Optimal Employment of Color Attributes to Achieve Saliency in Icon Matrix Designs

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Abstract: With the wide use of smart devices, through which information is presented in vast quantities, objective guidelines are needed to enable designers to choose appropriate colors for information display. The purpose of this study is to determine which colors are the most eye-catching in displays that employ icon matrices and thereby provide empirical grounds for strengthening the visual information structure of interface designs. Three attributes of color, which include hue, tone, and color combinations, are examined to optimize the color saliency in information displays. An eye-tracking study was conducted to evaluate saliency objectively by analyzing fixations of visual attention. Based on the hue-saturation-brightness color system, a 5-by-5 matrix of 25 color patches was adopted to generate 21 color stimuli. Part I of the study focused on hue and indicated that warm colors are perceptually more eye-catching relative to cool and neutral colors. Part II of the study investigated tonal influences and revealed that highly saturated colors provoked the greatest visual magnetism against a black background across all hue groups, although there was an alternative tendency for a blue hue. Contrary to expectations, no distinctive patterns were observed among brightness groups. With regard to color combination, Part III of the study provided empirical verification that high contrast between a foreground and a background generates a more dominant conspicuity. The results of the present study can be applied in designing electronic interfaces that display icon matrices to create effective communication by guiding visual attention and increasing aesthetic satisfaction. © 2014 Wiley Periodicals, Inc. Col Res Appl, 40, 429–436, 2015; Published Online 3 October 2014 in Wiley Online Library (wileyonlinelibrary.com). DOI 10.1002/col.21922

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INTRODUCTION

With the wide use of smart devices, through which information is presented in vast quantities, the demand to improve the means of visual communication via interface designs is rapidly increasing.[1] Typically, smart devices, such as smart phones, tablet PCs, and smart TVs, feature interface designs that display multiple icons arranged in matrices.[2] In these graphical arrangements, icons are relatively homogenous in size and shape to create organized structures that enable efficient processing of visual information. Previous studies have investigated the effects of the spacing and sizes of individual interface elements on saliency and visual perception. In particular, a study by Lindberg and Näsänen[3] regarding the performance of search-based visual tasks has suggested that inter-element spacing has minimal effect on how users perceive icons.

Color, on the other hand, provides a large degree of freedom and can be exploited to give icons a distinctive appeal or emphasize a particular meaning.[4] Color not only accounts for 80% of the human visual experience, but it is one of the most powerful information channels among the human senses. Therefore, color must not be taken for granted, especially when it comes to design.[5] In fact, the use of color variation is one of the most effective and intuitive ways to visually prioritize information.[6] Smallman and Boynton[7] have suggested that there is no limit of five or six colors that can be used for successful color segregation in a high-density display by adopting an efficient color coding. However, the visual presentation of color is often subjective to the eyes of the designers and can, in some cases, hinder how accurately visual information is perceived by the viewers. Therefore, objective guidelines are needed to enable graphic designers to choose appropriate colors for information display.

A variety of visual-search experiments have examined visual attention and the perception of color.[8,9] Through these studies, color-conspicuity models[8] have been developed to assess the visibility, discrimination, and relative visual weight of colors. Suggestive guidelines for effectively applying color in computer graphics[9] are also available. Nonetheless, works that empirically evaluate the influences of color on visual displays with icon arrays are still limited, particularly with regard to mobile devices. Therefore, this study aims to determine the effects that different color attributes—hue, tone, and color combination—have on the color saliency of visual displays structured with icon matrices. Ultimately, this study proposes a useful guideline for user experience (UX) designers and engineers on how to use different color attributes to channel a viewer's visual attention of icons arranged in matrices.

RELATED WORKS

Numerous studies have been conducted in the past to investigate color saliency, specifically the saliency properties of the red hue. There are many disciplinary perspectives on why red hue attracts the greatest attention. Humphrey[10] provided a rather psycological response to the discussed matter, explaining that red is a common signal color in nature and, consequently, the reactions to red are reflexive and impulsive. In another study, Rosch[11] proposes that there is a correlation between saliency differences among colors and the evolutionary order of the development of color names, as proposed by Berlin and Kay.[12] Another objective explanation of the exceptional dominance of red is provided by Mahnke and Mahnke,[13] which describes that the natural focal points of red lie behind the retina. Hence, due to the operational mechanisms of the eye, the lens of the eye has to adjust to focus on the red hue wavelength, creating the illusion that red objects are in closer proxity than in reality.

