



Color Ergonomics Research in Harsh Environment Under Three Task Modes

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Abstract. To investigate how text color can influence the information recognition and cognitive processing of on-board operators and therefore improve operation efficiency, we conducted color ergonomics research on harsh environment under three typical mission scenarios. First, we chose 25 colors based on the color loop of the Ostwald Color System, and used the Simple Reaction Time (SRT) Paradigm to explore the recognition performance of colored blocks on black backgrounds. Then, based on the results of the first experiment, we constructed two types of environment conditions (general environment, harsh environment), conducted a time-stress experiment on three typical task modes (search, calculation, monitor), and analyzed according visual performances of five colors (red, yellow, green, blue and white). The results show that yellow and white are the more suitable colors under the harsh airborne environment, while blue has the worst performance of all colors. As for effect of task scenarios, the impact caused by different colors on efficiency is greater on the recognition tasks compared with the cognitive tasks; As for effect of environment, harsh environment can aggravate the difference of colors, the good (yellow and white) become better and bad (blue and green) become worse than in the general environment.

Keywords: Color ergonomics · Harsh environment · Task modes

1 Introduction

With the significant development of military technology in the area of informatization and intelligence, the airborne mission system has increased its information volume in order to adapt to the increasingly complex combat environment. Reasonable color design of the airborne mission system helps to reduce the workload of the operator, improve the efficiency of recognition and cognitive processing, and ultimately serve the operational effectiveness of the system. Closed airborne cabin is an important workplace and operational environment in high-tech warfare, and the harsh airborne environment can aggravate the physiological and

psychological load of the worker due to the closed space, loud noise, physical vibration, and complex optical environment conditions.

There have been comprehensive studies on the effects of optical environment on color visual performance [4, 6], therefore this study focused on the issue of vibration and noise. Vibration environment has a significant impact on human visual performance. Wang [5] discovered the vibration frequency and amplitude has a significant impact on the visual task completion time and the difficulty rating, and the direction of vibration has a significant impact on the visual task completion success rate. The study by Mallick [3] points out that in the case of continuous vibrating, choosing the correct color combination of the text and the background can solve the problem of difficulties of data entry task on laptop computers.

Hearing and vision have a clear interaction compensation effect involving the central nervous system. Gai [1] found that noises can significantly affect the subject's scoring on visual retention, visual response time, curve matching, target tracking, and stereoscopic vision. Liu [2] conducted a visual search task performance study in a speech noise environment.

Most of the researches directly investigated visual ergonomics, and rarely explored the aspect of text color. Moreover, most of them focused on the influence on visual performance of one single environmental variable, and the interaction influence between environmental variables remains unclear. This paper conducted color ergonomics research on harsh environment condition under three task modes, which can help pilot improve information recognition speed and cognitive processing speed, as well as improve their operation efficiency.

2 Experiment 1 - Colored Block Experiment

2.1 Experiment Subject

We have 15 male participants as our subject for the colored-block experiment. Their age is between 21–23, average age 21.8 ± 0.6 . They are healthy, and have normal vision or corrected-to-normal vision, normal color vision, and normal color perception.

2.2 Experiment Equipment and Material

Computer. We use Lenovo Erazer Y50-70 Laptop: CPU Intel Core i5 4200H, memory 8 GB DDR3, hard drive 256 GB SSD, Graphics Card Nvidia Geforce GTX 860M/Intel GMA 4600, Screen 15.6" LCD, resolution 1920×1080 , color depth 32 bit, refresh rate 60 Hz.

