Using Eye Tracking to Investigate Saliency of Color Attributes for Digital Interfaces with Icon Matrix Arrangements

Analysis on the effects of hue, tone and color combination on visual attention and saliency

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Abstract: The purpose of this study is to determine which colors are most eye-catching in displays that employ icon matrices, and thereby provide empirical grounds for strengthening the visual information structure of interface designs. The experiment observes 3 aspects of color; hue, tone, and color combinations. Based on the HSB (hue, saturation, brightness) color system, a total of 21 stimuli were composed using 25 color patches arranged in a 5 by 5 matrix with a black background. All eye movements were recorded using the Tobii Eye Tracking Glasses. Part I, focusing on hue, indicated that warm colors are most eye-catching relative to cool and neutral colors. Part II, investigating tonal influences, revealed highly saturated colors provoked the greatest visual magnetism against a black background across all hue groups, although there was a slight exception for blue hue. Against expectations, brightness resulted inconsistent patterns among all stimuli. In regards to color combination, Part III provided empirical verification that high contrast between foreground and background generates more dominant conspicuity. Conclusively, these results can be used to create effective communication for interfaces displaying icon matrices by guiding visual attention and increasing aesthetic satisfaction.

Key words: Color Saliency, Eye-tracking, Icon Interfaces, Hue, Tone, Color Combination

1. Introduction

With the widespread of smart technology, interface designs of electronic devices such as computers, smart phones, tablets and smart TVs, are becoming increasingly important. Typically, these devices employ interface designs that display multiple icons arranged in matrices. In such graphical arrangements, icon sizes and shapes tend to be relatively homogenous to create organized structures that enable efficient and systematic processing of visual information. There have been studies that investigate the effects of spacing and size of individual interface elements on their perception [6]. Yet, the effects of inter-element spacing were found to be minimal when concerned with icons.

Color, on the other hand, is opened to a large degree of freedom and can be exploited to give icons distinctive appeal and/or emphasize particular meaning. Color not only accounts for 80 percent of the human visual experience, but is one of the most powerful information channels among human senses [1] that cannot be underestimated in the field of design. In fact, color variation is one of the most intuitive ways to effectively portray the priority levels of visual information. Unfortunately, the visual presentation and selection of color can often be weighed in heavily by the subjectivity of the designers and in some occasions, can hinder how accurately visual information is perceived by a viewer [9]. Therefore, there is a need for an unbiased guideline that allows designers as well as engineers to select appropriate colors (or color combinations) for visual presentation. Various visual search experiments have examined the visual attention and perception of color [3,4,7]. Through these researches, color conspicuity models [3] have been developed to assess a color's visibility, discrimination, and relative visual weight. Suggestive guidelines for effectively applying color in computer graphics [7] are also available. However, despite these resources, thorough works that empirically evaluate the influences of color on digital interfaces with icon arrays still remain at large.

2. Objective

This proceeding study aims to determine the effects that different color attributes – hue, tone, and color combination – have on color saliency of digital interfaces structured in icon matrices. For this study, color saliency was defined by how well a color attracts the eyes. One of the widely used scientific tools to improve usability of interface designs, particularly now in this digital era where display screens are overflowed with large amounts of information, is eye-tracking analysis. By analyzing eye movements, it is possible to compile objective measures of visibility for graphic elements that can be used to improve website interface designs [5]. Hence, this research employs eye-tracking technology to obtain valid accounts of eye movement and fixations on specific areas of interest (AOI) and thereby access the visual magnetism of numerous color samples. Ultimately, this research proposes a guideline for UX designers on how to use different color attributes to channel visual attention and increase aesthetic satisfaction of electronic interfaces.

