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# Performance Evaluation of Alarm Forms under Different Visual Coding on the Digital Interface

Y F Niu<sup>1,2</sup>, B Li<sup>2</sup>, X Y Zhang<sup>1</sup>, L C Qiu<sup>3</sup>, B Z Shi<sup>3</sup>, C Q Xue<sup>1\*</sup>, W Y Xiao<sup>1</sup>,  
Y T Zhang<sup>1</sup>, Z Q Li<sup>4</sup>

<sup>1</sup>School of Mechanical Engineering, Southeast University, Nanjing 211189, China;

<sup>2</sup>Science and Technology on Electro-optic Control Laboratory, Luoyang 471023, China;

<sup>3</sup>Shanghai Academy of Spaceflight Technology, Shanghai 201109, China;

<sup>4</sup>Petro China kunlun Gas Co., Ltd Security Oversight Center, Nanjing 210000, China

Corresponding author's e-mail address: ipd\_xcq@seu.edu.cn

**Abstract.** To investigate user performance evaluation for different alarm forms on the digital interface under single dimensional information coding, such as color, shape, flash frequency, size and number, this study designed 5 visual alarm modes by following the design specification of visual alarm signal and carried out behavioral experiments for a certain radar interface. Based on the statistical analysis of accuracy rate and reaction time and comprehensive experimental interviews, the results reveal that, visual coding alarm form in the best identification performance is number and the worst is flash frequency. The research conclusions can be applied to the actual alarm interface design. It has a certain reference value for reducing the cognitive friction between the user and the digital interface, establishing a good man-machine cognitive matching relationship and perfecting the usability evaluation system of information coding.

## 1. Introduction

The informational combat system has the characteristics of digitization and informationization, namely the digitization and visualization of the operational environment, battlefield situation and command system information. Almost all information on the battlefield is collected on the digital interface of information weaponry. The digital interface is the carrier for military personnel to analyze and process information. Military personnel judge and make decisions on equipment system information through digital interface. Only by ensuring the rationalization of the digital interface information can the military personnel make accurate judgments and implement precise operations on the battlefield situation in a short period of time. Therefore, the coding and design of information has become one of the research focuses of the digital interface of combat systems.

In the presentation information of the digital interface, the alarm information is particularly important. If the display form of the alarm information is contrary to the cognitive characteristics of the person, it will hinder the operator from correctly and efficiently processing the alarm information, which could cause serious consequences[1]. The alarm information in the digital interface is mostly a descriptive information[2], which is a kind of information used for the system alarm module, diversified form representation, describing system abnormal events or state changes to cause the



operator to be alert. In order to deliver system alarms more orderly and efficiently, the alarm information must be classified according to criticality or importance. According to the severity of the system fault, the alarm information that needs to be displayed in the digital interface can be divided into three levels: attention level, alert level, and dangerous level. The alarm information of different levels is applied differently, and the dangerous level has the highest alarm level and alert level is medium and the attention level is the lowest.

The digital interface has different alarm levels, and the visual representation is also diverse. The alarm information itself includes visual stimuli such as color, shape, flash frequency, size, and characters. Therefore, the information coding of the alarm information can be classified into five categories: color coding, shape coding, flash coding, size coding, character coding. In the research on the recognition performance of different information coding in digital interface, domestic and foreign scholars had carried out related research. Christ (1975) found that the search performance of color coding in search operations was significantly better than number coding, text coding and geometric shape coding, meanwhile the identifying performance was not as good as number coding[3]; Van Orden et al. (1993) used brightness and flash as the highlighting method to study the shape and color of the symbol, and concluded that the symbol shape and color affect the search time[4]; Nowell et al. (2002) investigated the correctness and reaction time of the nominal data and the quantized data in three different coding formats: color coding, shape coding and size coding, and the results showed that the color coding performance was optimal[5]; Dahlstedt (1991) studied the visual spatial information coding size of the flight attitude indicator (FAI) and found that the participants were more inclined to choose a combination of graphics with strong spatial correlation[6]; In the field of cognitive performance measurement of visual alarm information, Kou (2010) studied the concept compatibility of vehicle warning signal indicating device icons through subjective evaluation method, direct selection method and reaction time method, simultaneously designed and improved it[7]; Wickens et al. (1990) studied the color coding information and spatial positioning information cognitive performance under multi-channel conditions[8]; Ye et al. (2016) analyzed the alarm principle of the navigation radar system and studied the alarm flow and visual representation of the ship in different dangerous situations[9]; Chen et al. (2014) measured the behavioral performance of visual warning information of target and distracting objects in the cockpit interface, and found that the performance of target stimulation was significantly reduced with the intervention of distraction stimulation[10].

