Task Performance of Color Adaptation on the Screen Display

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Abstract. Smart devices have been gaining importance in our lives during the recent years, causing the human beings to spent increasingly more time on the electronic screen. Screens simultaneously act as an interface for both input and output. Therefore, the use of colors on screens have become an important topic. The experiment records the reaction time of each task after color adaptation. Color samples used in this study include the three primary colors and the three complex colors; the size of the stimulus shown in the experiments was a controlled factor, allowing participants to discriminate between each. Results of the experiments showed that the average reaction time after color adaptation is shorter than that of before color adaptation. The background color Blue showed the best performance each time. In other words, the human visual ability reaches a steady level after a very short time period. The results of this study can be applied on user interface design.

Keywords: Chromatic adaptation · Complex color · Primary color · Landolt C · Screen · Performance

1 Introduction

With the advances in technology, smart phones and tablets are playing an increasingly important role in our daily lives, resulting in us spending more and more time on these devices [1]. The most frequently performed activities on smart devices are social networking, online games, and E-commerce. Screens, and the colors appearing on them are closely related to our lives. Inferring from the current trend of social development, it is very likely that humans and websites are going to develop a closer interaction, therefore the design principle of use of color on screen will be highly valued. It not only enhances the aesthetics of appearance, but also improves the interaction between people and things. [2].

Along with the trend of electronic devices, the practice of reading has also transformed from printed books to e-book, which strengthens the fact that screens are linked to our lives in every possible way. Research also show that the digital version of books is able to provide more information than traditional books, at the same time showing higher comprehensive scores [3, 4]. Since the most commonly used output interface for these devices are monitors, the research on color adaptation on screens are exceptionally

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important in terms of enhancing the usability and efficiency of mobile applications, such as improving reader comprehensive level of digital books.

Cone cells are divided into three types, each responsible for the three different range of color lights respectively. People can only discriminate color in the photopic vision because rod cells are unable to discriminate different colors. When people got used to a certain color of stimulation, the human eyes will consider it as white. This process is called color adaptation. Current studies on color adaptations are mostly on primary colors. However, people use complex color more often in daily lives. In order to achieve greater contribution, this study has set the following goals: First, the sample of colors would include the primary colors as well as the complex colors of each primary color, in order to discriminate the differences between them. Second, to investigate is difference between each time point after color adaptation.

From Belmore and Shevell [5], the authors did an experiment to determine the cumulative effect of very-long-term and short-term chromatic adaptation on color perception. The results indicated that short-term chromatic adaptation caused the most shift on color perception, very-long term caused the least shift on color perception, and both chromatic adaptations have a cumulative effect on color perception. Werner [6] pointed out the focus of color research is how the color and spatial analysis of an image interact. His experimental results suggested a close relationship between color and form analysis during chromatic adaptation. This result disproved the theory proposed by previous predecessors that there is no influential relationship between different stimulus, and that chromatic adaptation is not only processed at the retina, but attributed to a temporal integration process during eye movements.

Based on Shevell [7], the participants in this experiment viewed an annulus composed of a mixture of green and red monochromatic lights and they were instructed to adjust the radiance of either green or red so that the annulus appeared a perfect yellow. The results of the experiments deduced a two-process theory. In the first process, a person will receive a changing signal when he or she is adapted to chromatic light. In the second process, a restoring signal that tends to drive back toward equilibrium the opponent response resulting from the adapting light.

Kuller [8] was a study on the effects of red and blue scheme offices on performance efficiency. The results demonstrated that there was no common influential factor between the two tasks on performance efficiency, but it showed that red color could trigger negative emotions. Meanwhile, the authors speculated that red had the most influence on proofreading, a tedious task, and blue had the most influence on writing essays, a creative task. Oetjen and Ziefle [9] proceeded with their experiment using Landolt C for the directional determination task. The position of participants and screen were fixed by a chin-rest, which allowed precise control of viewing distance and angle. Participants used the customized five cross positioned buttons to interact with the screen. The target appeared on screen when participants pressed the central button and the other four buttons were pressed for directional determination of the target gap. This two-step input approach effectively determines and records visual discrimination and motor reaction time from the participants. Although this input device can intuitively correspond to the direction of target stimulus, the cross positioned buttons resulted in inconsistent reaction times.

Therefore, the purpose of this study was to investigate the impact of adaptation between different colors during screen operation.

