Study on the Effects of Semantic Memory on Icon Complexity in Cognitive Domain

Jing Zhang, Chengqi Xue(✉), Zhangfan Shen, Xiaojiao Chen, Jiang Shao, Lei Zhou, and Xiaozhou Zhou

School of Mechanical Engineering, Southeast University, Nanjing 211189, China
ipd_xcq@seu.edu.cn

Abstract. It is a studying worthy problem whether highly visual complexity must bring low cognitive efficiency in icon design of visual interface. Although the visual noise of unreasonable and improper complexity seriously impacts the efficiency of users' access and visual search tasks, few are able to determine the effects of memory on icon complexity in cognitive domain. The goal of the present study was to investigate the interaction between semantic memory and icon in a complexity perceptual layering method. The CP (Complexity of Presentation) and CM (Complexity of Memory) are presented in this article by a complex perceptual layering. Three laboratory experiments are conducted to assess the cognitive performances of three different complexities (low, medium and high) in three CP dimensions (shape feature, color feature, texture feature). Results revealed that, (1) One influence of semantic memory on icon complexity is the familiarity, the cognitive efficiency is enhanced when stimulus are processed in a high complex semantically meaningful way. (2) The cognitive performance of low complexity coding and high complexity coding is greater than the medium coding in the familiar test and the correlation test. (3) When searching for a similar target with stimulus in different complex levels, the gaze opacity and heat map data demonstrate the efficiency of medium-low and high-low are the highest. Based on the experimental results, it is validated that the interaction between semantic memory and icon complexity is a visual dimensionality reduction in a complexity perceptual layering.

Keywords: Icon complexity · Semantic memory · Cognitive domain · Complexity perceptual layering · Icon design factors

1 Introduction

In various digital interfaces of computers and other devices, icons are often thought to be more useful at communicating tools than words because of their ability to transcend language barriers and present meaning in a condensed form [1]. The complexity selection of icons directly influences the cognitive efficiency users received from the graphical information. People are susceptible to irregular icons when identifying targets from a wide variety of icon-based interfaces, which may lead to clutter, confusion, and even human error. Correct icon complexity can help users to distinct appropriate icons and respond more quickly. It is well known that semantic memory has an impact on

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performance [2]. The icon design depends on two kinds: the fixed semantic factors and the visual factors (such as icon style, shape, color and texture). Previous psychological studies only focused on icon's visual factors and then concluded that the icon's cognitive efficiency would decrease with the increasing of the complexity. Although the visual noise of unreasonable and improper complexity seriously impacts the efficiency of users' access and visual search tasks, few are able to determine the effects of memory on icon complexity in cognitive domain. Therefore, the interaction between semantic memory and icon in a complexity perceptual layering method can help to provide a novel and valuable guidance to icon complexity.

In cognitive load of visual information processing, the early icon complexity research have conducted the following studies: Measures of the icon complexity study developed by Garcia as early as 1994 included six icon properties: icon foreground, the number of objects in an icon, the number of holes in those objects, and two calculations of icon edges and homogeneity in icon structure which uses image-processing techniques to measure icon properties [3]. McDougall et al. (1999) determined three characteristics of icons: concreteness, distinctiveness, and complexity, which reflected the primary importance in the measurement [4]. Maurizio (2009) used a fuzzy approach to reveal the evaluation of image complexity and classified as high, medium and low [5].

In terms of working memory, there were few approaches to study the icon complexity. A study of the memory capacity for the value of an icon or symbol by Harber and Hershenson (1973) found that the memory depends largely on the effort required for an accurate interpretation of its meaning [6]. Forsythe et al. (2008) investigated the role of complexity and familiarity in basic-level picture processing and their findings were in good agreement with a previous study of experiment method on the familiar test by Snodgrass [7]. However, event-related potentials (ERPs) provide lots of ideal methods to investigate behavioral findings about semantic memory influence users' cognition largely by modulating recollection [8].

In general, the previous studies on icon complexity focused on the styles and the constituent factors of icon belong to the visual presentation. But, these studies ignored the fact that acquiring information from icons was a cognitive behavior related with semantic memory. Previous studies have, in fact, separately provided evidences supporting the idea that both semantic memory and visual complexity influence the cognitive performance. This research is the first endeavor to investigate the interaction of the two factors on icon complexity.