Material. Twenty-five colors were chosen from Ostwald Color System (Fig. 1) together with white. Their index number and their RGB values are 0-(230,0,18), 1-(235,97,0), 2-(243,152,0), 3-(252,200,0), 4-(255,251,0),

5-(207,219,0), 6-(143,195,31), 7-(34,172,56), 8-(0,153,68), 9-(0,155,107), 10-(0,158,150), 11-(0,160,193), 12-(0,160,233), 13-(0,134,209), 14-(0,104,183), 15-(0,71,157), 16-(29,32,136), 17-(96,25,134), 18-(146,7,131), 19-(190,0,129), 20-(228,0,127), 21-(229,0,106), 22-(229,0,79), 23-(230,0,51), 24-(255,255,255). Colored block's size is 2.5 cm × 2.5 cm. Experiment interface's background color is black, its RGB value (0,0,0).

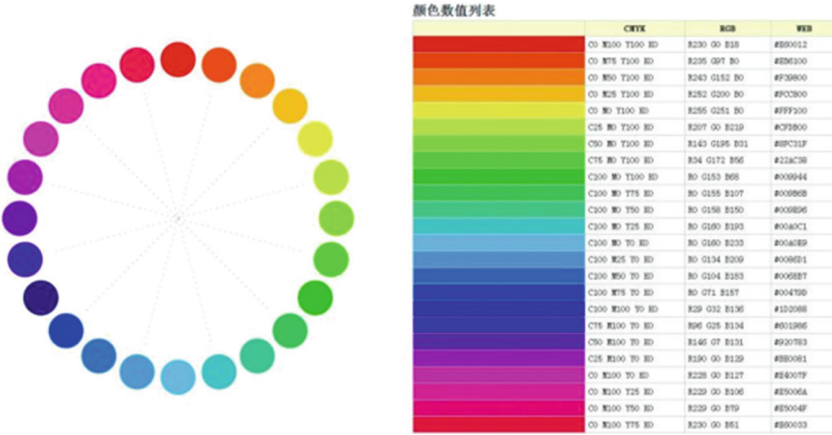


Fig. 1. Ostwald Color System and According Parameters (Color figure online)

2.3 Experiment Design

Experiment program is coded with C++ and Qt framework version 5.11. Before experiment starts, the subjects are sufficiently practiced in order to avoid the practice effect. During the experiments, the indoor light environment stays unchanged, subjects are seated on the chair 60 cm away from the display, both eyes keep parallel with the screen. The subject uses standard computer hardware such as standard mouse and standard keyboard to interact with computer.

Fixed-size colored block was randomly displayed in 25 colors at the center of the screen. Each subject was asked to look at the center of the screen, and press the space bar as soon as they noticed and recognized the color. The colored block will not disappear until the subject has reacted. The interval of the appearance of each colored block was random, ranging between 1–3 s. Each color was repeated 4 times, and each subject performed a total of 100 reactions. Their reaction time were recorded. During the experiment, the subject must be focused, and a reaction is only recorded if it is made after the colored block appeared, meaning pressing the space bar in advance is prohibited and also useless.

2.4 Experiment Results

We analyze the results from the experiment of the reaction time. The abnormal values are omitted from the analysis, then the mean value of each color are calculated and shown in Fig. 2.

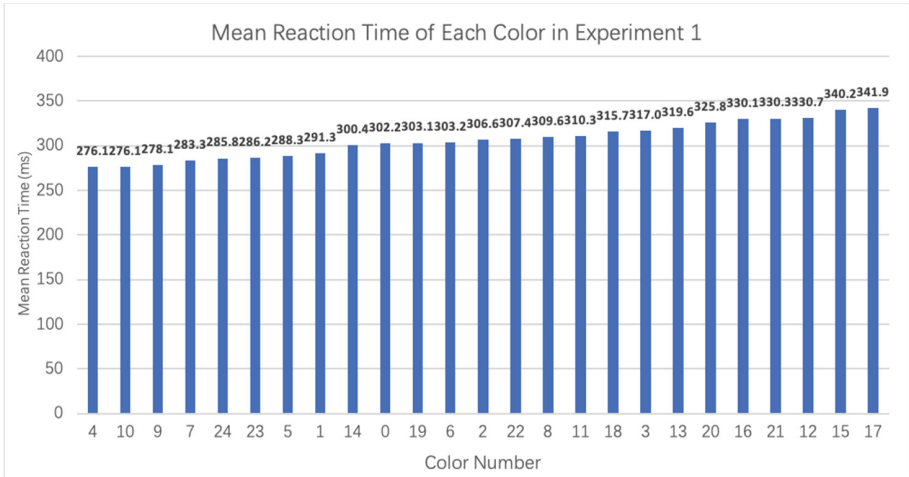


Fig. 2. Mean reaction time of each color in experiment 1 (Color figure online)

