Comparison Study of Visual Search on 6 Different Types of Icons

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Abstract. In order to study the similarities and differences of the visual search features on different types of icons in the human-computer interface, using digital icons, English icons, Chinese icons, abstract icons, graphical icons and image icons as experimental materials. Combined with eye tracking devices, a visual search experiment was designed adopting E-Prime programming, and a comparative study was conducted from 3 aspects of reaction time, correct rate, and eye movement characteristics. The results of single factor analysis of variance indicated that: (1) The difference among 6 different types of icons in reaction time of visual search was statistically significant, and the reaction time was ranked as digital icons > English icons > Chinese icons > abstract icons > graphical icons > image icons. (2) In addition to the abstract icons, the other 5 types of icons in the visual search showed no obvious error. (3) As for the eye movement characteristics of 6 different types of icons, there were significant differences in fixation duration, fixation times, saccade amplitude and saccade speed, however, pupil diameter and blink frequency were not significantly different. The research results have reference value for the icon design and usability evaluation in human-computer interface.

1. Introduction
Visual display is the main form of the information transmission and expression of the graphical user interface in the human computer interaction. Icons, as an important components of graphical user interface, play an important role in the software system interface, web page navigation interface, radar search interface, and aircraft display interface. At present, icon design mainly uses small-pictures that are intuitive and easy for the user to understand to represent specific meanings or functions, and are used for information identification and pointing interaction[1]. Reasonable icon design has a significant impact on the accuracy and efficiency of human-computer interaction, in view of the comparison of the visual search characteristics of different types of icons, it is of great significance to provide ergonomic basis for the design and evaluation of human-computer interface.

At present, the icons in the graphical user interface are mainly in the form of characters, graphics, images, etc. Among them, the characters are suitable for expressing abstract concepts, the images are more efficient in conveying entities and their context information, and the graphics are between the two forms of visual expression[2].

Dual Coding Theory holds that knowledge is stored in two forms which are language and imagery, and there are two independent cognitive subsystems, which are used to deal with these 2 forms of information[3]. Cognitive psychology points out that the process of human information processing is from input to processing and then to output, people recognize characters mainly by comparing their
semantic information, and for graphics and images, they are used to compare their visual differences and implicit semantic information[4].

Researchers have studied the visual search features of different types of icons. Isherwood[5] proved that the search efficiency and perception performance of graphic icons were better than the textual icons, and the subjective feelings of the participants in graphic icons were more beautiful. Ghayas et al. [6] studied the recognition rate of mobile phone icons for users of different ages and found that the recognition rate depends on the degree of familiarity of the participants with the icon, and pointed out that the icon design should follow the principle of consistency. Schröder[7] examined the influence of concreteness and complexity on the semantic transparency of icons, and found that complexity had a significant effect on response time, while concreteness had a greater impact on correctness. Passini et al.[8] found that the response time and accuracy were positively correlated with the icon visual degree(concreteness) in the match test of icon semantics and appearance. Johanna et al.[9] considered that the semantic distance is a critical factor in icon design for in-car infotainment systems, the research results showed that the primed product comparisons method could be efficiently utilised for finding an optimised set of icons for time-critical applications out of a larger set of icons. Federica et al.[10] investigated the extent to which a sample of Italian users comprehended safety pictorials used on agricultural machinery, the results indicated that many of the pictorials adopted for agricultural machinery investigated in this study yielded low comprehension scores.

The above research results provided an important theoretical basis for the design and evaluation of the icon in the human-computer interface, but the research object had not yet included all types of icons. Based on the above research results, this study used the icon types commonly found in 6 types of graphical user interfaces, including the Arabic numeral icons (abbreviated herein as digital icons), English icons, Chinese icons, abstract icons, graphical icons, and image icons. And visual search experiments were designed with eye tracking technique.

2. Experimental design

2.1. Experimental environment and equipments
The experiment was carried out in a specialized ergonomics laboratory, and the laboratory space was spacious, the temperature and humidity were suitable, the light intensity could be adjusted, no odor, no noise and other external interference factors. The experimental equipment included a laptop computer, a RED5 eye tracker, the highest sampling frequency is 500Hz, and the host display resolution was 1280 × 1024 pixel, and the screen brightness was adjusted to 300cd/m2, the distance between the eyes of the participants and the screen was about 50cm, the center of the screen and the participants’ eyes were at an equal level. The experiment used the standardized psychological experiment system E-Prime software to compile and automatically record the preservation of experimental data, the eye movement data was processed by BeGaze software.

2.2. Participants
Students at the Air Force Engineering University in China (N = 12) participated in this experiment, including 8 males and 4 females, aged 18 to 22 years old (SD = 3.08). All participants were in good health, and had normal or corrected-to-normal vision, no color blindness, color weakness or other characteristics. All participants have reached CET-4, and have more than 3 years of experience using computers.