Domestic and foreign scholars focused on the research of cognitive coding rules of basic element information coding for visual representation and recognition performance of digital interface information coding. There are relatively few coding designs and ergonomics studies on different alarm levels of digital interfaces, and few studies on the design specifications of digital interface visual alarm signals for reference. Therefore, it is particularly necessary to carry out research on the identification performance evaluation of different visual alarm forms in the digital interface.

Based on the interface background of the radar combat system, this paper aims to study the recognition efficiency of different visual alarm information coding under the design of color coding, shape coding, flash frequency coding, size coding and number coding. Through the correct rate and reaction time indicators in behavioral experiments, the types of alarms with the best visual recognition performance under single-dimensional coding were explored. It provides design basis and experimental support for the display format of digital dynamic interface alarm information, so that the coding design of visual alarm information is more in line with human cognitive psychology which improves the operator's situational awareness, the accuracy of information interpretation and combat effectiveness, accordingly reduce the operator's psychological load and operational errors.

## **2. Description of experimental materials and evaluation indicators**

### *2.1. Design of alarm coding experimental material*

This paper selected the radar dynamic interface of a military equipment system as the research object, and an alarm occurred when the enemy target was presented. The targets included helicopters, airplanes, air-to-ground missiles, and cruise missiles. The four types of target icons were redesigned according to the design regulations of the military standard GJB-87 for military aircraft. The background color of the interface selected by the experiment was unified to black, and the value of the RGB color system was (0, 0, 0), which was in accordance with the background color setting of the standard radar interface. According to the principle of visual coding, the experimental materials of five kinds of alarm forms: color group, shape group, flash frequency group, size group and digital group were respectively designed.

#### (1) Description of the enemy and my target code design

The target objects in the radar interface were divided into two types: the enemy target and our target. Both of them contained four kinds of targets. They were distinguished by positive and negative type of circle. The interface contained four target icons, the icon size was 20×20 Pixels, and the colors were all white. The radar interface design legend for the enemy and our military targets is shown in Figure 1.









	Helicopter	Aircraft	Air-to-ground missile	Cruise missile
Enemy target				
Our target				

Figure 1. Design map of radar interface target

#### (2) Color alarm

In the form of color-coded alarms, referred to the US military standard MIL-STD-1472G for the value of the alarm color[11], selected yellow (570nm wavelength) to indicate the attention level target, orange (600nm wavelength) to indicate the warning level target, red (700nm wavelength) to indicate the dangerous level target. The icon size is 20×20 Pixels.

#### (3) Shape alarm

In the form of shape alarm, the quadrilateral was selected from the 15 kinds of geometric figures[12] which were highly discernible and difficult to be confused. The pentagon represented the enemy alert level target, and the six stars indicated an enemy dangerous level target. The more sharp corners of the graph was, the higher the alarm level became. The icon size was 20×20 Pixels.

#### (4) Flash frequency alarm

In the flash frequency alarm mode, according to the best stroboscopic range (3 to 12 Hz) that could be recognized by the human eye, 3 Hz flash frequency was selected to indicate the attention level target, and 6 Hz flash frequency was the warning level target, and 10 Hz flash frequency was the dangerous level target. That was, when the target was the attention level, the icon flashed 3 times per second; when the target was the warning level, the icon flashed 6 times per second; when the target was dangerous, the icon flashed 10 times per second. The faster the flash frequency was, the higher the alarm level became. The icon size was 20×20 Pixels.

#### (5) Size alarm

In the form of large and small alarms, according to the experimental conclusions of LOURENCO S F et al. on the perception of human approach to objects, if a person thought that the distance between him and the target was slowly approaching, the degree of human perception of the danger of the target was more obvious. When the level of the alarm was higher, people would have a greater degree of cognition. Therefore, designing a 20×20 Pixels size indicated an attention level target, a 30×30 Pixels size indicated a warning level target, and a 45×45 Pixels size indicated a dangerous level target, and

the magnification between each alarm level remained at 150%. The larger the icon size was, the higher the alarm level became.