2 Method

Due to the increasing popularity of mobile devices and the topic of this study on color adaptation on screen based visual tasks, our experiment will simulate a visual search task done on the screen, with an aim to explore the impact of color adaptation on screen based visual tasks. The experiment consists of a pre-test and a post-test.

Independent variables include background color, color adaptation time, and stimulus color; Controlled variables include stimulus pattern size and ambient light; Dependent variables include reaction time and error rate.

2.1 Participants

There are 30 participants between the ages of 20 and 30 years old (14 male, 16 female). To ensure each subject's ability to distinguish colors, the Ishihara color blindness test is done before participation. During the experiment, participants are required to use both eyes during the discrimination task of the ring pattern of Landolt C, so a limit of vision acuity of at least 0.8 is set as a boundary for the choice of participants.

2.2 Equipment and Environment

The test book consists of a series of colored plates, called the Ishihara plates. Each of contains a circle of dots appearing in slight differences of colors and sizes. Dots within the pattern form a number or shape clearly visible to those with normal color visions, however, are invisible, or difficult to process for those with a red-green color vision defect, or vice versa.

The display and operation interface used is an Acer notebook of screen size 14 inches, resolution 1440 by 900 pixels, a Inter i3 Processor, and color setting on 32-bit color system. The color calibrator used in this study is Eye-One Display 2, which is a world leading brand of color calibrator, to ensure the color displayed in every trail of experiment is precise and consistent. E-Prime Professional Software, which is currently one of the most recognized experiment software worldwide with accurate timing and easy operation, is employed for this study.

Landolt C ring settings used refer to the previous Wu [10] and Schrauf and Stern [11] study results and recommendations. We have reduced the low visual acuity notch directions, keep the upper left oblique, lower the left, upper right, and lower right oblique notches. In addition, to ensure that the pattern type subjects to focus observation and reduces knee-jerk answer questions, the experiment will add no-gap patterns. Considering that ruse task (no-notch pattern) was added in this experiment, the index finger and middle finger will hit the response of four oblique notch direction, and the thumb will hit the response of no-gap stimulus. The middle fingers are placed on F and J, the index fingers are placed on V and N, and the thumbs are placed on the space bar.

The background colors chosen for the experiment are red, blue, green, and mixture of the three primary colors cyan, magenta, and yellow. The reason for the choices is to find out the differences between moonlight and complex colors. Stimulus pattern color is another independent variable. The colors used are black, red, green, blue, cyan, magenta, and yellow. The reason for the choices is to explore the color combinations which produce better task performance results and interface usability.

2.3 Procedure

In order to simulate the environment for the general use of computer operation, the experiment space, color temperature, and illumination simulation of the lighting are controlled. Luminance is set to about 700lux, and color temperature to about 6000 K. Table and chairs are maintained in a fixed position, with only the height of chair adjustable before the experiment in order to ensure the vision line is perpendicular to the computer screen. After introducing this study, an exercise is given to all participants to familiarize with the operation. All participants are instructed to place their fingers on the corresponding keyboards before pre-test started.

When the pre-test started, a stimulus is shown on the screen. Participants are required to determine the direction of the stimulus as soon as possible and press the corresponding direction keys. Reaction time is recorded by E-Prime software. Every participant has to complete 250 trials for the test given in random order. At the end of the pre-test, participants will take a rest for 3 min before proceeding to the post-test.

The difference between the pre-test and the post-test is the existence of a color adaptation phase in the post-test. The experiment program is set to arrange six background colors randomly in order at the beginning of every set of test, after that a two-minute long color adaptation begins. Two minutes later, a series of color stimulus, Landolt C in this experiment, start to appear. The color of the stimulus do not change until the next period of color adaptation begins. The program will then use another background color and stimulus color. After every trial of the test, a black screen will display for 1.5 s before the next stimulus appears. Participants are required to finish 25 questions with the same background color. After the completion of 25 questions, there will be a rest period, in which the whole screen will display black and the participant is told to look away from the screen. 1.5 min later, the program will proceed to the next color adaptation phase with another background color automatically. Each set of the test is composed of six different background colors, and each of the participants are required to complete a total of 3 sets of tests. The order of all tasks in the experiment will be generated randomly to prevent a learning effect during the experiment to ensure the accuracy of the results. The process of the post-test is shown as Fig. 1.

2.4 Analysis

The reaction time for the different combination of colors in the pre-test was used as a comparison baseline to the post-test. Incorrect responses in the test will be disregarded. All data will be rearranged in Microsoft Excel, and analyzed with SPSS statistics.

