Color Saliency Research on Visual Perceptual Layering Method*

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Abstract. It is a studying worthy problem whether operators can find targets among distractors quickly and correctly with lots of information presented on user interfaces. How to use color saliency properly to optimize interface design is dis-cussed in this paper, according to the guidance of visual perceptual layering. Three laboratory experiments are conducted to assess the anti-interference performances of different colors in three dimensions (hue, brightness and saturation). The an-ti-interference performance is evaluated in reaction time by using a non-parametric statistical test, and the unit of measurement is ΔE76 Euclidean metrics on the perceptually uniform CIE L*a*b* space. The obtained results show that, (1) The pop-out of information effectively can be established by the distance of visual perceptual layering. (2) Visual saliencies of warm colors are different from those of cool colors, and the formers are more salient. High saturated warm colors are more salient than low saturated warm colors, and high bright cool colors are more salient than low bright cool colors. Furthermore, high bright cool colors are less salient than high saturated cool colors. (3) In the hue-contrast condition, with the color difference is more than 20 ΔE76, the visual saliency of target may not change with the change in color differences. Target's saliency is more effected by distractor brightness than by background brightness, whereas it is more effected by back-ground saturation than by distractor saturation.

Keywords: Color Saliency, Visual Perceptual Layering, Anti-interference Performance, Color Difference.

1 Introduction

With numerous data and complex structures in the integrated display interface, people are easily to be distracted by irrelevant items when searching for target items, which caused clutter, confusion, and even more human error[1-2]. As a stage of information processing, hierarchy processing of visual perception influences the cognitive order of information. Designing basis can be offered for searching targets quickly and correctly, using cognition rules which are of high reliability and validity to build relationships between perceptual layers and design elements. With color as one such

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design ele-ment[3], Theeuwes[4-6] proposed that irrelevant singleton color captured attention faster when it is more salient than the target color. For the selection of objects is guided by pre-attentively acquired information about a limited set of attributes[7], color has effects on cognitive performance and also can help to guide visual perceptual layering[8].

2 Background

During the early research, there were two main approaches to study the perceptual distance among colors. One was the color segmentation using perceptual attributes (hue, brightness and saturation), such as perceived colors from the Munsell color solid. The other was the proposed color difference with which the obtained result of the difference or distance between two colors is consistent with that of the human eye[9]. With the rapid development of visual display interface, color can be used to highlight goals and weaken interference terms, guiding users' eye gaze. In the relevant fields, Darren Van Laar[10-11] strengthened the display segmentation by colors to provide visual clues. Jen-Her Wu and his partners[12] used different color combinations for textual display, finding the visual preference was not consistent with the reading speed. Peter B[13] suggested to put colored display items on several "conspicuity levels" and constructed a formula and some guidelines for the algorithm. Ulf Ahlstrom[14] dis-cussed the use of luminance contrast to manipulate salience and presented a prototype color palette that uses color-coding to maintain good legibility. Dennis[15] provided that intrinsic color structures can be formulated objectively and represented a visual hierarchy. Iztok Humar[16] studied the legibility of a web page text on displays ac-cording to the impacts of color combination and luminance contrast. Some other documents gave the order of cognitive performance for color combinations [17-19]. As the studies mentioned above, more and more studies have begun taking the problem of attaining efficient color coding for large numbers of data and information seriously. Few scholars have set foot in visual perceptual layering method through color saliency.

In the present article, we first give a qualitative discussion of visual perceptual layering in the information design field. Then with the stimulus-driven selection and attentional capture mechanism, a mapping relation between color saliency and perceptual distance is presented. A systematic experimental study based on the three color attributes is investigated. Combining non-parametric statistical method with color difference formula, color saliency is judged with the anti-interference performance of target color, and effect factors are analyzed with multiple linear regression equation method. Finally, propose design optimization methods according to the results.

3 Visual Perceptual Layering Method

In the brain of human being, the visualizing information entered the recoding phase of cognition through the visual sense (in Fig.1). With a large amount of information presented on the display interface, a reasonable visual information space can be established by using appropriate priorities and hierarchical rhythmic structures. Visual perceptual layering refers to guide users to recognize information in sequence according to different visual saliency. It gives a control of information classification and management through the mapping relationship between information encoding and its cognition, basing on the mechanism of attentional capture.