In other studies, different attributes of colors have been assessed to determine their impacts on saliency. A study by Egusa[14] noted that an increased saturation of color with respect to background generates a decrease in visual proximity of the stimuli. Another attribute of color considered to play a role in color saliency is brightness. A study by Mount *et al*.[15] on the distance judgement of colored objects showed that a higher brightness contrast in relation to a background gives colors greater saliency. Einhäuser and König[16] in their examination using digital displays, evaluated natural and modified images to uncover the salient effects of luminance-contrast. However, according to experimental results, no casual contribution of luminance-contrast to a saliency map of human overt attention was detectable.

Numerous studies examining color saliency have been conducted using images of nature or still-life objects as stimuli.[17] It is important to note, though, that the effects of color attributes on saliency can vary, depending on the type of stimuli. The matrix-based interface displays of smart devices are often task-oriented and require different navigational skills, as compared to observing images. Camgöz *et al*.[18] employed a 9-by-7 color-squares matrix on a computer monitor to investigate attention responses for foreground-background color relationships. However, the study investigated cognitively salient colors based on the participants' subjective evaluation, which might differ from the unconsciously salient colors detected from actual eye movements.

A widely used scientific technique to improve the usability of interface designs is eye-tracking analysis.[19] First utilized for reading research over 100 years ago, eye-tracking allows researchers to compile objective measures of visibility for graphic elements.[20] In the digital era, where display screens overflow with large amounts of information, eye-tracking techniques have supported researchers to determine both where on the screen a user looks and how the user's eyes shift from one location to another.[21] Hence, eye-tracking analysis was adopted in the present study to obtain objective data for analyzing color saliency and overt visual attention with respect to icon matrices.

COLOR STIMULI FOR EMPIRICAL STUDIES

With the main focus being information displays with aligned icons, the design of the stimuli used involved a 5-by-5 matrix structure. Moreover, the background color of the stimuli used was set to be black with a luminance near or equal to zero since, to lengthen battery life, most default background colors of electronic devices range from black to dark navy.

To study the color attributes of hue, tone, and color combination, 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*). The *HSB* color system is a common method of color entry for digital screen applications, with its simple transformation of an RGB color space that preserves its gamut.[22] Agoston[23] refers to the *HSB* system as particularly useful when observing the diverse psychological effects commonly experienced in color vision. Practically, when it comes to information display, the *HSB* system has become the most commonly available color space for graphic designers,[24] since the model is perception-oriented and is based on the intuitive concepts of tint, shade, and tone.[25] For the current experiment, it was particularly useful that the system offers an independent component range, which made it convenient to manipulate hue while controlling tone, and vice versa.[26]

Part I—Hue

Part I of the experiment focused on the color attribute of hue. Visual stimuli were sampled from the Web-safe

TABLE I. Part I color stimuli consisting of 24 hues, plus gray.

Color stimuli	Hue (°)	L^*	a^*	b^*	C^*	h (°)
	–	44.08	−4.95	2.86	5.72	149.98
	0	37.51	38.91	34.98	52.32	41.96
	15	39.28	34.86	36.93	50.78	46.65
	30	47.02	19.00	45.21	49.04	67.20
	45	56.60	2.32	54.84	54.89	87.58
	60	67.67	−13.97	64.71	66.20	102.18
	75	64.03	−26.46	63.65	68.93	112.57
	90	61.57	−36.54	62.55	72.44	120.29
	105	60.09	−43.22	61.90	75.50	124.92
	120	59.69	−45.27	61.77	76.58	126.24
	135	59.98	−44.38	53.27	69.33	129.80
	150	60.87	−41.60	34.38	53.97	140.43
	165	62.41	−37.39	14.39	40.06	158.95
	180	64.75	−30.14	−8.50	31.32	195.75
	195	52.28	−16.06	−27.56	31.90	239.77
	210	41.26	−1.11	−45.00	45.01	268.59
	225	32.61	13.56	−59.15	60.68	282.91
	240	29.51	19.55	−64.19	67.10	286.94
	255	30.74	21.27	−62.26	65.79	288.86
	270	34.53	26.02	−56.16	61.89	294.86
	285	39.99	32.13	−47.59	57.42	304.02
	300	46.66	38.87	−37.42	53.95	316.09
	315	42.53	37.90	−15.75	41.04	337.43
	330	39.69	38.43	4.48	38.69	6.65
	345	38.01	38.82	24.70	46.01	32.47

The following table provides the CIE 1976 $L^*a^*b^*$ values when displayed on the tablet PC.