From Table 1, analysis of variance showed that there was a significant difference in reaction time of the 25 colors ($F = 1.84, P < 0.05$). Least Significant Difference (LSD) of the 25 colors showed that, the blue-violet color series (No. 15, 16, 17) have performance significantly slower than the yellow color series. Also, red, yellow, cyan and white has the tendency of faster than other colors. The difference in other colors' performance is not significant.

Table 1. ANOVA: the effect of colors on completion time

TIME					
	Sum of squares	df	Mean square	F	Sig.
Between groups	381341.036	24	15889.210	1.846	.008
Within groups	8392924.800	975	8608.128		
Total	8774265.836	999			

Based on these results, also considering the integrity of color series, five colors were chosen as the color for the interface in the following experiment 2: red (230,0,18), yellow (252,251,0), green (0,155,107), blue (0,134,209) and white (255,255,255).

We also studied the count of the color with the shortest reaction time (Fig. 3) and longest reaction time (Fig. 4) within each experiment group (of 25 experiments). In the shortest reaction time count, the top color is yellow (5 times), accounting for 12% of the total, followed by white. In the longest reaction time count, blue color series (dark blue, light blue, sky blue) are the most (12 times), accounting for 30% of the total.

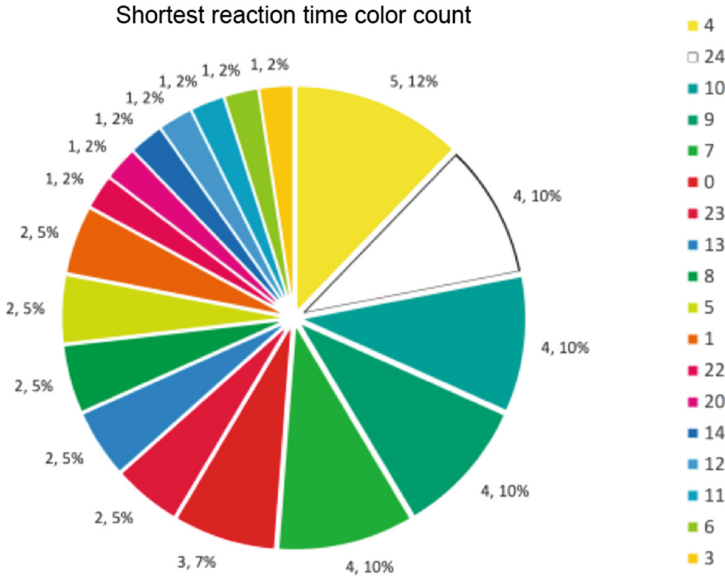


Fig. 3. Count of shortest reaction time for each color (Color figure online)

3 Experiment 2 - Color Ergonomics Experiment

3.1 Experiment Subject

We have 10 male participants as our subject for this experiment. Their age is between 21–23, average age 22.3 ± 0.4 . They are healthy, and have normal vision or corrected-to-normal vision, normal color vision, and normal color perception.

3.2 Experiment Equipment and Material

Computer. We use Lenovo Erazer Y50-70 Laptop: CPU Intel Core i5 4200H, memory 8 GB DDR3, hard drive 256 GB Solid State Drive, Graphics Card Nvidia Geforce GTX 860M/Intel GMA 4600, Screen 15.6" LCD, resolution 1920×1080 , color depth 32 bit, refresh rate 60 Hz.