2.3. Experiment materials
The experimental materials consist of 6 different types of icons, which are made up of Arabia digital coding, English words, Chinese words, abstract graphics, image and physical images, each of the icons has 64 (8×8) total 384 experimental elements.

Table 1 shows a group of experimental materials of different types of icons. In the experimental material: the Arabia digital icon is made up of two digits. The English icon is made up of high-
frequency words with the number of letters 4 to 5, and the Chinese icon is composed of high-frequency words including two Chinese characters (word frequency is higher than 200 times / million times). The abstract icons and graphical icons mainly come from various types of symbols and common display interface graphics, and the image icons are mainly physical photos with the same semantics as Chinese and English icons. The experimental icon size is 30×30 pixels. In order to avoid the color interference, all the experimental icon materials are processed into grayscale images using Photoshop except the image icon retain the source color.

| Table 1. A set of experimental materials |
|-----------------------------------------|
| digital icons | English icons | Chinese icons | abstract icons | graphical icons | image icons |
| 04 | tank | 坦克 | | | |

2.4. Experimental Procedures
The experiment required the participant to have a good mental state. Before the formal experiment, the participants needed to read the introduction guide first, and then through 3 practice operations to ensure familiarity with the experimental procedure.

Figure 1. Experimental process

As shown in Figure 1, when the experiment started, the participants needed to read the experimental introduction until understood the content of the introduction, then pressed the keyboard’s any key, next, a cross graphic was displayed in the center of the computer screen, after 1000 ms, the screen automatically entered the next interface. At this time, the target icon was displayed in the center of the computer screen for a duration of 2000 ms, and then the computer screen automatically presented experimental stimuli (as shown in Figure 2 is the experimental stimuli of the abstract icon). It can be seen that the experimental stimuli are divided into four areas: the upper left, the lower left, the upper right, and the lower right. Participants needed to find the target icon in the 8×8 icon array as soon as possible, and then pressed the keyboard number key according to the area where the icon was located to end a search task, the corresponding rules for the experimental interface area and the
numeric keys were: upper left=4, lower left=1, upper right=5, and lower right=2. After a search task was completed, the computer screen was displayed with a black screen, after 3000 ms, the next operation experiment was automatically entered, and the above process was repeated until all 10 search tasks were completed. All 18 subjects were tested separately until the end of the experiment.

3. Experiments results

3.1. Reaction time and correct rate
Each participant in the experiment completed visual search tasks for 6 different types of icons. After processing a few extreme data, the average response time and average correct rate of each type of icon were collected and calculated. As shown in Figure 3, it can be seen that the order of reaction time is as follows: image icon > graphical icon > abstract icon > Chinese icon > English icon > digital icon, in addition to the low correct rate of the abstract icons, the other types of icons are more than 95% correct rate in visual search tasks.

![Figure 3](image)

**Figure 3.** Reaction time and correct rate of different types of icons

*Note: In Figure 3, DI = digital icon, EI = English icons, CI = Chinese icons, AI = abstract icons, GI = graphical icons, II = image icons, the short form in the following text stands for the same meaning.*

The results of single factor analysis of variance (ANOVA) found that there were significant differences in the reaction time among 6 different types of icons ($F(5,85) = 5.50, p < 0.001$), further paired t-test was analysed on the reaction time of the 6 different types of icons. The results are shown in Table 2. It can be seen that the digital icon vs English icon $t(17)=3.972, p > 0.05$, the digital icon vs Chinese icon $t(17)=2.126, p > 0.05$, and the digital icon vs abstract icon $t(17)=3.576, p > 0.05$ have no significant difference in reaction time, however, digital icon vs image icon $t(17)=3.287, p < 0.05$ and digital icon vs image icon $t(17)=2.785, p < 0.001$ have a significant difference in reaction time. Similarly, it can be seen that the paired t-test difference between any other two different types of icons.

In addition to the low correct rate of the abstract icon (AI), the correct rate of the other 5 types of icons in the visual search is greater than 95%, and mainly due to mistakes in the experiment operations. Therefore, in this study, we did not perform the paired t-test on the correct rate, but believed that there was a significant difference between the correct rate of the abstract icon and the other types of icons, and the latter did not show obvious errors in the visual search experiment.

|        | EI  | CI  | AI  | GI  | II  |
|--------|-----|-----|-----|-----|-----|
| DI     | 3.792 |     |     |     |     |
| EI     | 4.128 | 2.049* |     | 5.419* | 3.683** |
| CI     | 4.598 |     | 2.369* |     | 2.979** |
| AI     |     |     | 5.211 | 3.210** |     |
| GI     |     |     |     | 1.875* |     |
In the table: * indicated that the paired t-test results were significant at the 0.05 level; ** indicated that the results were significant at the 0.01 level.