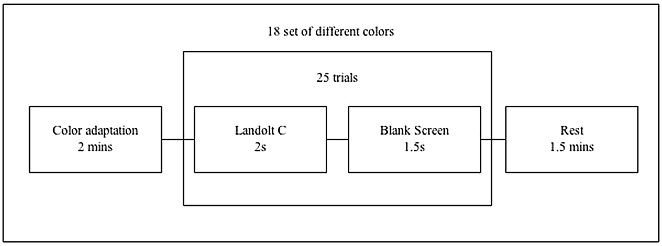

Fig. 1. Process of the post-test

Within subjects effects and Repeated measures will be conducted in SPSS, to discriminate the difference of each colored light. As the six stimulus colors that would appear in each background color are not entirely the same, these two factors will be analyzed respectively. First, Repeated measures of the background color; second, Repeated measures of the stimulus color in different background colors. Mauchly's sphericity test is conducted. Finally, the simple main effect test will be conducted when there is a statistically significant difference in the within subjects effects.

3 Result

3.1 Repeated Measures of Background Color in Pre-Test

As shown in Table 1, the results of Mauchly's test showed a background color $W = 0.346$, $p = 0.012 < 0.05$, reaching a significant level. However, it did not match sphericity assumption and is modified with Epsilon.

Table 1. Within subjects effects of bgColor without color adaptation

Tests of within-subjects effects						
Source		Type III Sum of Squares	df	Mean Square	F	Sig.
bgColor	Sphericity Assumed	227568.838	5	45513.768	49.652	.000
	Greenhouse-Geisser	227568.838	3.562	63889.348	49.652	.000

After modifying, pair wise comparison of background color is conducted and summarized in Table 2. The result showed that background color of Blue is significantly different from all the other background colors. The difference between background colors Cyan and Green did not reach significant level. Finally, the difference between Magenta, Red and Yellow did not reach significant level either.

3.2 Repeated Measures of Background Color and Time in Post-Test

The results of Mauchly's Test of repeated measures of background color and time after color adaptation show that, neither of them (background color $W = 0.085$,

Table 2. Pair wise comparison of background color without color adaptation

Mean difference (I-J)						
(I) bgColor	(J) bgColor					
	Blue	Cyan	Green	Magenta	Red	Yellow
Blue		−94.226*	−89.266*	−29.974*	−23.976*	−22.005*
Cyan	94.226*		4.960	64.251*	70.249*	72.221*
Green	89.266*	−4.960		59.292*	65.290*	67.261*
Magenta	29.974*	−64.251*	−59.292*		5.998	7.969
Red	23.976*	−70.249*	−65.290*	−5.998		1.971
Yellow	22.005*	−72.221*	−67.261*	−7.969	−1.971	

* The mean difference is significant at the .05 level.

$p < 0.0001 < 0.05$; time point $W = 0.000$, $p < 0.0001 < 0.05$) had matched sphericity assumptions and need to be modified with Epsilon.

Amongst the six background colors, Cyan and Green showed a similar performance, the difference of Magenta, Red and Yellow was not significant, while the difference between Blue and Yellow was not significant either. Finally, Red and Yellow background colors showed similar performance. Pair wise comparisons between the rest of the pairs were all significant. Data in details is shown in Table 3.

Table 3. Pair wise comparisons of each background color after color adaptation

Pairwise comparisons						
Mean difference (I-J)						
(I) bgColor	(J) bgColor					
	Blue	Cyan	Green	Magenta	Red	Yellow
Blue		−75.343*	−83.135*	−26.135*	−37.350*	−19.653
Cyan	75.343*		−7.792	49.208*	37.993	55.690*
Green	83.135*	7.792		57.000*	45.785*	63.483*
Magenta	26.135*	−49.208*	−57.000*		−11.215	6.483
Red	37.350*	−37.993	−45.785*	11.215		17.698
Yellow	19.653	−55.690*	−63.483*	−6.483	−17.698	

* The mean difference is significant at the .05 level.

3.3 Repeated Measure of Stimulus Color in Post-Test

The results of Mauchly's test show that, stimulus colors (red background color $W = 0.133$, $p < 0.0001 < 0.05$; green background color $W = 0.201$, $p < 0.0001 < 0.05$; blue background color $W = 0.334$, $p = 0.009 < 0.05$; magenta background color $W = 0.161$, $p < 0.0001 < 0.05$; cyan background color $W = 0.142$, $p < 0.0001 < 0.05$; and yellow background color $W = 0.112$, $p < 0.0001 < 0.05$) reached a significant level, it doesn't match sphericity assumption and need to be modified with Epsilon.