3. Color Stimuli for Empirical Studies

Staying focused on the context of digital interfaces with aligned icons, the design of the stimuli adopted a 5 by 5 matrix structure. A total of 21 stimuli were produced, each stimulus consisting of 25 identically sized color chips arranged in random order within the matrix. In order to study the color attributes of hue, tone and color combination and their effects on overall color saliency, all variables of color attributes used in the experiment were extracted based on the HSB color system provided by Photoshop 5.0, where a color is identified by three parameters: hue(H), saturation(S) and brightness(B). Tone is created by combining both black and white (or adding gray) to a color. In Photoshop 5.0, saturation is related to adding or removing white while brightness provides the function of adding or removing black. Specifically, white is added when saturation decreases, while black is added when brightness decreases (i.e. 100% saturation has no addition of white and 100% brightness has no addition of black). Hence, hue and color combination samples were selected by controlling hue values while tone samples were selecting by adjusting both saturation and brightness. Moreover, given that most default background colors of electronic devices are black or dark navy, the background color of the stimuli was set to be black with a luminance of close to, if not, zero.

3.1 Part I – Hue

Part I of the experiment focused on the color attribute of hue. Visual stimuli were sampled from the Web Safety Color palette. Ranging from 0 º to 360 º, a total of 24 hues were extracted by adding 15º to each hue stimuli, starting from 0 º. As gray is a color that has no hue but often mistakenly recognized as a color by the general populace, an appropriate gray was selected and added (brightness parameter of 60%) to the stimulus. Therefore, a total of 25 color samples with a saturation level of 100% were selected and categorized as 'vivid tone' hues (Table 1). Prior to the experiment, the luminance (Y) of each color sample was measured to further compare the impacts of hue and luminance.

Table1. Part I color samples consisting of 24 hues plus gray. The following table provides the HSB value as well as the luminance values for each color stimulus when displayed on the PC tablet.

Color Sample													
Hue Angle	-	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°
Saturation/ Brightness	100% / 100%												
Y (luminance)	59.7	43.6	47.5	70.5	108	166	147	132	127	124	125	130	138

Color Sample												
Hue Angle	180°	195°	210°	225°	240°	255°	270°	285°	300°	315°	330°	345°
Saturation/ Brightness	100% / 100%											
Y (luminance)	150	89.8	52.2	31.7	26.1	28.2	35.6	48.0	67.7	55.4	48.3	44.2

In order to avoid position bias, the 25 color samples were arranged randomly in three different ways. Although it would have been appropriate to investigate the effects of saliency when the color samples were in different tones (variations in levels of saturation and/or brightness), Part I of this experiment primarily focused on vivid tones (when saturation and brightness were both 100%) to principally investigate the influences of hue without the results being distorted by any interaction effect with tone.

3.2 Part II – Tone

Part II of the experiment sought to determine the tone that attracted the most visual attention of subjects. To do so, stimuli of 25 different tones of the same hue, for three different hues – red (255, 0, 0), green (0, 255, 0), blue (0, 0, 255) – were produced. The 25 different shades of tones for each hue were chosen by dividing the saturation levels and brightness levels (each ranging from 0% to 100%) by 5 as shown in Figure 1. Hence, both saturation and brightness consisted of 5 groups with the following percentage levels: 20%, 40%, 60%, 80% and 100%. Similar to Part I, samples with the same hue were randomly arranged in three different ways to avoid position bias. Thus, a total of 9 stimuli (3 hue x 3 arrangements) were used in Part II.

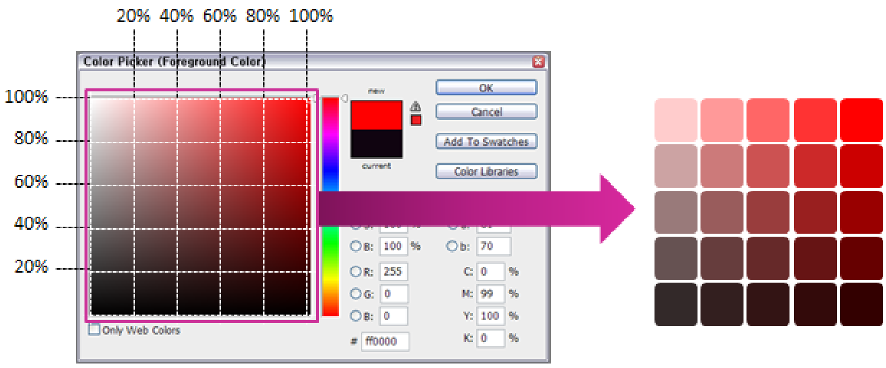

Figure 1. Sample stimulus for investigating tonal effects on color saliency for red hue. The x-axis corresponds to saturation percentage, and the y-axis corresponds to brightness percentage.