3.2. Eye Movement characteristics analysis
Collecting eye movement characteristic data of participants during the visual search of each type of icon. Selecting the fixation duration, total fixation counts of a single search task, saccade amplitude, pupil diameter, blink frequency and saccade velocity’s average of the participants in the visual search experiment as evaluation indexes of eye movement characteristics. The calculation results are shown in Figure 4 and Table 3.

![Figure 4](image-url)

**Figure 4.** Eye movement characteristics of 6 types of icons

It can be seen that for the 6 types of icons, the average fixation duration for searching for English icons is the longest, while searching for the Chinese icons is the shortest. Similarly, it can be seen that the average pupil diameter when participants searching for abstract icons is significantly larger than searching for the other 5 types of icons, and the average blink frequency and saccade amplitude of searching graphical icons are significantly larger than the other 5 types of icons. The average saccade velocity is smaller when searching for the English icon and the Chinese icon, and the saccade velocity are higher when searching for the abstract icon, the graphical icon and the image icon. In addition, the participants shows a decreasing trend in the average fixation counts of gazes when searching for the 6 types of icons (from digital icons to image icons).
Table 3. The results of eye movement characteristic

|   | FD  | FC  | SA  | PD  | BF  | SV  |
|---|-----|-----|-----|-----|-----|-----|
| DI| 320 | 17.5| 11.18| 27.48| 0.070| 81.52|
| EI| 354 | 13.8| 8.18 | 26.82| 0.080| 62.83|
| CI| 274 | 12.1| 9.48 | 26.50| 0.075| 63.74|
| AI| 313 | 9.2 | 8.63 | 27.94| 0.116| 87.25|
| GI| 288 | 7.3 | 14.86| 26.99| 0.231| 95.32|
| II| 269 | 6.2 | 10.82| 26.90| 0.152| 90.21|
| F | 1.88| 26.66| 8.05 | 2.29 | 34.82| 3.79 |
| P | 0.134| 0.000| 0.001| 0.771| 0.000| 0.000|

Note: In Table 3, FD = fixation duration, FC = fixation counts, SA = saccade amplitude, PD = pupil diameter, and BF = blink frequency, SV = saccade velocity.

As shown in Table 3, single factor variance analysis shows that there are significant difference in fixation duration ($F(5,85)=1.88, p<0.05$), fixation counts ($F(5,85)=6.06, p<0.001$), saccade amplitude ($F(5,85)=8.05, p<0.001$) and saccade velocity ($F(5,85)=3.79, p<0.001$) among 6 types of icons in visual search experiment, while the differences in pupil diameter ($F(5,85)=2.29, p>0.05$) and blink frequency ($F(5,85)=4.82, p>0.05$) are not significant.

3.3. Analysis of visual search strategy

The eye movement scanning path diagrams of 6 different types of icons were analyzed, and the eye movement characteristics such as the fixation points distribution and the fixation counts of searching for each type of icon can be directly observed through the scan path diagram (as shown in Figure 5). It can be seen that when searching for the digital icons, the English icons, the Chinese icons, and the abstract icons, participants have significantly more fixation counts than abstract icons and image icons. While searching for digital icons and English icons, the participant's fixation duration (the size of the dots in the figure) is significantly greater than the other 4 types of icons. Similarly, it can be seen that the saccade amplitude (spacing of fixations) of the participants when searching for the graphical icons and image icons is significantly greater than the searching for the other 4 types of icons, and the fixations distribution of searching for these 2 types icons is more sparse.

![Figure 5. Eye movement path](image-url)
4. Discussion

4.1. Analysis of visual search performance of different types of icons

This paper studied the difference in reaction time and correct rate of different types of icons in the visual search experiment. The experimental results not only confirmed the conclusions of some scholars but also had new discoveries. The analysis of specific conclusions and causes were as follows:

The difference among 6 types of experimental icons in this study was considered to be the difference in visual degree (or concreteness). This paper holds that for Chinese people, their visual degree (or concreteness) sequence is: image icon > Image Icon > Abstract icon > Chinese icons > English icons > Digital icons, the sequence is exactly the opposite of reaction time in their visual search experiments. The reaction time in the visual search experiment mainly depends on the difficulty of the feature extraction of the search target by the participants, it is considered that the more concrete of icons in visual search tasks, the easier the feature extraction is. The semiotic theory held that characters was more advanced than images in the symbol system, the more advanced symbols required more complex cognitive processing in the brain, the longer the reaction time was [11]. We believed that the higher the visual degree of icon types, the closer the cognitive mechanism needed for visual search was to human instincts, and therefore the less reaction time. The paired t-test showed that there was a greater possibility of significant differences in reaction time between the two types of icon materials which had a larger distance in visual degree (eg, digital icons and image icons). This also indicated that the reaction time in the visual search had a great relationship with the visual degree of the target icon.