2 Cognitive Icon Complexity

People retrieve information stored in long-term memory in two ways: episodic memory and semantic memory [9]. Semantic memory is retrieval of knowledge about the world without reference to any specific event, whereas episodic memory refers to retrieval of personally experienced events. The cognitive processing of visual information involves five important components: stimulate, percept, recognize, memory and comprehend. Semantic memory in the memory component directly affects comprehension as recognition is enhanced when stimuli are processed in a semantically meaningful way. Familiarity refers to a fast acting process that reflects a quantitative assessment of memory strength, while similarity plays an associative role and recollection is the retrieval of qualitative contextual information about a previous event [10].

As is shown in Fig. 1, to study the functional interaction of semantic memory and its perceived complexity on cognitive performance, the present study define the icon complexity into two kinds: CP (Complexity of Presentation) and CM (Complexity of Memory). CP represents the basic visual features of icon (shape feature, color feature, texture feature, etc.) in the shallow level of cognitive processing, whereas CM represents the internal relationship (familiarity feature, similarity feature and correlation feature) between memory and image complexity.

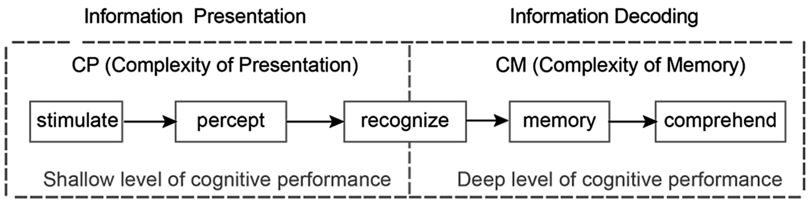

Fig. 1. The Cognitive Process of Icon Design Information

3 Materials and Methods

3.1 Participants

Twenty-eight subjects (15 males and 13 females) were present undergraduates (n = 7), postgraduate (n = 13) and doctoral candidates (n = 8) from Southeast University. They ranged in age from 20 to 35 years, with a mean age of 24 years. They had no color blindness or hypochromatopsia, with the corrected visual acuity over 1.0. They were required to practice and train to know the experimental procedure and operation requirements. Each participant sat in a comfortable chair in a soft light and sound-proofed room, and eyes gazed at the center of the screen. A 21.5-in. CRT monitor with a 1920 × 1080 pixel resolution was used in the experiment. The distance between participant eyes and the screen was approximately 60 cm, while the horizontal and vertical picture viewing angle was within 2.3° [11].

3.2 Materials

The experimental materials were semantic icons selected from real digital interface and the size of icon image is 128 * 128px. As is shown in Fig. 2, eighty-one icons were selected and redesigned based on expert score and Likert scale. Each row represents three same sematic icons in CP under nine semantic category names: Time, Transport, Music, Weather, PC, Message, Document and Movie.

The CP represent three different complexities form low to high: shape feature coding with easy lines, color feature coding with three colors and texture feature coding with design details and background graphics. The three columns represent three

