknown place names were used. For the tests involving a non-crowded symbology, participants read the overlaid labels in any order they wanted, which produces some data about which labels are most noticeable. For

the test involving crowded symbology, participants were timed on the task of finding certain labels. In the second experiment we also wanted to find if gender or other traits were factors.

3.4. Response Summaries

Table 1 shows summaries of responses of the 40 participants in the second experiment. The average time, minimum, maximum, and standard deviation of response time (in seconds) for each tested visualization (labeled Map 1 to 5) are shown for the ColorOid (Oid) and ColorWheel (W) color space tests, broken down by female (F) and male (M) responses.

	Map1				Map2				Map3				Map4				Map5			
	Oid		W		Oid		W		Oid		W		Oid		W		Oid		W	
	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F	M	F
Mean	4.2	2.3	4.1	3.8	3.2	2.6	3.1	2.5	5.8	5.9	5.9	6.3	6.3	6.4	4.3	4.5	8.5	8.9	8.2	8.4
Min	1.8	1	2.1	1.5	1.5	1.2	1.5	1.2	4.6	4.6	3.5	3.2	4.6	3.9	2.8	3.8	7.3	5.5	5.4	4.1
Max	15.5	5.2	11.2	9.3	6.8	5.4	6	5.1	7.5	7.1	7.1	7.1	7.3	7.5	5	6.4	10.7	11	10.8	10.7
Std. Dev.	3.12	1.17	2.27	2.25	1.40	1.20	1.16	0.87	0.70	0.61	1.00	0.90	0.80	0.80	0.50	0.60	0.86	1.44	1.47	1.94

Table 1: Time (in sec.) for reading labels on Maps1 to 5. Label colors selected using ColorOid (Oid) or ColorWheel (W), Female (F) vs. Male (M).

The Table 2 shows the average time, min, max, and standard deviation of response time (in seconds) the participants took for self-directed label reading exercise.

	Map1		Map2		Map3		Map4		Map5	
	Oid	W	Oid	W	Oid	W	Oid	W	Oid	W
Mean	3.3	3.9	2.9	2.8	5.8	6.1	6.3	4.4	8.7	8.3
Min	1.8	1.9	1.5	1.8	5	4.4	4.3	3.6	6.8	5.5
Max	10	7.4	6.1	4.8	6.4	7.1	7.1	5.5	9.7	10.3
Std. Dev.	1.97	1.53	1.17	0.89	0.4	0.65	0.64	0.39	0.69	1.36

Table 2: Average time (in seconds) for reading the harmonious label overlays on five maps for symbology color selected from the ColorOid (Oid) versus ColorWheel (W) space.

In Table 3, we show the average time, min, max, and standard deviation of response time (in seconds) for reading labels overlay on all maps (labeled Map 1 to 5) for each gender.

Color Space	Gender	Mean	Min	Max	Std. Dev.
Oid	F	5.21	3.9	6.1	0.56
Oid	M	5.59	4.6	8.4	0.887
Wheel	M	5.14	4.2	6.3	0.45
Wheel	F	5.11	3.7	6.6	0.702

Table 3: Time statistics (in seconds) for reading the harmonious label overlaid on five maps. Color of the labels selected using ColorOid (Oid) or ColorWheel (W) for Female (F) and Male (M) participants.

Table 4 shows the average time, min, max, and standard deviation of response time (in seconds) for reading labels overlay on all maps (labeled Map 1 to 5) using ColorOid and Color wheel color system.

Color Space	Mean	Min	Max	Std. Dev.
Oid	5.34	4.5	6.1	0.418
Wheel	5.14	4.5	5.8	0.417

Table 4: Total average Time (in seconds) for reading the harmonious label overlays on five maps. Color of the labels is based on ColorOid (Oid), or ColorWheel (W).

We used two maps (Figure 10 and 11) for comparing non harmonious versus harmonious colors selected using ColorWheel space harmony rules. Tables 5 and 6 present the average time (in seconds) for reading the 13 labels of two maps. They are based on the ColorWheel color system for females versus males. Each column summarizes one label.