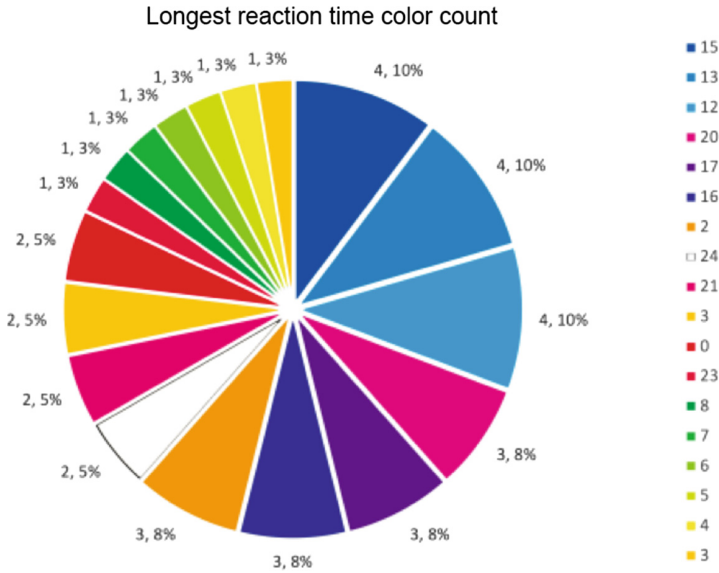


Fig. 4. Count of longest reaction time for each color (Color figure online)

Material. Experiment material used in this experiment are shown in Fig. 5. The three parts on the interface are (from left to right respectively) search task, calculation task and monitor task. We use five colors chosen from Experiment 1 as the interface color: red (230,0,18), yellow (252,251,0), green (0,155,107), blue (0,134,209) and white (255,255,255). The noise is simulated by the software *Soundmasker*.

3.3 Experiment Design

Experiment program is coded with C++ and Qt framework version 5.11. Before experiment starts, the subjects are sufficiently practiced in order to avoid the practice effect. During the experiments, the indoor light environment stays unchanged, subjects are seated on the chair 60 cm away from the display, both eyes keep parallel with the screen. The subject uses standard computer hardware such as standard mouse and standard keyboard to interact with computer.

During the experiment, the subject needs to complete three type of tasks.

- Search task (T1): 25 randomly-chosen different English letters will appear in a 5×5 matrix in random order, and one of the letters will be randomly chosen as the target letter. Subject should find and click the target letter in the matrix as soon as possible.
- Calculation task (T2): Two-digit to two-digit add and subtract tasks will be randomly generated and displayed on the interface. The subject need to input the calculated result by keyboard and click “enter” to submit the answer.

- Monitor task (T3): The program will randomly display words from four major categories (animals, plants, food, city names) in a 5×3 matrix. We randomly chose one category as the target category. During each task, there will be only zero or one word of the target category. Subjects need to monitor if any word from the target category is shown in the matrix. If there is, the subject needs to click on it; if not, the subject do not need to react.

To simulate different environment scenarios, the experiment designed different vibration levels and noise levels. Vibration level includes no vibration and high vibration (frequency 20 Hz, amplitude 2 mm) to the graphic interface. Noise level includes low noise (45 dB white noise) and high noise (80 Hz white noise).

Each subject was asked to complete tasks in two environments.

- General Environment (E1): low noise (45 dB) with no vibration.
- Harsh Environment (E2): loud noise (80 dB) with high vibration (frequency 20 Hz, amplitude 2 mm).

There were five task groups in each environment corresponding to the five colors selected from Experiment 1. There were four task page within each task group, and each task page consisted of a search task, a calculation task, and a monitor task. The operation completion time and success rate of the subject were recorded.