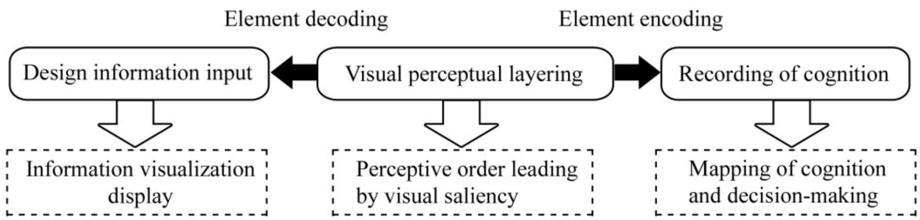

Fig. 1. The Transfer Process of Design Information

There are two hierarchical and two mapping relationships connected with it (in Fig.2). Information layering is a hierarchical management structure of information, basing on structures and attributes of information elements. With prior knowledge, memory structure and schema, cognition layering manages to regulate cognitive processing activities according to the order and important degree of information. By analyzing the semantic mapping relation between information attribute and design style, design elements (i.e. color, shape, direction, position) and visualization structures (i.e. list structure, coordinate structure, space position structure, net or tree shaped structure, time flow structure and composite structure)[20] can be used to create design feature model and array mode, which afford the mapping relationship between information elements and visual perception. The mapping relationship between visual perception and brain cognition has effects on reconstruction rules of information processing, which refers to that perceptive order guides cognitive order.

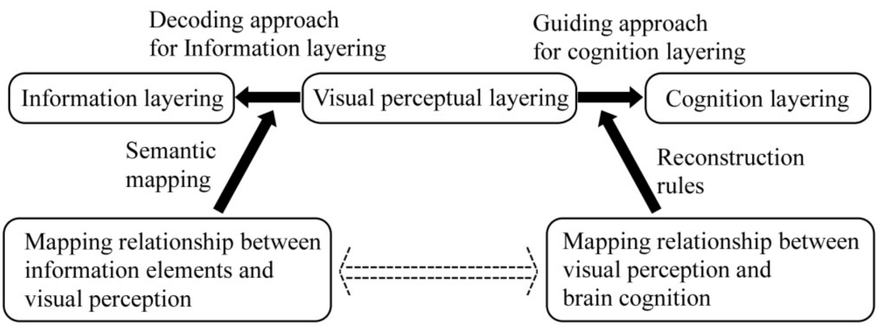

Fig. 2. The Relationships of Visual Perceptual Layering

As one of the design elements, colors have the most effective guiding function. In the digital interface with multicolor encoding, the more possibility of one color being disturbed by others, the worse its saliency value performed. Colors with strong visual saliency become the foreground colors on the psychological recognition, which have close distances to users on the visual perception of space (in Fig.3). As seen in Fig.4, directions of arrows are guidelines for visual flows according to layered color perception. It is likely to make for a better cognitive performance with visual flows toward the same direction, whereas it may be harmful to the performance with visual flows have opposite directions.