3.3 Part III– Color Combination

In contrast to Part I and Part II, in which single color chips were used, Part 3 was conducted using stimuli made up of color combinations: an icon (foreground) color and a background color. This part was intended to investigate whether color combinations have an influence on subjects' attention in a manner different from that of single colors and to determine which color combinations grab the eyes' attention the most. Three different pictograms (camera, phone and Wi-Fi signal) in the shade of red (255, 0, 0) were layered on top of the stimuli from Part 1 (Figure 2). The same process was applied using green (0, 255, 0) and blue (0, 0, 255) colored icons to create a total of 9 stimuli (3 stimuli for each icon color).

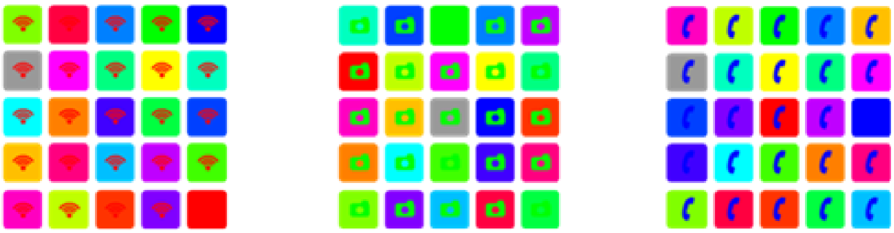

Figure 2. Examples of stimuli for Part III (left: red icons; middle: green icons; right: blue icons).

4. Method

4.1 Participants

A total of 20 university students (10 females and 10 males) with an average age of 22.60 and a standard deviation of ± 1.93 were recruited. All subjects were not colorblind and had no vision problems. The experiment was divided into three parts to observe each color attributes, hue, tone, and color combination. Subject participated in all three parts of the experiment.

All eye detection data were collected using the Tobii Glasses Eye Tracker™. Each subject was calibrated to the eye tracking system, then were informed on the instructions of the experimental task by completing a pre-test using a randomly generated stimuli set. Eye tracking data was not collected during the pre-test.

4.2 Eye-Tracking Apparatus

During all three parts of the experiment, the stimuli were displayed on a 12-inch tablet PC (Model: HP

EliteBook Tablet PC). Unfortunately, due to the limitations of the Tobii Glasses Eye Trackers^{TM}, it was difficult to conduct the experiment using smaller display devices to create a context for handheld devices like smartphones, one of the key devices that utilize icon array interfaces. The subjects were seated at a distance of 0.7 to 1.0 meters away from the monitor (depending on the height of the subjects) to insure that the viewing angle was approximately 2 degrees, creating a similar condition as when using mobile devices, and also to make sure that at least 4 IR markers were within the field of view of the glasses at all times during the experiment (Figure 3). This set up was essential in order for the eye tracker to obtain accurate eye movement readings.

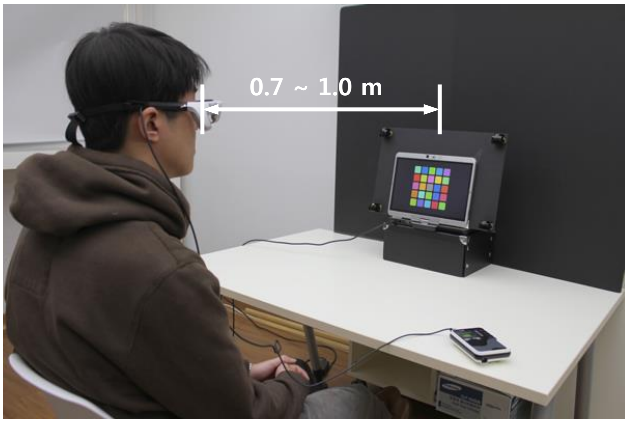

Figure 3. Experimental apparatus with stimulus on tablet PC. Subject was seated 0.7~1.0 m from the display screen depending on his/her height and the visual angle that the camera of the Tobii Glasses Eye Tracker could capture.