Therefore overall, each subject needs to complete 40 search tasks, 40 calculation tasks and 40 monitor tasks. For monitor tasks, however, the subject need not to react if there are no words from the target category, therefore no reaction time on these tasks. We programmed 10 out of 40 tasks to contain words from the target category. That means, for each subject we have the experiment results for 40 search tasks, 40 calculation tasks and 10 monitor tasks.



Fig. 5. Graphic interface of experiment 2 (Color figure online)

3.4 Experiment Results

The mean completion time of each task under different environments is shown in Fig. 6. The analysis of variance is shown in Table 2.

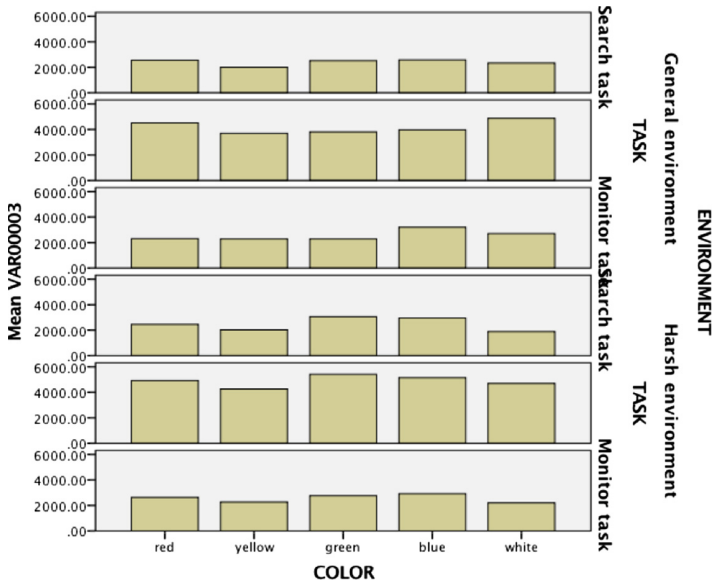


Fig. 6. Mean value of completion time of experiment 2 (Color figure online)

General Environment (Low Noise, No Vibration). In search task, there was significant difference in performance for different colors ($F = 16.122, P < 0.05$). Combined with Least Significant Difference (LSD), the results showed that yellow was significantly better than other colors. In calculation task, there was a trend of significant difference ($F = 1.999, P < 0.1$). In monitor task, there was no significant difference in completion time between colors.

Harsh Environment (Loud Noise, High Vibration). In search task, there was significant difference in performance for different colors ($F = 29.163, P < 0.05$). Combined with histogram and Least Significant Difference (LSD), the completion time of yellow and white was significantly shorter than that of blue and green, and there was no significant difference between red and white. The completion time ranking from fastest to slowest is yellow, white, red, blue, and green. In calculation task, there was a significant difference in performance for different colors ($F = 2.511, P < 0.05$). Blue and green were significantly slower than the other three colors, while the other colors were not significantly different. In monitor task, there was no significant difference in completion time between colors.

Table 2. ANOVA: the effect of colors on completion time, grouped by environment and task

TIME							
Env.	Task		Sum of squares	df	Mean square	F	Sig.
General environment	Search	Between groups	52800285.310	4	13200071.327	16.122	.000
		Within groups	142462010.277	174	818747.185		
		Total	195262295.587	178			
	Calculation	Between groups	16923663.273	4	4230915.818	1.999	.097
		Within groups	370433611.971	175	2116763.497		
		Total	387357275.244	179			
	Monitor	Between groups	8666006.194	4	2166501.548	.755	.562
		Within groups	91842561.050	32	2870080.033		
		Total	100508567.243	36			
Harsh environment	Search	Between groups	94014689.263	4	23503672.316	29.163	.000
		Within groups	132174190.713	164	805940.187		
		Total	226188879.976	168			
	Calculation	Between groups	26437219.242	4	6609304.810	2.511	.043
		Within groups	471140332.215	179	2632068.895		
		Total	497577551.457	183			
	Monitor	Between groups	3286249.244	4	821562.311	.663	.623
		Within groups	35926358.286	29	1238839.941		
		Total	39212607.529	33			

Combined with Table 3 and LSD results, the differences between colors in the general environment and the harsh environment are both significant, and the difference is slightly larger when in the harsh environment. The multivariate analysis of variance (Table 5) also showed that the interaction of the color and environment had a significant effect on the completion time ($F = 3.345, P < 0.05$).