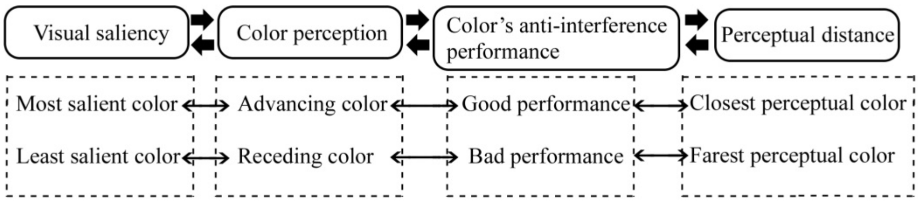

Fig. 3. Relation between color's visual saliency and perceptual distance

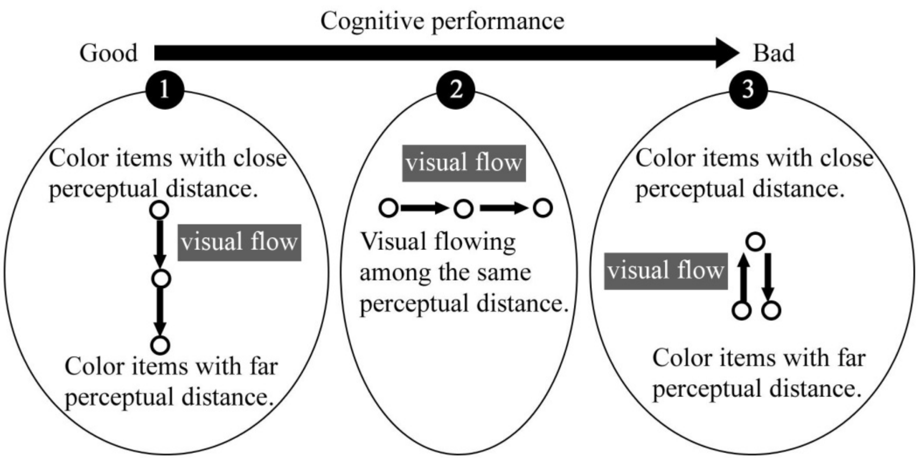

Fig. 4. Visual flowing lines based on perceptual distance

4 Visual Search Experiments

4.1 Materials

Taking the perceptual distance in the Munsell color solid into consideration, 55 colors given in Table 1 were chosen as experimental stimuli, using CIELAB color notation system. On search trials the target was presented with 11 white and 11 colored homogeneous distractors. All visual stimuli were presented on a uniform black

Table 1. Experimental stimuli

Hue experiment: 10 colors of different hue										
Code	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8	A_9	A_{10}
L,a,b	60,29,10	60,22,29	60,6,37	60,-14,35	60,-32,16	60,-30,-3	60,-14,-28	60,13,-37	60,21,-21	60,30,-13
Brightness experiment: yellow, green, and blue colors at 9 brightness levels										
Code	B_y^1	B_y^2	B_y^3	B_y^4	B_y^5	B_y^6	B_y^7	B_y^8	B_y^9	
L,a,b	99,-6,25	98, -10,49	98,-14,71	98,-15,87	98,-16,93	80,-13,79	62,-11,64	42,-8,48	20,-5,28	
Code	B_g^1	B_g^2	B_g^3	B_g^4	B_g^5	B_g^6	B_g^7	B_g^8	B_g^9	
L,a,b	95,-24,19	92,-46,39	90,-64,59	88,-75,74	88,-79,81	72,-67,68	55,-54,55	37,-40,41	17,-25,24	
Code	B_b^1	B_b^2	B_b^3	B_b^4	B_b^5	B_b^6	B_b^7	B_b^8	B_b^9	
L,a,b	83,8,-25	67,19, -51	50,35,-78	36,55,-101	30,68,-112	23,58,-95	15,47,-77	7,35,-57	2,11,-30	
Saturation experiment: yellow, green, and blue colors at 6 saturation levels										
Code	C_y^1	C_y^2	C_y^3	C_y^4	C_y^5	C_y^6				
L,a,b	98,-16,93	89,-14,84	83,-13,74	76,-11,61	69,-9,45	62,-6,27				
Code	C_g^1	C_g^2	C_g^3	C_g^4	C_g^5	C_g^6				
L,a,b	88,-79,81	80,-72,72	74,-64,63	69,-54,51	63,-42,37	59,-26,21				
Code	C_b^1	C_b^2	C_b^3	C_b^4	C_b^5	C_b^6				
L,a,b	30,68,-112	29,58,-99	30,46,-86	34,32,-68	39,20,-49	45,10,-28				

Table 2. Experiment Item

Item	Target sets	Colored distractor sets	Number of trials
Hue	A_1、A_3、A_5、A_7	Other hues different from the target	36
Brightness	All levels of lightness in table 1	Other lightness different from the target	216
Saturation	All levels of saturation in table 1	Other saturations different from the target	90

background. As shown in Table 2, targets and colored distractors were chosen from color sets separately. The stimuli were small squares (16mm×16mm) on a black background, and were presented within a 8.2°×6.2° region at a viewing distance of 0.5 m.

4.2 Equipment and Participants

The experiments were conducted in an ergonomics lab of Southeast University under the normal lighting condition (40W daylight continuous current tungsten lamp). Stimulus presentation and response collection were performed using a purpose-written E-Prime script (Psychology Software Tools). The display of visual stimuli was presented on a CRT monitor whose CPU main frequency was 3.0 GHZ and display size was 17 inch (1280 by 1024 pixels).

The participants consisted of 10 students (5 male, 5 female), ranging in age from 22 to 26 years. All participants had normal or corrected vision without color blindness or color weakness.