In Red background color, Magenta and Yellow stimulus are significantly different with respective to all the others color. The difference between Blue and Cyan was not significant, but Blue was significantly different from the others. Black, Cyan and Green performed in a similar way. According to the descriptive statistics, Yellow is the only one that showed outstanding performance, while Magenta showed unsatisfactory performance.

In Green background, with an exception to Blue and Red, pair wise comparison of all the others showed significant results. According to the descriptive statistics, Black is the only stimulus color that showed outstanding performance; while Cyan is the only stimulus color that showed unsatisfactory reaction time.

In Blue background, performance of stimulus colors of Yellow and Cyan did not reach significant level. All the others were pairwise significantly different. According to the descriptive statistics, Yellow and Black are the colors that showed best performance, and Magenta, Red and Black are the colors with the most unsatisfactory performance.

In Magenta background, Red is the only stimulus color that showed significant difference in performance, while the rest of the stimulus colors showed no significant difference. According to the descriptive statistics, Black, Blue, Cyan, Green and Yellow have the best and similar performance, while Red is the only color showing an unsatisfactory performance.

In Cyan background, Green, Magenta and Yellow showed significant difference to the rest of the stimulus colors, while Black, Blue and Red showed no significant difference and acted in similar ways. According to descriptive statistics, Black, Blue and Red showed the best performance, and Green is the only stimulus color that showed unsatisfactory performance.

In Yellow background, Cyan and Green showed significant difference to the rest of all stimulus colors. The following three pairs of stimulus colors, Black and Blue, Magenta and Red, Blue and Red, all showed no significant difference in between. According to the results of descriptive statistics, Black and Blue showed the best response performance, and Cyan is the only stimulus color that showed unsatisfactory performance. The descriptive statistics of different color combinations of the post-test is summarized in Table 4.

Table 4. Descriptive statistics of different color combination of the post-test

Descriptive statistics								
Background Color	Stimulus color							
	Black	Blue	Cyan	Green	Magenta	Red	Yellow	Total
Blue	638.25		579.94	602.68	650.12	621.45	567.84	607.27
Cyan	567.30	559.69		1137.36	629.08	592.92	711.89	679.87
Green	575.89	608.01	1105.58		645.70	586.18	704.86	686.85
Magenta	604.24	628.11	606.30	624.47		751.14	608.46	633.37
Red	618.91	647.80	629.77	629.39	782.12		567.45	644.40
Yellow	562.49	586.86	753.46	653.94	609.46	595.06		626.53
Total	593.86	608.31	714.10	720.90	668.27	622.75	624.34	646.10

3.4 Summary

Before adaptation, Blue has the shortest average response time amongst all 6 background colors, and it is significantly different to all the other colors. Cyan background color showed the longest average response time, and the background color green showed no significant difference with it. After adaptation, Blue background color has the shortest average response time compared to all the other colors, and is also significantly different. Cyan background color has the longest average response time, an the background colors of green with Cyan was not significant. Overall, it showed same results without color adaptation, but the average response time after color adaptation is shorter than without.

Before adaptation of Red background color, the black, cyan, green, yellow stimulus showed better performances, while magenta showed an unsatisfactory performance. After adaptation of Red background, yellow showed the best performance, and magenta showed the most unsatisfactory results. Before adaptation of Green Background, black, blue, magenta, red, showed better performance, while cyan showed an unsatisfactory performance. After adaptation, black showed the best performance, while cyan showed the most unsatisfactory performance.

In Blue background, cyan, green, magenta, red, and yellow, showed better performance, while black showed the most unsatisfactory performance before adaptation. After adaptation, cyan and yellow performed better, while black, magenta, and red showed unsatisfactory performance. In Magenta Background, black, blue, cyan, green, and yellow showed better performance, while red showed the most unsatisfactory performance before adaptation. Black, blue, cyan, green, yellow performed well, while red showed the most unsatisfactory performance after adaptation.

Before adaptation with a Cyan background, black, blue, magenta, and red performed well, while green showed the most unsatisfactory performance. After that, the black, blue, and red, performed better, while green showed the most unsatisfactory performance. In Yellow background, black, blue, magenta, and red showed better performance, while cyan and green showed the most unsatisfactory performance before adaptation. On the other hand, black and blue performed better, while cyan and green showed the most unsatisfactory performance after adaptation.