Table 3. ANOVA: The effect of colors on completion time, grouped by environment

TIME						
Environment		Sum of squares	df	Mean square	F	Sig.
General environment	Between groups	56847839.856	4	14211959.964	5.311	.000
	Within groups	1046349945.303	391	2676086.817		
	Total	1103197785.159	395			
Harsh environment	Between groups	103005204.044	4	25751301.011	8.011	.000
	Within groups	1227866758.653	382	3214310.887		
	Total	1330871962.698	168386			

Combined with Table 4 and the LSD results, the difference between colors was significant in Task 1 ($F = 38.244, P < 0.05$), while the difference between Task 2 and Task 3 was not significant. The multivariate analysis of variance (Table 5) also showed that the interaction of color and task type had a significant effect on the completion time ($F = 2.866, P < 0.05$).

Table 4. ANOVA: The effect of colors on completion time, grouped by task

TIME						
Task		Sum of squares	df	Mean square	F	Sig.
Search	Between groups	130567194.003	4	32641798.501	38.244	.000
	Within groups	292755724.583	343	853515.232		
	Total	423322918.586	347			
Calculation	Between groups	14951827.944	4	3737956.986	1.502	.201
	Within groups	893260937.473	359	2488192.026		
	Total	908212765.418	363			
Monitor	Between groups	6514559.549	4	1628639.887	.807	.525
	Within groups	133225481.550	66	2018567.902		
	Total	139740041.099	70			

Table 5. The multi-factor variance analysis of the influence of color, environment and task on completion time

Tests of between-subjects effects						
Dependent variable: TIME						
Source	Type III sum of squares	df	Mean square	F	Sig.	
Corrected model	1213737412.753 ^a	29	41853014.233	25.334	.000	
Intercept	5616758030.160	1	5616758030.160	3399.912	.000	
COLOR	55030226.777	4	13757556.694	8.328	.000	
ENVIRONMENT	5834307.184	1	5834307.184	3.532	.061	
TASK	976390456.223	2	488195228.112	295.512	.000	
COLOR * ENVIRONMENT	22103333.779	4	5525833.445	3.345	.010	
COLOR * TASK	37881196.638	8	4735149.580	2.866	.004	
ENVIRONMENT * TASK	8100586.592	2	4050293.296	2.452	.087	
COLOR * ENVIRONMENT * TASK	6252711.306	8	781588.913	.473	.876	
Error	1243979064.511	753	1652030.630			
Total	12746999853.000	783				
Corrected total	2457716477.264	282				

^aR Squared = .494 (Adjusted R Squared = .474)

4 Conclusion

Color Performance. For different tasks and different environments, color performance has a clear trend. As for the speed of recognition process and cognitive process, yellow and white performs considerably better than blue and green, and red is of medium performance. This indicates that. Both experiment 1 and 2 showed that the blue has the lowest performance in recognition and cognitive.

Impact of Color in Different Environments. The selection of color has less effect in the general environment than in harsh environment. When the environment worsened, people are more sensitive to color, and the differences between the performances of colors are magnified. This shows that in severe

environments, the choice and application of color needs to be made with more caution.

Impact of Color on Different Task Modes. Color selection has a significant impact on the search task, but not on calculation and monitor tasks. A search task is a process of identification and matching which involves little processing, while the calculation and monitor tasks have longer information processing time, thus the effect of color is weakened. Therefore, when applying of principles of color selection, it is best to focus on recognition rather than cognition. Color selection should be designed with great effort for recognition tasks.

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