(or Netscape) color palette.[27] Ranging from 0° to 360°, a total of 24 hues were extracted by controlling the H component with an interval of 15°. As gray is a shade that has no hue but is often mistakenly recognized as a color by the general populace, gray (B value of 60%) was added to the stimuli. Therefore, a total of 25 color samples with S and B levels of 100% were selected and categorized as "vivid tone" hues. Although it would have been appropriate to investigate the effects of saliency when the color samples were of different tones, Part I of this experiment primarily focused on vivid tones to principally investigate the influences of hue without the results being distorted by any interaction effect occurring with tone. For analysis, the CIE 1976 $L^*a^*b^*$ values for all stimuli were measured using a spectroradiometer (Konica Minolta CS-2000), as listed in Table I. The 25 color samples were randomly arranged in three different ways to avoid position bias.

Part II—Tone

Part II of the experiment sought to determine the tone that attracts 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), and blue (0, 0, 255)—were produced. In Photoshop 5.0, S component decreases when either white is added or the chroma is increased, while B component decreases when the white is subtracted. In this study, the 25 different shades of tones for each hue were chosen by dividing the S levels and B levels (each ranging from 0% to 100%) by 5, as shown in Fig. 1. Hence, both saturation and brightness consisted of 5 groups with the following percentage levels: 20, 40, 60, 80, and 100%. Similarly to Part I of the experiment, samples with the same hue were randomly arranged in three different ways to avoid position bias. Thus, a total of 9 stimuli (3 hues × 3 arrangements) were used in Part II.

Part III—Color Combination

In contrast to Part I and Part II, in which single color chips were used, Part III was conducted using stimuli made up of color combinations: an icon (foreground) color and a background color. This part of the experiment investigated whether color combinations have an influence on subjects' attention in a manner different from that of single colors and to determine which color combinations attract the eyes' attention the most. Three different icons (camera, phone, and Wi-Fi signal) in the shade

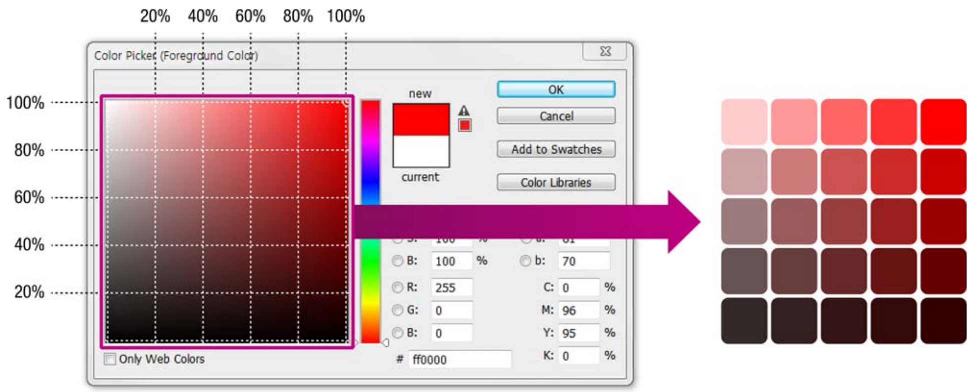

Fig. 1. Sample stimulus for investigating tonal effects on color saliency for red hue. The horizontal axis corresponds to saturation percentage, and the vertical axis corresponds to brightness percentage.

of red (255, 0, 0) were layered on top of the stimuli from Part I (Fig. 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 icon hues × 3 arrangements).

METHOD

Participants

A total of 20 college students (10 males and 10 females) were recruited for the experiment. The average age of the subjects was 22.60 years, with a standard deviation of 1.93 years. All participants were tested for color-detection deficiency using Ishihara's color vision test. No significant color deficiencies were observed. All eye detection data were collected using the Tobii Glasses Eye Tracker. Each test subject was calibrated to the eye-tracking system, and then each was provided instructions for the experimental task while completing a pretest using a randomly generated stimuli set. Eye-tracking data was not collected during the pretest.