4.3 Procedure

The nature of the test was to search for the color-singleton target among white and colored distractors, and to identify which side of the rectangle field (right or left) does the target lay on. Buttons “a” and “l” were used to response the left and right side separately. During the test phase, participants completed two sets of practice trials and test trials in each experiment. Each trial began with a fixation cross in the center of the screen, displayed for 1000ms. Then, a black screen displayed for 500ms, followed by the search display. Each trial terminated if the participant pressed one of the response buttons (a or l) , or no response was made within 5s (in Fig.5).

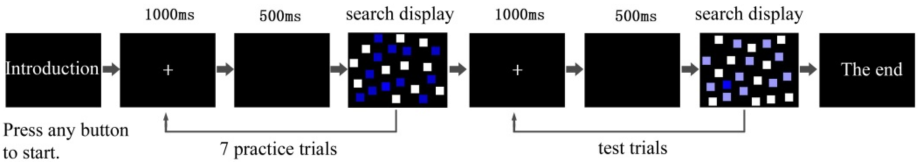

Fig. 5. The experimental procedure

5 Data Collection and Analysis

A color’s anti-interference performance refers to the reaction time and accu-racy when searching for it among distractor colors. Excluding the errors, the faster the reaction time is obtained, the better the anti-interference performance per-formed. Color saliency is evaluated by the anti-interference performance which can be calculated through the non-parametric statistical method. It is transformed to be

$$C_a = \{t_{aj} | a \in S_{11} / S_2 / S_3; j \in S_{12} / S_2 / S_3; a \neq j\} \quad (1)$$

where S11 is the target set of the hue experiment, S11={A1、A3、A5、A7 }, S2 ={different levels of lightness in table 1}, S3 ={different levels of saturations in table 1}, a is the target, j is the distractor, is the reaction time, t_{aj} and C_α is the color saliency.

5.1 Saliency Comparison Among different Hue Targets

The relationship between reaction time and color difference between target and colored distractor is described in Fig.6. Differences in anti-interference performances between any two hues were assessed with the Wilcoxon rank-sum test (in Table 3). The visual saliencies of red and yellow were significant different from those of green and blue. Moreover, according to the Wilcoxon-Mann-Whitney rank sum test, red and yellow targets were more salient than green and blue targets (U=308,α=0.05), which confirmed the previous research results[21-22].

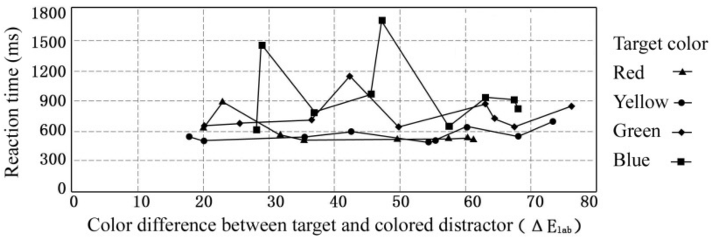

Fig. 6. Reaction time as a function of the color difference between target and distractor colors

Table 3. Rank statistics of the four colors

target/target	A_3/A_1	A_5/A_1	A_5/A_3	A_7/A_1	A_7/A_3	A_7/A_5
Rank statistic	77	116*	122*	122*	125*	105

(Note: α=0.05 and "*" means significant difference. The lower and upper limits of the acceptable threshold of producing a significant difference in reaction times between two colors are calculated that r_1=63 and r_2=108)

5.2 Saliency Comparison among different Saturation Targets

The comparison of saliency for any two saturations levels of the same hue (yellow, green and blue) was calculated by using the Wilcoxon rank-sum test (in Table 4). The anti-interference performances of Cy1, Cy2, and Cy3 were significant different from those of Cy4, Cy5, and Cy6, and the formers were better. No difference was found among different saturation levels of green and blue.