To reduce possible differences in color perception among subjects inflicted by ambient lighting and natural lighting depending on the time of day, the experiment was conducted under a controlled lighting environment with color temperature of 6500 K and luminance of 500 lx. All curtains were fully closed.

4.3 Experimental Task

Prior to being shown the stimuli, the subjects were asked to carefully observe the monitor and to select a color that was most eye-catching. This way, the concentration of the participants was continually focused on the experiment. The subjects were then shown a stimuli set, consisting of 3 stimuli with the same 25 color samples but in different cell positions of the 5 by 5 matrix. Because this study had a greater focus towards determining the most salient colors at first point of exposure, each stimulus was displayed on the monitor for only 5 seconds followed by a 2 seconds break. During the break, a black screen was displayed to prevent the occurrence of an afterimage effect when moving from one stimulus to the next. After being exposed to the 3 stimuli, the subjects were shown the last stimulus of the stimuli set with cell numbers embedded in the cell centers and asked to read aloud the cell numbers that corresponded to the color which attracted the most attention and subject’s most preferred color. The second question was added to additionally explore whether there is a correlation between color saliency and color preference. The process described above was repeated for Part II and Part III. No intermissions were given when progressing from one part to the next. The total time required to complete the experiment was approximately 7 minutes, excluding the time it took to calibrate the eye-tracker. Figure 4 provides screen captured images of Part I, illustrating the flow of the experiment.

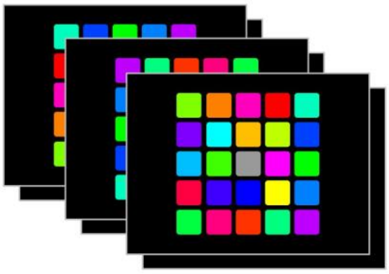

Figure 4. Stimuli set from for Part I as shown on the display. Subjects were visually exposed to each stimulus for 5 seconds, followed by a 2 second break.

5. Results & Data Analysis

Color saliency is often measured by search time, eye fixation time or pair-wise comparison [3,10]. For this experiment, saliency was calculated by extracting the total number of fixation counts on each color sample for all 21 stimuli using the Tobii Studio Beta 3.2 software, where one fixation equates to eye gaze lasting between 60 ms to 70 ms. When analyzing the data, only color samples that had fixation counts greater than 4 were taken into consideration. This was because 4 was the minimum value for greatest fixation count. By taking this approach, random fixation counts that might have occurred during the experiment could be filtered out.

All the data was exported to Microsoft Excel for sorting and organization. In order to statistically analyze the results, the data was exported to SPSS 20. For all segments, the initial fixation was removed from analysis under the assumption that the initial fixations are generally at the center of the screen or on a random point, having no correlation with color saliency [10].

5.1 Part I – Hue

To analyze the saliency of different hues, the 25 color samples were divided into 3 groups: warm hue, neutral hue and cool hue. The hue ranges for each hue group are as follow: 0° ~ 90° for warm hue (7 color samples); 91° ~ 224°, 316° ~ 359°, and gray for neutral hue (13 color samples); 225° ~ 315° for cool hue (7 color samples). The results of Part I indicated that overall, warm hue group is relatively more salient compared to neutral and cool groups as shown in Table 2. Based on the results of the Chi-square, a statistical significance was found between the differences of fixation counts among the warm, neutral and cool groups ($X^2 = 13.0$ (df = 2), $p < 0.05$). Within in warm hue group, hue angle of 0° (red) was most salient, followed by 45° (yellow) which had the greatest value of luminance among all color samples. In general, hues with high luminance values were most eye-catching, particularly yellow and yellowish-green.

Table 2. Fixation counts for different hue groups.

Warm (Hue angle 0°~90°) Average Y = 97.1	**Neutral** (Hue angle 91°~224°, 316°~359°, gray) Average Y = 96.0	**Cool** (Hue angle 225°~315°) Average Y = 40.0	**Significance of Difference**
30	15	9	Differences between total fixation counts among different contrast groups were statically significant ($X^2 = 13.0$ (df = 2), $p < 0.05$).