Experimental Setup

During all three parts of the experiment, the stimuli were displayed on a tablet PC with a 12-inch diagonal LED-backlit HD display. When measured with a spectroradiometer (Konica Minolta CS-2000), the luminance of the tablet PC was 53.64 cd/m^2, and the white point was 5,857 K in correlated color temperature. Unfortunately, due to the limitations of the Tobii Glasses Eye Trackers, it was difficult to conduct the experiment using smaller display devices to create a context for handheld devices, like smart phones. However, to account for the limitations of the display, each participant was seated at a distance of ∼0.6 m away from the monitor to ensure that the viewing angle was ∼2°, thereby creating a similar condition as when using a mobile device (Fig. 3). To reduce any possible differences in color perception among subjects caused by ambient lighting versus natural lighting, depending on the time of day, the experiment was conducted under a standard illuminant D65.

Experimental Task

Prior to being shown the stimuli, the subjects were asked to observe the monitor carefully and to select a color that was most eye-catching. This way, the concentration of the participants was continually focused on the experiment.[28] The subjects were then shown a stimuli set, consisting of 3 stimuli with the same 25 color samples but in different cell positions. Because this study had a greater focus towards determining the most salient colors at the first point of exposure, each stimulus was displayed on the monitor for only 5 s, followed by a 2 s break. During the break, a black screen was displayed to prevent the occurrence of an afterimage effect. 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. Subjects were asked to read aloud the cell

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

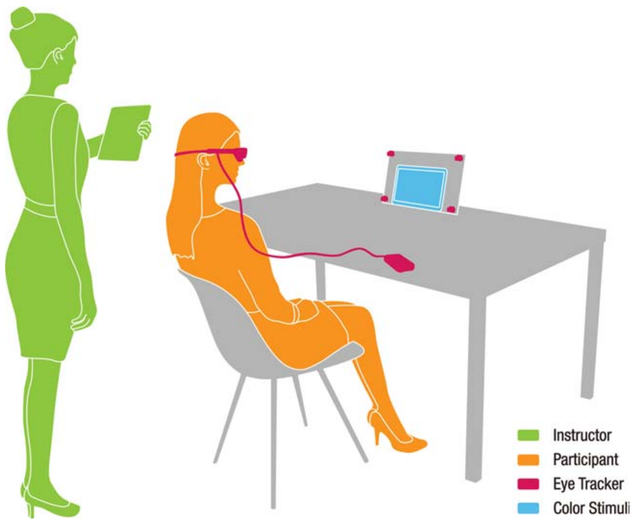

Fig. 3. Experimental apparatus with stimulus on tablet PC. Subject was seated at 0.6 m away from the display screen, depending on his/her height and the visual angle that the camera of the Tobii Glasses Eye Tracker could capture.

numbers that corresponded to the color which attracted the most attention and the 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. The total time required to complete the experiment was ~7 min.

RESULTS AND DATA ANALYSIS

All eye-movement data were analyzed using Tobii Studio 3.2 software. The main measurements used in eye-tracking research are fixations, saccades, and scanpath.[28] Fixation count is the total number of fixations a participant has on a predefined area of interest (AOI). A higher fixation frequency on a particular area indicates that the area is more noticeable, or more important, to the viewer than the other areas. Therefore, color saliency is often measured by fixation count, while the duration of a fixation usually acts as a measure of processing difficulty during encoding.[29] On the other hand, saccades, which are quick eye movements occurring between fixations, does not reveal anything about the salience or complexity of an object in the interface.[30] Scanpath, which describes a complete saccade-fixate-saccade sequence, indicates the participant's search strategy for a desired target, for instance, a top-down or bottom-up direction.[31] Therefore, in this study, saliency was calculated by extracting the total number of fixation counts. One fixation was defined as a gaze within an AOI for at least 100 ms to distinguish a fixation from the saccades.[32] Each color chip was defined as an AOI, and the number of fixations per participant was calculated. For all segments, the initial fixation was removed from the 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.[33]

Part I—Hue

The color chips with the highest fixation counts were, in order, red (H: 0°), yellow–orange (H: 45°), cyan–blue (H: 195°), and red–violet (H: 345°). Smallman and Boynton,[7,34] in their studies on the usefulness of color coding in an effective color segregation, observed that the performance difference between basic versus nonbasic colors was trivial and inconsistent in direction. Therefore, instead of analyzing 25 color samples individually, the color samples with a similar hue were grouped into different hue groups to understand the effect of hue on color saliency. The 25 color samples were divided into three groups—warm hue, neutral hue, and cool hue—based on the hue angle (h) measured for each stimulus. Red–orange (hue angle 45°) and blue–green (hue angle 225°) were defined as two poles of warm-cold contrast, referring to the previous studies on color emotion.[35,36] The hue angle ranges for each hue group were as follows: $0° < h \leq 90°$ for a warm hue (6 color samples); $90° < h \leq 180°$, $270° < h \leq 360°$, and gray for a neutral hue (16 color samples); and $180° < h \leq 270°$ for a cool hue (3 color samples).