Table 4. Rank statistics of the saturation levels

Target/Target	C_y^1/C_y^2	C_y^1/C_y^3	C_y^1/C_y^4	C_y^1/C_y^5	C_y^1/C_y^6	C_y^2/C_y^3	C_y^2/C_y^4	C_y^2/C_y^5	C_y^2/C_y^6
Rank statistic	28	32	19*	19*	15*	30	19*	19*	15*
target/target	C_y^3/C_y^4	C_y^3/C_y^5	C_y^3/C_y^6	C_y^4/C_y^5	C_y^4/C_y^6	C_y^5/C_y^6	C_b^1/C_b^2	C_b^1/C_b^3	C_b^1/C_b^4
Rank statistic	19*	19*	15*	26	21	25	23	23	21
target/target	C_b^1/C_b^5	C_b^1/C_b^6	C_b^2/C_b^3	C_b^2/C_b^4	C_b^2/C_b^5	C_b^2/C_b^6	C_b^3/C_b^4	C_b^3/C_b^5	C_b^3/C_b^6
Rank statistic	23	24	28	26	26	28	26	27	28
target/target	C_b^4/C_b^5	C_b^4/C_b^6	C_b^5/C_b^6	C_g^1/C_g^2	C_g^1/C_g^3	C_g^1/C_g^4	C_g^1/C_g^5	C_g^1/C_g^6	C_g^2/C_g^3
Rank statistic	26	27	29	25	24	21	21	21	25
target/target	C_g^2/C_g^4	C_g^2/C_g^5	C_g^2/C_g^6	C_g^3/C_g^4	C_g^3/C_g^5	C_g^3/C_g^6	C_g^4/C_g^5	C_g^4/C_g^6	C_g^5/C_g^6
Rank statistic	20	20	23	24	26	29	31	21	29

(Note: α=0.05 and "*" means significant difference. The lower and upper limits of the acceptable threshold of producing a significant difference in reaction times between two colors are calculated that r3=19 and r4=36)

5.3 Saliency Comparison among different Brightness Targets

With the Wilcoxon rank-sum test, there was no significant difference among different brightness levels of yellow, green or blue. The variance analysis was used to test the difference between searching for high bright colors among low bright ones and searching for low bright colors among high bright ones. According to Table 5, it shows that no difference was found between the two conditions in yellow encoding ($F=2.145$, $P=0.162$, $P>0.05$), whereas the significant differences appeared in green ($F=12.82, P=0.002, P<0.05$) and blue ($F=6.957$, $P=0.018$, $P<0.05$) encodings. Moreover, the anti-interference performances of high bright colors were better than those of low bright colors in green and blue encodings.

Table 5. One-way analysis of variance table

Source		Sum of Squares	df	Mean Square	F	Sig.
Yellow	Inter-group	147098.880	1	147098.880	2.145	0.162
	Intra-group	1097371.880	16	68585.742		
	Total	1244470.760	17			
Blue	Inter-group	2040873.389	1	2040873.389	6.957	0.018*
	Intra-group	4693777.669	16	293361.104		
	Total	6734651.058	17			
Green	Inter-group	3304934.801	1	3304934.801	12.82	0.002*
	Intra-group	4123843.436	16	257740.215		
	Total	7428778.236	17			

(Note: $\alpha=0.05$, and "*" means significant difference.)

5.4 Saliency Comparison Between High Bright Colors and High Saturated Colors

Since both the high bright color and the high saturated color had good an-ti-interference performances, which one of them is more salient? According to the brightness experiment, reaction times of high bright colors and high saturated colors shown in Table 6 were analyzed by using the variance analysis. Results showed that there was no significant difference between the two conditions in yellow encoding ($F=0.374$, $P=0.549$ $P>0.05$), whereas anti-interference performances of high saturated colors were better than those of high bright colors in green ($F=10.897$, $P=0.005$, $P<0.05$) and blue ($F=9.519$, $P=0.007$, $P<0.05$) encodings.

Table 6. High bright colors and high saturated colors

Target color	Yellow	Green	Blue
High saturated colors	B_y^1, B_y^2, B_y^3	B_g^1, B_g^2, B_g^3	B_b^1, B_b^2, B_b^3
High bright colors	B_y^4, B_y^5, B_y^6	B_g^4, B_g^5, B_g^6	B_b^4, B_b^5, B_b^6

5.5 Interference Factors of Target's Salient Degree

According to the design of the former experiments, target's salient degree was effected by the background color and distractor colors. With multiple linear regression equation, the interference degrees of background, white distractor and colored distractor were analyzed. According to Table 7, the established regression equation in the hue experiment is invalid (F=0.6, P=0.618, P＞0.05). By combining Fig 6 and earlier researches[23], it is known that with two colors have different hue values, the search speed of one color is fast enough if the color difference of them is greater than 20 ΔE76. Furthermore, it did not have significant change with the increase in color difference. As in the brightness and saturation experiments (in Table 8), following regression equations were obtained:

$$RT_{brightness}=648.304-4.537\Delta E(T\text{-}D)+3.501\Delta E(T\text{-}B)+4.234\Delta E(T\text{-}W) \quad (2)$$

$$RT_{saturation}=2441.124-5.548\Delta E(T\text{-}D)-18.091\Delta E(T\text{-}B)+14.136\Delta E(T\text{-}W) \quad (2)$$

Where ΔE(T-B) is the color difference between target and background, ΔE(T-D) is the color difference between target and colored distractor, ΔE(T-W) is the color difference between target and white distractor. For color difference is inversely linked to reaction time[24], by the formulas above, target color was more effected by colored distractor brightness than background brightness, and it was more effected by background saturation than colored distractor saturation.