5.2 Part II – Tone

The results of Part II indicated that overall, colors with higher levels of saturations (80% to 100%) are relatively more salient compared to colors with low saturation (20% to 40%). The results complied with expectations, in that vivid colors with greater saturation levels caught the greatest attention, particularly for red and green hues. However, for blue, there was tendency for the 40% saturation group to also be conspicuous. This result is probably due to the darkness of blue (low luminance) and its lack of contrast against a black background (luminance ≃ 0). Chi-square test, however, indicated that there was no significant difference between the total fixation counts of different tonal groups when divided by saturation ($X^2 = 5.41$ (df = 4), p = 0.25).

Table 3. Fixation counts for different tone groups divided by saturation percentage.

Tone Group (Saturation Percentage)	Red	Green	Blue	Total Fixation Count	Significance of Difference
20%	6	5	1	12	Differences between total fixation counts among different contrast groups were insignificant ($X^2 = 5.41$ (df = 4), p = 0.25).
40%	7	2	12	21	
60%	2	1	5	12	
80%	11	7	4	22	
100%	7	7	11	18	

In contrast to expectations that color samples with high brightness, particularly against a black background, are more eye-catching than samples with low brightness, the results showed that the darker tones grabbed more attention, although the results were statistically insignificant ($X^2 = 7.41$ (df = 4), p = 0.17). Furthermore, because tone is the addition of gray to a color, it was assumed that there would be a relationship between saturation (representing level of whiteness) and brightness (representing level of blackness) in color saliency. However, a two-way ANOVA revealed that there was no interaction effect between the two variables.

Table 4. Fixation counts for different tone groups divided by brightness percentage

Tone Group (Brigthness Percentage)	Red	Green	Blue	Total Fixation Count	Significance of Difference
20%	10	10	5	25	Differences between total fixation counts among different contrast groups were insignificant ($X^2 = 7.41$ (df = 4), p = 0.17).
40%	8	3	6	17	
60%	9	7	3	19	
80%	4	1	9	14	
100%	2	1	7	10	

5.3 Part III – Color Combination

To analyze the saliency effect of color combinations, the 25 color combination stimuli were divided into three contrast groups – low contrast, medium contrast, and high contrast – based on the absolute value of hue angle difference between foreground and background. The ranges for each contrast group are as follow: |background hue

- foreground hue| ≤ 60º for low contrast; 60º < |background hue - foreground hue| ≤ 120º plus gray for medium contrast; 120º < |background hue - foreground hue| ≤ 180º for high contrast.

As expected, Part III showed that, typically, color combinations with high contrast between background and foreground are more eye-catching compared to low and medium contrast groups. Although Chi-square test indicates that the differences in total fixation counts among the different contrast groups were insignificant, the overall total fixation counts were highest for high contrast groups and lowest for low contrast groups ($X^2 = 1.46$ (df = 2), p = 0.48), as shown in Table 5. For stimuli using red icons, the results were slightly different. Although high contrast samples had a greater fixation count than medium contrast groups, the group with the greatest fixation count was the low contrast group. In Part I of the experiment, it was discovered that warm hue groups are more salient relative to cool and neutral groups. As such, the reason that low contrast groups were more salient than high contrast groups and medium contrast groups is due to the fact that warm colors attract more attention. Red icon samples with low contrast, hence, created a larger area of interest for the subjects' eyes to be attracted to. Hence, the results for red icons provide further empirical support on the highly salient property of warm hues.

Table 5. Fixation counts for different contrast groups.

Contrast Group	Red Icon	Green Icon	Blue Icon	Total Fixation Count	Significance of Difference
Low |background hue - foreground hue| ≤ 60º	15	6	6	27	Differences between total fixation counts among different contrast groups were insignificant ($X^2 = 1.46$ df = 2, p=0.48)
Medium 60º < |background hue - foreground hue| ≤ 120º, gray	11	8	10	29	
High 120º < |background hue - foreground hue| ≤ 180	14	10	12	36	

6. General Discussion

It was initially hypothesized that all three color attributes (hue, tone and color combination) affect color saliency, by which there exists a hue group, tone group, and color combination group that is more perceptibly alluring than others. To investigate the degree of saliency, fixation count was assigned as the dependent variable and analyzed for verification of the hypotheses. By comparing mean fixation counts, it was possible to determine which colors have potential recurring effects of repeatedly and frequently drawing back visual attention. Through experimentation, however, the hypothesis was proven only partially true. The differences in fixation counts among different groups within color attributes were found insignificant, except for hue. However, in order to obtain significant results using the Chi-square test, it is essential to have a sufficient sample size. It appears that a sample size of 20 subjects was too small, and thus, to add further validity to these results, it would be appropriate to perform the experiment again with a larger sample size.