#### (6) Number group

In the form of digital alarm, according to the urgency of the alarm level from the attention level-alert level-danger level, the alarm was coded from the order of 1-2-3 according to the numerical size, and the number "1" was selected to indicate the attention level target. The number "2" indicated the alert level target and the number "3" indicated the dangerous level target. The higher the number was, the higher the alarm level became. Numbers were displayed on the icon to easy identification for the participant. The icon size was 20×20 Pixels, the digital aspect ratio was 2:3, and the word height was set to 12 lbs.

### 2.2. *Description of identifying performance evaluation indicators*

According to the international standard ISO9241-11, product availability could be summarized into three aspects: effectiveness, the accuracy and completeness achieved by the user using the system to accomplish various tasks; high efficiency, the resources consumed by the user to complete the task according to accuracy and completeness, including intelligence, physical strength, time, materials and economic resources; satisfaction, the subjective response of the user's use of the system, described the comfort and acceptance of the product[14]. This paper referred to the standard, and used effectiveness, efficiency and satisfaction as the evaluation index of digital interface visual alarm identification performance. The correct rate of completing the experimental task was selected as the evaluation index of effectiveness and the response of the experimental task was correctly completed as evaluation indicators of the high efficiency. After the experiment, the users' satisfaction was investigated through interviews and inquiries. Finally, through the comprehensive analysis of effectiveness, efficiency and satisfaction, the visual alert coding form of optimal recognition performance was obtained. The optimal recognition performance had the characteristics of fast response, high correct rate and high subjective satisfaction.

## 3. Experimental design

### 3.1. *Experimental subjects*

This experiment recruited 20 master students from the Department of Industrial Design of Southeast University as the subjects. Considering that the military personnel were mostly male, more male candidates were selected, including 12 males and 8 females in 24-28 years old. The average age of the subjects was 26 years old, physical and mental health, right hand; normal color vision and visual ability, or corrected visual acuity of 1.0 or above; all had military design interface design experience; the subjects were fully rested and highly awake before the experiment. The experiment followed the principle of informed consent of the participants, and the participants were given a certain reward after the end.

### 3.2. *Equipment and experimental environment*

The experimental procedure was written using E-prime software and visual stimulus. The visual distance between the eyes and the center of the display was 70 cm, the brightness of the control display was 120cd/ m<sup>2</sup>, and the indoor illumination was 500 Lux. The hardware device was a USB reaction box with a standard keyboard layout. Only the letter keys for reaction were reserved, and other keys could not be pressed. The keyboard illumination was 150Lux.

### 3.3. *Experimental design*

This experiment was designed based on a radar interface. The single factor internal design was used to study the influence of visual information single-dimensional alarm coding form factors on recognition performance. It was divided into 5 levels: color, shape, flash frequency, size, number. The experimental materials included four kinds of targets: helicopters, airplanes, air-to-ground missiles,



and cruise missiles. The alarm levels were divided into four categories: attention level, warning level, dangerous level, no alarm (our target), and visual alarm forms total  $5$  (horizontal)  $\times 4$  (target)  $\times 4$  (alarm level) = 80 kinds (experimental samples), each group of targets was randomly presented in the experiment, and there were 3 trials of danger level, alert level, attention level and no alarm, and colors, shapes, flash frequencies, sizes, and numbers showed  $4 \times 4 \times 3 = 48$  trials, and the total number of trials was 240 trials.

The experimental material is normalized, and the stimulus material in the form of color, shape, size and number is an image type stimulus, and the stimulus material in the form of a flash frequency alarm is video stimulation. The picture stimulus is BMP format, the picture size is  $1920 \times 1080$  Pixel, 72PPI, 16-bit color depth; the video stimulus is WMV format, the frame height is 1920 Pixel, the frame width is 1080 Pixel, the total bit rate is 792kbps, and the frame rate is 30. Frames/sec, the video duration is 1000ms.

### 3.4. Experiment process

The experiment was divided into five groups of experiments, including color group, shape group, flash frequency group, size group and number group. Each coding dimension was a set of experiments. The experiments were performed in the order of color-shape-flash-size-number, and each group experiment included an exercise phase and an experimental phase. After the end of all experiments, entered the interview stage.

#### (1) Practice stage

First, the participants were presented with the guidance of the group of experiments, including the introduction of the experiment, the alarm form, the corresponding button response of the alarm level, etc. Then, the participants were shown examples of the alarm forms under the three alarm levels of the group, providing recyclable practice program. During the practice, the participant could see the feedback information of the button and practiced repeatedly for the group with higher error rate. Among them, the practice process did not record data. After being fully familiar with the experimental tasks, the participants were transferred to the formal experimental phase.