Figure 10: Non-harmonious #1

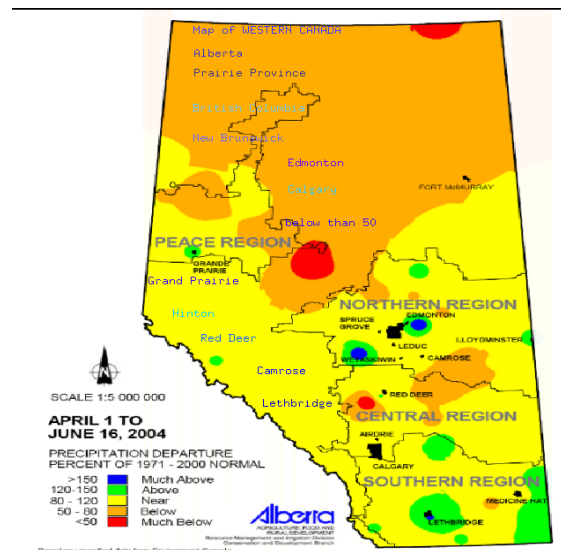


Figure 11: Non-harmonious #2

	Color Space	Label #												
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Map1	Opponent	3.2	5.1	3.80	4.1	1.8	3.60	2.6	3.2	3.0	1.4	3.2	1.7	2.6
	Harmony	5.2	5.25	4.9	4.6	3.30	2.9	3.3	2.90	4.85	4.6	4.9	2.9	3.45
Map2	Opponent	1.60	3.5	2.0	2.4	2.9	2.5	2.20	2.0	1.7	2.1	1.9	2.9	1.7
	Harmony	3.0	3.8	3.0	3.30	3.0	3.5	4.0	3.0	3.0	2.3	3.8	4.0	3.0

Table 5: Time (in seconds), per label, for comparing readability of the labels on two visualizations based on inharmonious (Opp) and ColorWheel (Harmony) for male participants.

	Color Space	Label #												
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Map1	Opponent	2.9	3.3	3	3.5	2.4	1.6	1.5	2.4	2.1	1.3	1.4	1.8	2.5
	Harmony	3.6	5.15	3.9	5.4	4.1	2.8	2.3	4.5	3.85	3.6	3.9	3.5	3.2
Map2	Opponent	1.10	2.4	2.0	1.5	1.7	1.4	1.8	1.4	1.9	1.9	0.9	1.3	1
	Harmony	1.7	4.0	2.0	3.4	3.0	2.8	2.0	3.0	2.0	1.9	2.3	3.0	2.3

Table 6: Time (in seconds), per label, for comparing readability of the labels on two visualizations based on inharmonious (Opp) versus harmonious (Harmony) for female participants.

Table 7 compares average time (in seconds) for reading the labels on these two maps. Color of the labels chosen based on Opponent color and ColorWheel color system. Each column is the summary for one label.

Color Space	Label #												
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Opponent	1.7	4	2	3.4	3	2.8	2	3	2	1.9	2.3	3	2.3
Harmony	3.2	5.1	3.8	4.1	1.8	3.6	2.6	3.2	3	1.4	3.2	1.7	2.6

Table 7: Average time (in seconds), per label, for comparing readability of the label overlays based on inharmonious (Opp) versus harmonious for all participants.

4. Analysis of Results

Next, we analyze the results. The analysis includes statistical testing of significance.

4.1. Compare ColorWheel with ColorOid color space

Our results suggest for visualizations involving a crowded display, choosing harmonious colors in the ColorWheel space produce more pleasing and readable results than choosing them in the ColorOid space. However, for non-crowded maps, the ColorOid system yielded more pleasing colors. The timed experiments suggest that task completion time may be roughly equivalent no matter which color space the colors were chosen. The participants and data were too close to each other, so there were not many significant differences between ColorWheel and ColorOid.

4.2. Inharmonious Overlays

Our first experiment focused on visibility of harmonious or non-harmonious colors. A prior report indicated that colors separated by 80 degree on the color wheel space are the most non-harmonious combination [16]. That work also indicated that colors separated by 150 degree are non-harmonious, but less than colors separated by 80 degrees. In our experiment, we found that colors separated by 150 degrees on the color wheel space were slightly more visible together than colors separated by 80 degrees.

In the second experiment, as shown in Figures 10 and 11, we compared ColorWheel and Opponent (non-harmonious) color in crowded maps. We used a Blue-Yellow combination of colors for background and label and compared with ColorWheel. There were twenty participants in this part (10 Female and 10 Male). Here, there was a big difference between non-harmonious color and ColorWheel selected harmonious colors for map labels.

4.3. Statistic test on Results

We conducted statistical testing to determine significance of our results, including independent T-Test, Paired T-Test, and ANOVA. These tests outcomes are presented next.