Stimulus colors with the most satisfactory and unsatisfactory performance against each background color before and after adaptation had been concluded as Table 5.

4 Discussion

The results of the pre-test show that amongst the 6 background colors, Blue presented the shortest average reaction time, following by Yellow, Red, Magenta, Green, and Cyan. From the results of the pair wise comparison, these 6 background colors can be divided into 3groups by performance. The first group consists of Blue, it is significantly different to all the other background colors. The second group consists of Yellow, Red and Magenta. These 3 background colors showed similar performance. Finally, in the third group are Green and Cyan, which also showed similar performance.

Table 5. Color combination that have better performance

Background color	Better performance (no color adaptation)	Worst performance (no color adaptation)
	Better performance (after color adaptation)	Worst performance (after color adaptation)
Red	Black, Cyan, Green, Yellow	Magenta
	Yellow	Magenta
Green	Black, Blue, Magenta, Red	Cyan
	Black	Cyan
Blue	Cyan, Green, Magenta, Red, Yellow	Black
	Cyan, Yellow	Black, Magenta, Red
Magenta	Black, Blue, Cyan, Green, Yellow	Red
	Black, Blue, Cyan, Green, Yellow	Red
Cyan	Black, Blue, Magenta, Red	Green
	Black, Blue, Red	Green
Yellow	Black, Blue, Magenta, Red	Cyan, Green
	Black, Blue	Cyan, Green

None of these 6 background colors showed outstanding performance with a stimulus color combination, but most of them did show unsatisfactory performance with a certain stimulus color. These unsatisfactory combinations are: Magenta background with Green stimulus, Blue background with Black stimulus, Magenta background with Red stimulus, Cyan background with Green stimulus, and finally, Cyan stimulus and Green stimulus showed the worst performance with a Yellow background. The color combinations listed above were difficult to distinguish from appearance.

In the post-test, Blue performed the best amongst the 6 background colors. Listing from the shortest time to the longest, they are Yellow, Magenta, Red, Cyan, and Green respectively. Quite similar to the results of the pre-test, the 6 background colors can be divided into 3 groups by their performance. Cyan and Green have similar performance, Blue and Yellow can be put into the same group, and finally, Red and Cyan background colors showed similar performance.

With regard to the effects of the stimulus colors against these 6 background colors, not all of them showed a significant performance with the stimulus-background color combinations, but several stimulus colors did show similar performance. Comparing the results of the two tests, we can see that the process of color adaptation amplifies the difference between the stimulus colors.

5 Conclusion

According to past literature, color adaptation phenomena is very common in our daily lives. Most of the current studies are on the field of color contrast or color and design. Since smart phones, tablets and portable computers are the most common types of display today, this study aims to find out the effects of color adaptation on screens.

Participants in this study fixate the screen to achieve the adaptation of colors. The task of participants is to discriminate the direction of the Landolt C while the reaction time before and after color adaptation was recorded. The effects of the different color combinations are discussed.

Pre-test was set up by using the experience gained from other researchers, including the notch size and direction of the Landolt C. There are a total of 6 background colors and 7 stimulus colors. The reaction time of each trial of task was recorded to evaluate the performance and compare the difference between each background color. With an addition of a color adaptation phase in the post-test, the rest of settings are based on the pre-test. The length of the color adaptation is 2 min in total, and the reaction time at the following 25 time points are recorded.

Magenta is the only background color that showed the same result before and after color adaptation. The four background colors Red, Green, Cyan and Yellow showed parts of the same results before and after color adaptation, with the differences of stimulus colors amplified. The most outstanding performance occurred with background color Blue. Against background color Blue, a stimulus color that performed well showed unsatisfactory results after color adaption. According to the results of the analysis, some background colors had less choices of desirable stimulus colors after color adaptation. These changes were caused by color adaptation unquestionably. In other words, when you have a specific background color, you can choose a stimulus color that works better, but in another situation, when the background color was not decided beforehand, a background with a good stimulus color may perform less desirable than another background with a bad stimulus color, because background color itself like Blue has the shortest average reaction time amongst all background colors.

According to the performance summary of all color combinations, color scheme suggestions for an interface may vary under different conditions. First, if there is no color image preferences, we can consider using Blue as the background color, because it showed the best performance score amongst the 6 color samples in the study. Next, if we had a specific color image determined, in other words, we had a background color decided beforehand, then we can simply apply the stimulus colors with the best performance shown in Table 5. For example, in Cyan background color, Black, Blue and Red stimulus would be the best choices.

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