The results of Part I indicated that, overall, the warm hue group is the most salient, followed by the cool hue and neutral hue groups (Table II). Based on the results of the Chi-square test, a statistical significance was found between the differences of fixation counts among the warm, neutral, and cool groups ($X^2 = 68.68$ ($df = 2$), $P < 0.01$). Moreover, there was no relationship observed between the lightness (L^*) and the fixation counts. Within the warm hue group, the color sample with the smallest lightness contrast (red; H: 0°) was found to be most salient, while the color sample with the greatest lightness contrast (yellow–orange; H: 45°) ranked second. It is interesting to note that, despite having the highest lightness, yellow was not as eye-catching as red. Greenish–blues, despite their high lightness, were also less salient.

Part II—Tone

As listed in Table III, colors with higher levels of saturations (80% ~ 100%) were relatively more salient compared to colors with lower levels of saturation (20% ~ 40%). The results were consistent with expectations in that vivid colors with greater saturation levels gained the greatest attention, particularly for red and green hues. However, for blue, there was tendency for the 60% saturation group to also be conspicuous. There was significant difference between the total fixation counts of different tonal groups when divided by saturation ($X^2 = 73.06$ ($df = 4$), $P < 0.01$). However, as listed in Table IV, the effect of brightness was inconsistent ($X^2 = 2.83$ ($df = 4$), $P = 0.59$), conflicting with the assumption that color samples with a high brightness level would be eye-catching.

TABLE II. Fixation counts for different hue groups.

Warm ($0° < h \leq 90°$)	Neutral ($90° < h \leq 180°$, $270° < h \leq 360°$, gray)	Cool ($180° < h \leq 270°$)
217	77	137

Moreover, there was no relationship observed between the lightness (L^*) and the fixation counts.

Part III—Color Combination

To analyze the results, the 25-color combination stimuli were divided into three contrast groups—low contrast, medium contrast, and high contrast—based on the H value difference between foreground and background (ΔH_{fb}). The ranges for each contrast group were as follows: $0° < |\Delta H_{fb}| \leq 60°$ and $300° < |\Delta H_{fb}| \leq 360°$ for low contrast; $60° < |\Delta H_{fb}| \leq 120°$ and $240° < |\Delta H_{fb}| \leq 300°$ for medium contrast; and $120° < |\Delta H_{fb}| \leq 240°$ for high contrast. As can be seen in Table V, Part III of the experiment showed that, typically, color combinations with high contrast are more eye-catching compared to low- and medium-contrast groups ($X^2 = 26.88$ ($df = 2$), $P < 0.01$). For stimuli using red icons, the results were slightly different. Although high-contrast samples had the greatest fixation count, the low-contrast group had a greater fixation count than the medium-contrast group. Moreover, there was no relationship observed between the foreground-background lightness (L^*) contrast and the fixation counts.

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, a tone group, and a color combination group that is more perceptibly alluring than the other groups. Through experimentation, however, the hypotheses were proven to be only partially true. Contrary to expectations, although there was a tendency for highly saturated color samples to be more eye-catching, no distinctive patterns were observed among brightness groups. The lack of significant findings could have been a consequence of ineffective tone grouping for analyzing the stimuli. For further experimentation, it is recommended that the stimuli for evaluating the saliency of tone have equal proportions between saturation and brightness levels. For example, the highest tonal group could be composed of color samples ranging from 80 to 100% in both saturation and brightness. Another possible way of conducting the experiment could be to observe saturation and brightness independently, as observed by Camgöz *et al.*,[18] in that the stimuli set for saturation all have a unified brightness and vice versa for the brightness stimuli set. Accounting for the limited methods of this experiment, it might be worthwhile to conduct a study that focuses more closely on the effects of tone in color conspicuity using adjusted sets of stimuli and different tone groupings.

For color combination, the results indicated that higher contrast between a foreground and a background makes an icon stand out more. However, for stimuli using red icons, the low-contrast group was also observed to be salient. In Part I of the experiment, it was discovered that warm hue groups are the most salient, relative to cool and neutral groups. As such, the reason that low-contrast groups were salient might be due to the fact that warm colors attract more attention. Hence, red icon samples with low contrast created a larger area of interest for the subjects' eyes to be attracted. Moreover, 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, would be useful. Using more colors in such combinations would 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.