#### (2) Experimental stage

First, the center of the screen presented a red cross, which disappeared automatically after 500ms. Then, the target appeared in the center of the screen, and the subject recognized the alarm level of the target. When enemy dangerous level target displayed, subject needed to press A, S for the enemy's alert level, D for enemy attention level target object, L for our target object, and disappeared after pressing the button. This process required the subject to react quickly and accurately. Finally, the black empty screen appeared, and automatically disappeared after 800ms. The average total duration of the experiment was about 20 minutes. In order to eliminate the fatigue effect, rest time was provided after each group of experiments, and then any key is pressed to enter the next set of experiments. The E-prime software recorded the correct rate and response time of the five sets of visual alert forms. The experimental process was shown in Figure 2.

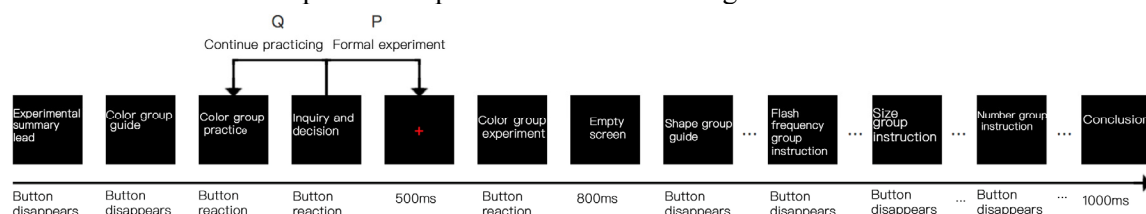


Figure 2. Experimental flow chart

#### (3) Interview stage

After the experiment, 20 subjects were interviewed, and the groups with the highest matching visual alarm form and the most difficult to identify were recorded.

## 4. Data statistics and analysis

#### 4.1. Descriptive statistics

Excluding the error value and the extreme value in the original data, the ratio of the culled data to the total experimental data was  $4.7\% < 5\%$ . The original data of the reaction time and the correct rate satisfied the normal distribution. Statistical analysis was performed using SPSS software, including descriptive statistics and one-way analysis of variance with a significance level of 0.05. Both the correct rate and the effective sample size at the time of the reaction were 20.

The average recognition accuracy rate (unit: %) of 20 subjects was ranked as: shape group (98.369) > color group (98.147) > number group (97.802) > size group (95.828) > flash group (88.221). The average recognition reaction time (unit: ms) was sorted as: flash frequency group (960.903) > shape group (680.348) > color group (678.525) > number group (595.757). Average correct rate and average reaction time data were as shown in Figure 3.

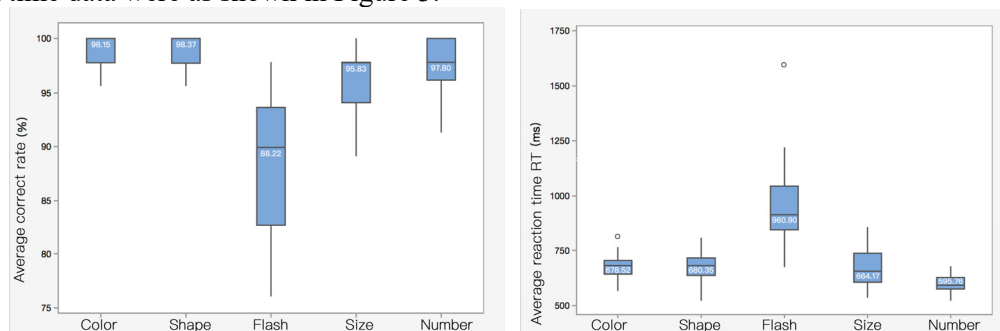


Figure 3. Average accuracy rate(left) and reaction time(right) box pattern

The correct rate and standard deviation was sorted under different visual alarm forms: flash frequency group (6.868) > size group (4.246) > color group (2.854) > shape group (2.717) > number group (2.245); in the comparison of the standard deviation, the correct rate was almost the same as the sorting result reflected in the reaction, that was, the standard deviation of the flash frequency form was relatively large, and the standard deviation of the digital form was relatively small.

#### 4.2. Variance analysis

There was a significant difference in the average recognition accuracy rate and the single-factor ANOVA analysis of variance for the five groups,  $p=0.000<0.05$ . The five groups of data were tested for homogeneity of variance and found that the variance was not uniform. Therefore, Dunnett's T3 (Dunnett's T3), which did not assume equal variance, was used to compare the two groups after the two, and further confirmed the significance between the five groups.