4.3.1. Independent T-Test or Two Sample T-Test for First Experiment

We used T-testing to determine the statistical significance of visibility responses for various separation angles between color pairs. (Testing was done for the color wheel space.) We focused on visibility for colors separated by 80 and 150 degrees for female and male participants. Table 8 shows the results. Based on this test, there is not a statistically significant difference between 150 degree and 80 degree separations for both participants.

t-Test: Two-Sample Assuming Equal Variances (i-type for Female/Male participants)		
	80 degree	150 degree
Mean	6.04	6.39
Variance	34.2486	11.9684
Observations	14	14
df	26	
t Stat	-0.1966	<1.7056
P(T<=t) one-tail	0.4229	> .05 (alpha)
t Critical one-tail	1.7056	

Table 8: Independent t-test for comparing legibility of labels with 80 and 150 degree separation in color wheel for male and female participants.

4.3.2. Independent T-Test or Two Sample T-Test for Second Experiment

For comparing statistical significance of response differences for different demographics (Female/Male, Graduate/Undergraduate, and With/Without glasses) we used T-testing. We were able to do this since scatter plots and residual plots of the data suggested that the data were normally distributed. With Two Sample T-test we answer one question here: is there any significant difference between female and male for legibility of labels based on ColorWheel or ColorOid?

Table 9 shows the result of independent t-testing for the comparing noticeability of labels with color chosen based on ColorOid color system for male and female participants. As the table shows, the mean for overlay colors selected using ColorOid is lower for males than for females. However, this difference was not significant at the .05 level.

(Labels with ColorOid is more legible to Male than Female)		
	Female	Male
Mean	5.59	5.21
Variance	0.7890	0.3111
df	35	
t Stat	1.5351	< 1.6896 (tcritical)
P(T<=t) one-tail	0.0668	

Table 9: Independent t-test for comparing legibility of labels with color based on ColorOid (Oid) for male and female participants.

4.3.3. Paired T-Testing

We also tested if there was any significant difference between color harmonies chosen using rules of harmony in the ColorWheel and ColorOid systems. Table 10 summarizes the two sample t-test for comparing legibility of labels with color harmonies chosen based on ColorWheel versus ColorOid color systems. As the table shows, there is a statisti-

cally significant difference; overlay colors selected using a ColorOid harmony are more noticeable than overlay colors selected using a ColorWheel color system harmony.

(ColorOid preferred to Color Wheel by Male Participants)		
	ColorOid	ColorWheel
Mean	5.59	5.17
Variance	0.789	0.2251
Pearson Correlation	-0.1924	
df	19	
t Stat	1.7298	>1.7291(tcritical)
P(T<=t) one-tail	0.04994	<0.05

Table 10: Paired t-Test for comparing legibility of labels colors chosen from ColorWheel (Wheel) or ColorOid (Oid) for male participants.

4.3.4. ANOVA Test

ANOVA testing was then applied to find if there is any significant difference for each map for each category for ColorWheel and ColorOid. We compared the mean of each category in each color system for each map, then we checked if $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5$. By this test we were able to determine that there is a significant difference between ColorWheel and ColorOid for each map. Results of the test are shown in Table 11. From this, we conclude that in general ColorOid is a preferred choice for selecting overlay colors that have high legibility.

SUMMARY						
Groups	Count	Sum	Average	Variance		
ColorOid	20	108.08	5.404	0.2331		
ColorWheel	20	102.135	5.107	0.1655		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F critical
Between Groups	0.8836	1	0.8836	4.4333	0.0419	4.0982
Within Groups	7.5736	38	0.1993			
Total	8.4572	39				

Table 11: ANOVA test for comparing legibility of labels colors chosen from ColorWheel (Wheel) or ColorOid (Oid) for all participants.

5. Conclusion

Noticeability of the label overlays on the map depends on the background color, surrounding areas, and the position of the labels, size, font and some other aspects. In this paper our focus was on background color and surrounding color for the label. Choosing effective color for the labels on the map can follow one of the color theories. Our experiments considered two color spaces and tried to determine which color space theory about harmonious colors creates the most visible and pleasing effect in the human visual system, especially to determine which color combination creates the highest visibility for overlaid on maps.

Future studies of visibility's relation to color harmony could be valuable. Some things we would like to investigate include perceptions by different demographic groups. For example, it would be interesting to determine if age or known eye disorders, such as glaucoma, cataracts etc., affect the relations of perceived visibility with color separations. Such results can benefit geographers, social science, urban researchers, and more.

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