In previous studies, lightness contrast was found to contribute significantly to color saliency.[15,37] However, in this study, it has been observed that hue plays a greater role in increasing the conspicuity of icons, rather than the parameter of lightness, even in direct-light sources, such

TABLE III. Fixation counts for different tone groups divided by saturation percentage.

Tone group (saturation percentage)	Red	Green	Blue	Total fixation count
20%	49	61	42	152
40%	78	77	88	243
60%	45	73	100	218
80%	132	94	91	317
100%	110	95	99	304

TABLE IV. Fixation counts for different tone groups divided by brightness percentage.

Tone group (brightness percentage)	Red	Green	Blue	Total fixation count
20%	99	81	78	258
40%	92	68	65	225
60%	104	100	49	253
80%	56	89	99	244
100%	63	62	129	254

TABLE V. Fixation counts for different contrast groups.

Contrast group	Red	Green	Blue	Total fixation count
Low Contrast ($0° < \|\Delta H_{fb}\| \leq 60°$, $300° < \|\Delta H_{fb}\| \leq 360°$)	140	118	102	360
Medium Contrast ($60° < \|\Delta H_{fb}\| \leq 120°$, $240° < \|\Delta H_{fb}\| \leq 300°$)	127	134	134	395
High Contrast ($120° < \|\Delta H_{fb}\| \leq 240°$)	167	167	170	504

as digital displays. Einhäuser and König[16] also observed no causal contribution of luminance-contrast to a saliency map of human overt attention. Furthermore, Whitfield[38] has observed that the role of lightness on the salience of an object's color was unclear. Therefore, accounting for the limited methods of the present experiment, further studies that focus more closely on the effects of lightness in color conspicuity might be worthwhile.

In this study, the *HSB* color system was adopted, as it is the most commonly used color space for graphic designers when working with digital screen applications.[24,27] Hence, by adopting the *HSB* system in the experiment, the result of this study could suggest an intuitive and applicable guideline for graphic designers. However, choosing this color space is not without its weaknesses. The *HSB* color space confounds the perceptual effects of all three of its dimensions.[22] For example, in Part I, while the brightness values of the *HSB* color space are equal, the corresponding CIE L^* values (which are related to brightness) are different, ranging from 29.51 (blue) to 67.67 (yellow). Another problem with the *HSB* space is that the Euclidean distance between two colors does not correspond to any perceptual difference.[26] Therefore, for a more thorough experiment, other color models, such as CIE 1976 $L^*a^*b^*$, should be used to provide superior perceptual uniformity. Moreover, this study implies that graphic designers have to be cautious when using the *HSB* color system when designing icon interfaces for digital devices.

In this study, the test subjects were asked two questions at the end of each stimulus set: (1) "Which color is most eye-catching?" and (2) "Which color do you prefer?" For all stimuli, there appeared to be no correlation between the most eye-catching color (as determined by fixation count and not the subjects' answers) and color preference. This goes to show that what the subconscious mind interprets as salient and what the conscious mind interprets as favorable or salient are different. Moreover, while all stimuli in this experiment were created on a 5-by-5 matrix, the number of matrix cells differs for all interface displays. Additional experiments should be conducted using stimuli with different matrix configurations. Last, additional studies using differently sized displays may be appropriate to observe whether the same tendencies occur regardless of the size of displays.

CONCLUSIONS

Color can provide a great deal of assistance when it comes to visually prioritizing information in an effective and intuitive manner. Therefore, objective guidelines for color usage are needed to provide designers with universal means by which to communicate information to users and thereby to improve visual communication in interfaces using icon array matrices. The purpose of this research was to determine which colors are most eye-catching in displays that employ icon matrices and, thereby, to help strengthen the visual information structure of interface designs. The presented experiment observed the effects of three color attributes on color saliency: hue, tone, and color combinations. Part I, focusing on hue, indicated that warm colors are the most eye-catching, relative to cool and neutral colors. Part II, investigating tonal influences, revealed that vivid colors with greater saturation levels gained the greatest attention, although no distinctive tendency was observed among the brightness groups. Part III provided empirical verification that high contrast between a foreground and a background generates a dominant conspicuity. Although further research should be conducted to increase the validity of these experimental results, our study provides a guideline and information for designers to consider when designing visual displays of information for mobile communication contexts.

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