#### 4.3. Post-experiment interview

At the end of the experiment, interviews were conducted on 20 participants who participated in the experiment. The interview results showed that among the 20 subjects, 9 subjects considered that the color group was the least difficult to identify, 11 considered that the number group was the most recognizable. The 17 subjects considered that the flash frequency group was the most difficult to identify, and the three considered the most difficult group identification. In the flash frequency group, the subjects considered that the 6 Hz indicating the warning level and the dangerous level indicating the 10 Hz were the most difficult to distinguish.

### 5. Discussion

#### 5.1. Discussion of results

The data results show that within the 95% confidence interval of the mean:

(1) There was no significant difference between the groups in the color group, shape group, size group and number group ( $p>0.05$ ). The average correct rate of the flash group and the other four groups showed significant difference,  $p<0.05$ . The average correct rate of the flash frequency group was the lowest. At the same time, the average response of the flash frequency group and the other four

groups also showed significant differences between groups,  $p=0.000$ , and the average response time of the flash frequency group was the slowest. It could be seen that the form of the flash frequency alarm was the most effective and efficient. And this conclusion was consistent with the post-experimental interview results and can be mutually verified.

(2) There were significant differences in the average response time between the digital group and the color group, shape group, flash frequency group and large group,  $p<0.05$ , and the average response time of the digital group was the fastest. The comprehensive performance evaluation index in 1.2 was available. The digital alarm form was optimally efficient. Consistent with the majority of subjects (11/20) who believed that digital alarms were the most recognizable.

(3) According to the average correct rate of 5 groups and the standard deviation of the average reaction, the standard deviation of the flash group and the size group were both larger and more unstable. The standard deviation of the digital group was the smallest, reflecting the subjects in the digital group. When the alarm level was identified, the behavioral performance was minimally affected by individual differences.

### *5.2. Guiding significance for interface design*

When the number code passed the visual alarm information, the operator could react quickly and accurately according to the different alarm levels presented, that was, the availability of the code was higher. Compared with color coding, shape coding, flash coding and size coding, number coding could be better compatible with the concept of visual alarm. The operator's decoding process was relatively easy and not easy to make mistakes. The reason was that the number was more advantageous in the semantics of the bound alarm code. Therefore, in the human-machine interface design of pure visual alarm, the number code is used to design the alarm level, which will better conform to the operator's psychological behavior characteristics, which can improve work efficiency and reduce the probability of errors and accidents.

When the flash frequency code transmitted the visual alarm information, it was difficult for the operator to distinguish the difference between the visual alarm levels, the lowest correct rate and the slowest response time. When three kinds of blinking frequencies were used to indicate different alarm attributes, the difference perception threshold of the flash frequency form was not obvious. Compared with color coding, shape coding, size coding and number coding, the compatibility between flash coding and visual alarm was poor and the operator's decoding process was relatively difficult, which was easy to cause wrong operation. However, the flash code still had a very significant visual highlighting effect, which could quickly attract the attention of the operator. In the actual alarm interface and the context of a single level alarm, the flash frequency alarm form had strong application value. For example, when there is only a dangerous level alarm, the flash frequency coding can quickly attract the attention of the operator.

Color recognition in this experiment was also very good at identifying performance, which could transmit visual alarm information very well. In practical applications, color coding can be applied to the complex alarm interface for visual data presentation as one of the main alternative codes in the form of visual alarms, but the color alarm form also has limitations that cannot be considered by the color blindness operator.

## **6. Conclusion**

Based on the dimensions of color coding, shape coding, flash coding, size coding and number coding, this study designed five visual alarm forms and conducts behavioral experiments based on a radar interface and following the design specifications of visual warning signals. Through statistical analysis of the correct rate and reaction time after comprehensive experiment interviews, it is found that the visual coding alarms with the best performance is identified as number group, and the worst is the flash frequency group. Finally, the application of visual alarm information coding form in design was discussed, and the guidance for interface design was given. This research helps to improve the design of visual alarm information, which makes it more in line with human cognitive psychology



characteristics and is more easily recognized by operators. It provides experimental basis and theoretical basis for the display specifications and requirements of digital dynamic interface alarm information. This paper conducts ergonomic research from single-dimensional visual coding, and has certain reference value for alarm coding. However, the actual alarm process is very complicated, and it needs to be integrated with the auditory channel and multi-dimensional visual coding. The future research work will be carried out for multi-channel and multi-dimensional alarm forms.

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