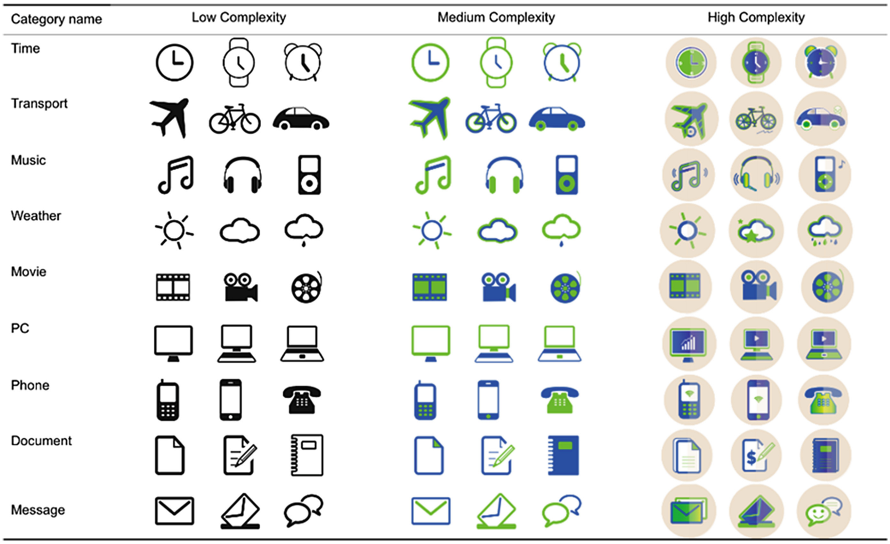

Fig. 2. Semantic icons with CP coding under nine category names

different relationships in CM: familiarity, similarity and correlation, as shown in Fig. 3. Four color combinations were used in color feature from simple to complex: white/black, blue/green, white/green/blue and white/green/blue/beige. These color combinations were proved to improve a subject's visual search performance on an LCD monitor with high vision saliency in highly saturation and brightness [23]. The color value (L, a, b) of the colors used in the present study are shown in Table 1 followed the opponent-color theory.

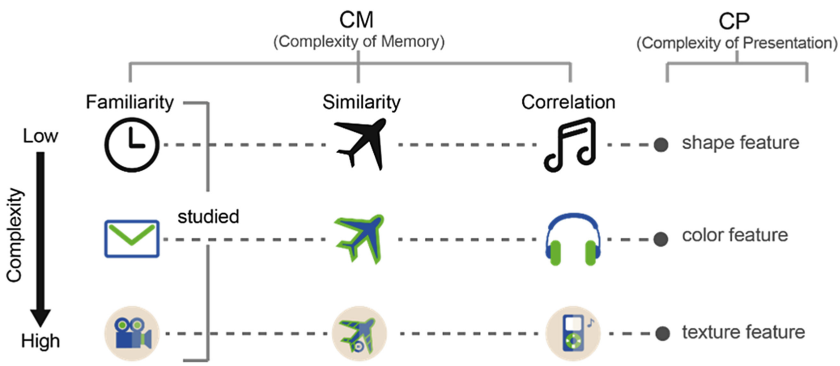

Fig. 3. The experimental materials in CP and CM

Table 1. The Lab value of the colors used in the present study

	Color				
	Green	Blue	Beige	White	Black
L	69	34	90	100	0
a	−54	32	2	0	0
b	51	−68	11	0	0

3.3 Procedures

This experiment was divided into three phases: study phase, distraction phase and test phase. In the study-test blocks, category names were displayed in central vision and then the associated icons were shown to the participants to remember as semantic memory (see Fig. 4A). Then the participants were instructed to do some distract mental arithmetic for 1 min. Test phase involves three test trials: familiarity test (see Fig. 4B), similarity test (see Fig. 4C) and correlation test (see Fig. 4D). Each test trial starts with a fixation cross (+) displayed for 1000 ms in the center of the screen, followed by a blank screen for 200 ms. The sematic icon/word was then presented for 1500 ms, followed by a blank screen for 500 ms and then replaced by nine icons for 2000 ms. Participants were instructed to find which one of the icons was same/similar/correlated to the sematic icon and click the left mouse bottom.

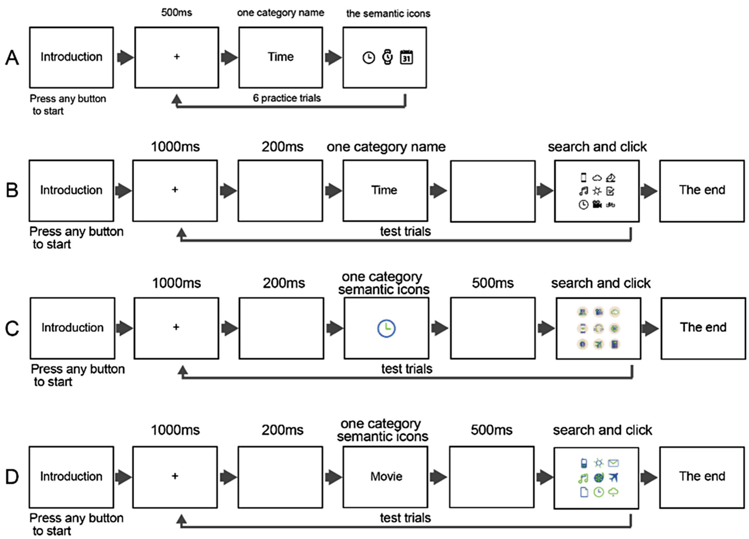

Fig. 4. The schematic of the experimental flow (A) Practice trials. (B) Familiarity test trials. (C) Similarity test trials. (D) Correlation test trials

The eye movement data includes the mouse trajectory, click location, reaction time, TVD (total visit duration), TFD (total fixation count), Gaze Opacity and heat map and which were acquired by Tobii X2-30 Eye-tracking Device in the experiment are recorded for data analysis.