Table 7. ANOVA in regression equation

Model		Sum of Squares	df	Mean Square	F	Sig.
Hue experiment	Regression	148251.435	3	49417.145	0.600	0.618[a]
	Residual	4115800.214	50	82316.004		
	Total	4264051.648	53			
Brightness experiment	Regression	8646255.669	3	2882085.223	8.375	0.000[a]
	Residual	7.296E7	212	344148.075		
	Total	8.161E7	215			
Saturation experiment	Regression	3768425.779	3	1256141.926	3.429	0.021[a]
	Residual	3.151E7	86	366366.974		
	Total	3.528E7	89			

a. Predictors: (Constant), ΔE(T-D), ΔE(T-B), ΔE(T-W)

b. Dependent Variable: RT

Table 8. The regression equation coefficient

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
Brightness Experiment	(Constant)	648.304	239.865		2.703	0.007
	ΔE(T-D)	-4.537	1.732	-0.181	-2.620	0.009
	ΔE(T-B)	3.501	1.358	0.179	2.579	0.011
	ΔE(T-W)	4.234	1.797	0.153	2.356	0.019
Saturation Experiment	(Constant)	2441.124	331.735		7.359	0.000
	ΔE(T-D)	-5.548	3.094	-0.190	-1.793	0.077
	ΔE(T-B)	-18.091	10.116	-0.708	-1.788	0.077
	ΔE(T-W)	14.136	12.577	0.443	1.124	0.264

a. Dependent Variable: RT

6 Conclusion

As the effective "pop out" of information may be established by the distance of visual perceptual laying, some design points can be clarified by the current study:

(1) The visual saliency of the warm color is different from that of the cool color, and the former is more salient.
(2) The influences of saturation levels and brightness levels on saliency are different between warm colors and cool colors. High saturated colors are more salient than low saturated colors in warm colors, whereas there was no significant difference between the two conditions in cool colors. High bright colors are more salient than low bright colors in cool colors, whereas no difference is found be-tween the two conditions in warm colors.
(3) High bright colors are less salient than high saturated colors in cool colors, whereas both of the conditions are equal in warm colors.
(4) As presented in Fig 7, the order of visual saliency may be concluded.

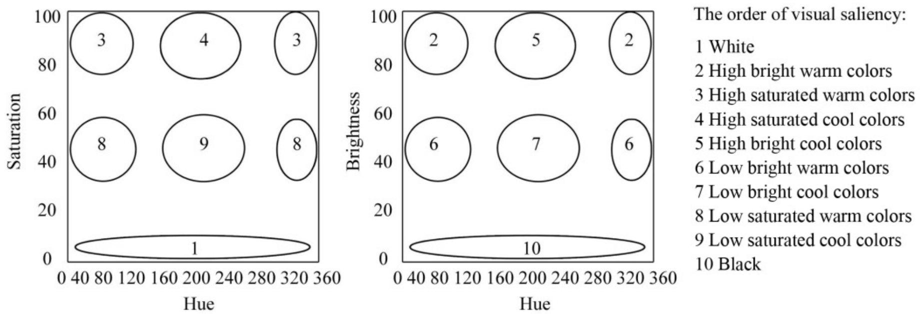

Fig. 7. The distribution of visual saliency in HSB color plane

(5) In the hue-contrast condition, with the color difference is more than 20 ΔE76, the visual saliency of target may not change with the change in color differences. Target's saliency is more effected by distractor brightness than by background brightness in the brightness-contrast condition, whereas it is more effected by background saturation than distractor saturation in the saturation-contrast condition.

7 Application

As color coding of complex information on controller displays is still new, a palette that achieves good margins of legibility and color identification for different information is needed. According to the experimental conclusion, it is possible that cognitive performance of display interface could be optimized with standard settings of visual perceptual layering by using color contrast. This study was not conduced for all colors, so the data is not an exact science but represents a trend.

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