For hue, there was a clear distinction between the color saliency of different hue groups, where warm hues were more salient relative to cool hues. According to a study conducted by Rosch [8], there is a relationship between the learnability of colors and the fixed evolutionary order in which colors terms enter languages, as proposed by Berlin and Kay [2]. He proposes that if the salience of focal colors is found to play a role in the learning of basic color names, then it is reasonable to suppose that salience differences among colors might lead to an evolutionary order of color names in a language. The evolutionary order is as follows: black, white, red, yellow, green, blue, brown, pink, purple, orange and gray. Supporting such view, the most salient colors in this experiment were red followed by yellow and shades of green. It is interesting to note that, despite having a higher luminance, yellow was not as eye-catching as red. Greenish-blues, despite their high luminance, were also less eye-catching than red. This suggests that in digital interfaces, hue plays a greater role in increasing the conspicuity of icons rather than the parameter of luminance.

Contrary to expectations, a strong correlation between tonal variables (saturation and brightness) and color saliency was not discovered. The results suggested that although there was a tendency for highly saturated color samples to be more eye-catching, there was no gradual correlation observed, and no visible tendencies for the effects of brightness. Therefore, it might be worthwhile to conduct a research that focuses more closely on the effects of tone in color conspicuity.

For color combination, the results indicated that higher contrast between background and foreground makes an icon stand out more. However, in real contexts, icons typically tend to use more than two color combinations. As such, more in-depth studies using three or more color combinations could serve to be relevant. Using more colors in the combinations can also provide opportunities to explore the most appropriate colors that can be used for different areas of a single icon to emphasize the icon's meaning.

The subjects were asked two questions at the end of each stimulus set, which are 1) which color is most eye-catching, and 2) which color do you prefer. For all stimuli, there appeared to be no correlation between most eye-catching color (determined by fixation count, not the subjects' answers) and color preference. This goes to show that what the subconscious interprets as salient and what the conscious mind interprets as favorable or salient are different. Moreover, all stimuli in this experiment were created on a 5 by 5 matrix. However, the number of matrix cells differs for all interface displays. Additional experiments should be conducted using stimuli with different matric configurations. Lastly, the purpose of this experiment was to observe color saliency of icons when presented in the form of a matrix. Various devices use this type of interfaces structure, including smartphones, tablets and even large displays like smart TVs. Hence, additional studies to this research using different sized displays may be appropriate to observe whether same tendencies occur regardless of the size of displays. Together with such studies, it might also be interesting to consider the relationship between overall icon size and color saliency and determine suitable sizes of icons for the effects of color attributes on color saliency to be amplified and/or be most effective.

7. Conclusion

Color can be greatly helpful when effectively and intuitively prioritizing visual information. In this light, there is a need for an objective guideline in color usage that enables designers to improve visual communication in interfaces using icon array matrices and communicate with users universally. The purpose of this research was to determine which colors are most eye-catching in displays that employ icon matrices to help strengthen the visual information structure of interface designs. The experiment observed the effects of three color attributes, hue, tone, and color combinations on color saliency. Part I, focusing on hue, indicated that warm colors are most eye-catching relative to cool and neutral colors. Part III provided empirical verification that high contrast between foreground and background generates more dominant conspicuity. However, Part II was unsuccessful in identifying the effects the tone has on the color saliency. Although further research should be implemented to increase the validity of these experimental results, it would not hurt for designers to take these findings into consideration when designing visual displays of information for mobile communication contexts.

8. Acknowledgment

This work was supported by the IT R&D program of MKE/KEIT. [KI10039177 , User-Centered LED Lighting System Development Enabling Daylight Spectrum for Educational/Residential Facilities]

9. References

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