4 Results

4.1 TVD and MFD Data Analysis

In terms of behavioral data in the present experiment, there were 28 subjects, but the data were available in only 24. Behavioral data included the accuracy of target stimulus identification and the reaction time. In normal circumstances, the reaction time includes the visual visit time, the decision making time and the behavioral reaction time. After repeated testing, the decision making time and the behavioral reaction time is constant and the TVD (total visit duration) can be regard as the reaction time. It was found by analyzing the experimental accuracy that the accuracy was over 99 % in all test trials, thus such data were not statistically significant. During the visual processing, when the total time of a certain point over 100 ms can be defined as fixation and then the information processing occurs. The information coding efficiency can be calculated as MFD (mean fixation duration) = TFD (total fixation duration)/TFC (total fixation count) [12]. Therefore, the reaction time analyzed as TVD is described in Fig. 5 and the MFD is described in Fig. 6.

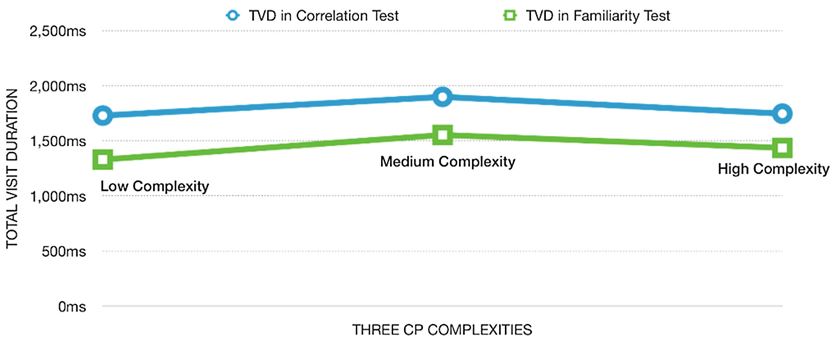

Fig. 5. TVD to three different complexities in familiarity and correlation test

Comparing the TVD of three different complexities for semantic target stimulus identification in familiarity and correlation test, the mean recognition efficiency of familiarity was higher than correlation in all complexity coding as the TVD in the two tests were: 1333.33 ms < 1728.75 ms in Low complexity, 1553.33 ms < 1898.75 ms in medium complexity, 1436.67 ms < 1746.25 ms in high complexity. The information coding efficiency of correlation was higher than familiarity in medium and high complexity as the MFD in the two tests were: 218.89 ms > 213.28 ms in medium complexity, 222.64 ms > 219.10 ms in high complexity, while the MFD in low

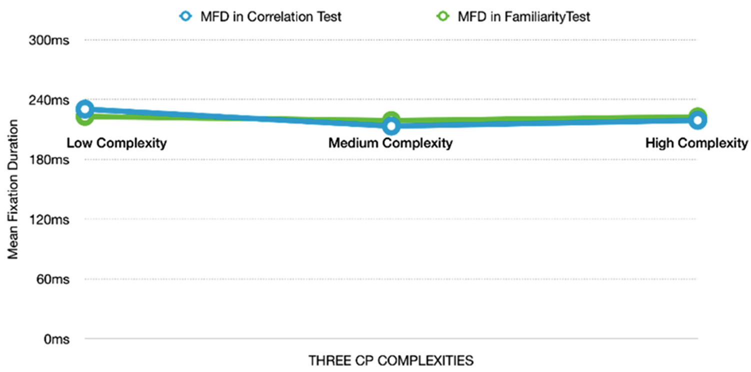

Fig. 6. MFD to three different complexities in familiarity and correlation test

familiarity was 222.96 ms < 230.28 ms which suggested the different excellent coding advantages in familiarity. Moreover, according to the result in MFD two tests, medium complexity in correlation test (MFD = 213.28 ms) was the most efficient, which broke the traditional view that RT is growing by the increased complexity.