The visual search task of this study required relatively low visual cognition of participants. Therefore, this study initially assumed that all 6 types of icons will not show obvious errors in the visual search task (the correct rate is greater than 95%). However, the experimental results showed that the correct rate of abstract icons was less than 85%, while the correct rates of the other 5 types icons were greater than 95%. And the participants reported that the visual search for abstract icons might be forgotten and confused, further analyzing the experimental data, it was found that 90% of the participants in searching for abstract icons were wrong if the reaction time was greater than 10s (the average reaction time of the abstract icons was 3.82s). This also indicated that after more than 10 seconds, the participants’ memory of the abstract icon would become blurred, according to the feature matching theory, participants might confuse some icons with similar appearance characteristics and cause misoperation. The other 5 icons can all be associated with a semantic concept, so only if the corresponding functional memory area of the brain has been activated, this kind of memory is often long-term, so the visual search task can hardly go wrong.

4.2. Analysis of visual search strategies for different types of icons

Visual search strategies include system search, random search, and semi-systematic search. This study analysed the visual search strategies of participants of 6 types icons experimental materials through eye movement path and other eye movement characteristics data. The experimental results showed that the participants tended to adopt semi-systematic search strategy to search for coding symbolic class experimental icon materials (digital icons, English icons, and Chinese icons), as for graphic symbolic class experimental icon materials (abstract icons, image icons, and image icons) tended to choose random search strategy. In the interview with the participants, it was also learned that when searching for digital icons or English icons, the participants would use a search strategy that matches the characteristics of the head-end feature (such as the first digit of the digital icons, the first letter of English icons). This semi-systematic search strategy could reduce the number of repeated searches, while searching for graphic symbolic class icons, the search efficiency could be effectively improved by adopting a random strategy.
4.3. Analysis of visual perception performance for different types of icons

Analysing the visual perception performance of different types of icons based on reaction time, correct rate, and eye movement characteristics. The experimental results of the reaction time confirmed the difference in the perceived performance of the 6 different types of icons, in section 4.2 it was analysed that might be related to the visual degree of icon materials. The correct rate of experimental results indicated that abstract icons are more likely to be misoperated in visual search than other types of icons. Therefore, it could be considered that the visual perception performance of abstract icons was poor, and it should be avoided to use abstract icon as much as possible in the actual graphical user interface design.

The eye movement characteristics data indicated that the average fixation duration of the digital icons, the English icons and the abstract icons was longer, which could reflect the visual processing of these 3 types of icons in the visual search was more difficult. As it was showed in Figure 4, it could be seen that the average fixation counts had a downward trend from the digital icon to the image icon. It could be considered that the average fixation counts was negatively related to the icon’s visual degree, which also indicated that the higher the visual degree, the higher the visual search efficiency of experimental icons materials. The shift of the fovea of the visual system causes saccade. We held that the saccade amplitude can reflect the range of the visual processing sampled area. The experimental data indicated that the English icon and the abstract icon had the smallest saccade amplitude, while the graphical icon had the largest saccade amplitude, which also proved that the visual perception performance of the graphical icon was better. The pupil diameter can reflect the psychological workload of the participants during the experiment. The experimental results indicated that the pupil diameters of the participants when searching for the digital icon and the abstract icon experimental material were larger. This also indicated that these 2 experimental materials might cause higher psychological workload in visual search tasks. Some scholars have proved that when the visual cognitive workload was high, the brain needed to pay more attention to the fixation and saccade activities, and the blinking frequency would be reduced accordingly. The experimental data indicated that when searching for graphical icon, the participant’s blink frequency was the highest, which was consistent with the above conclusion.

To sum up, we believed that the graphical icons had the best visual perception performance among the 6 icon types, and had the highest visual search efficiency in human-computer interaction, while the abstract icon had the worst visual perception performance in visual search task. Digital icons were suitable for expressing content that needed to be quantified and had unique advantages in expressing quantity concepts. While the English icons and the Chinese icons had advantages for expressing abstract concepts, its visual perception performance was related to the language used by the operator, so the design of icons in the human-computer interface should also take into account the type of users.

5. Conclusion

In this paper we comprehensively studies and compares the search performance and eye movement characteristics of 6 common types icons in the graphical user interface in visual search experiment. The research results provide ergonomic evidence for the selection and evaluation of icon types in human-computer interaction graphical user interface, which is of great significance for improving the interaction efficiency of the graphical user interface. Next stage, we will combine with EEG and other physiological measurement devices to further study the visual cognition mechanism of different types of icons.

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