In the second similarity test, the search tasks included six kinds of target-stimuli in different complex levels: low-medium, low-high, medium-low, medium-high, high-low and high- medium. The TVD and TFD are shown in Figs. 7 and 8. The result demonstrates the medium-low (1013.33 ms in TVD and 225.93 ms in MFD) is the highest efficiency and low-high (1226.67 ms in TVD and245.9 ms in MFD) and medium-high (1663.33 ms in TVD and 225.93 ms in MFD) are most difficult to be perceived.

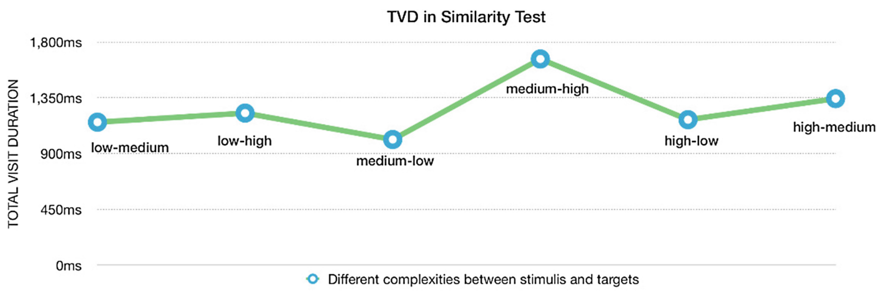

Fig. 7. TVD to six different target-stimuli complexities in similarity test

4.2 Gaze Opacity and Heat Map Data Analysis

The GO (Gaze Opacity) in eye movement data reveals the clear visual scopes and the amount of information processing of an image. The GO assigns different opacities in black and white to represent the gaze degree and the visual search efficiency increased as the GO narrowed and the TVD decreased. With a portfolio analysis of the TVD and

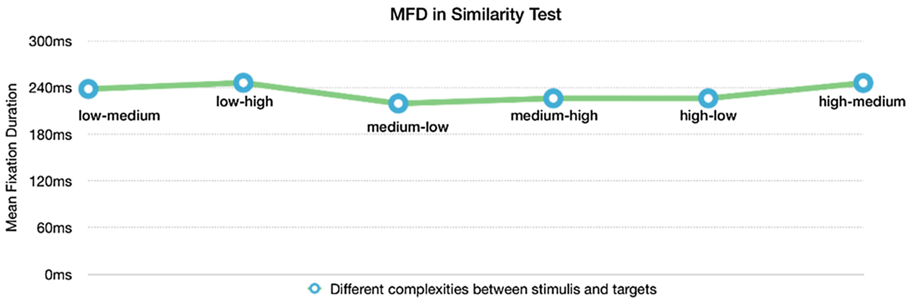

Fig. 8. MFD to six different target-stimuli complexities in similarity test

GO, the search efficiency of the different complexity encodings in three tests can be estimated. As is shown in Fig. 9, the number of icons in the clear visual scopes of GO were counted in ascending order classified from “1” to “5” as the visual clarity. Here, visual clarity is 5 when the number of clear icons > 7 and visual clarity is 1 when the number of clear icons $\leq$ 2.

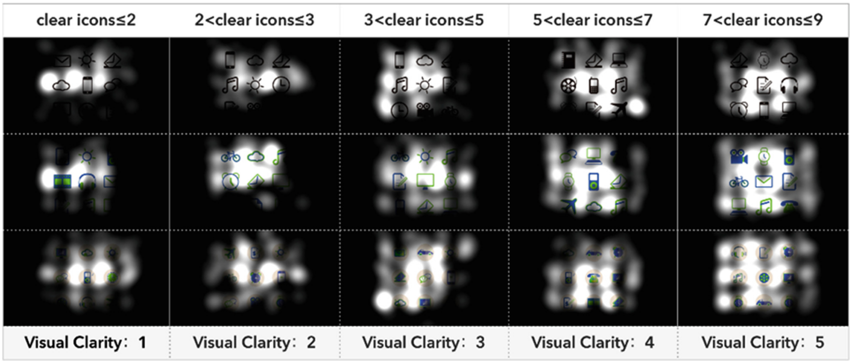

Fig. 9. Classification example of visual clarity in three complexities

As the classification above, the TVD and mean visual clarity of three tests is shown in Table 2. The scatter diagram of the relationship between visual clarity and TVD in three complexities is shown in Fig. 10. These results indicated that the visual search efficiency of medium-low and high-low in similarity test were highest, whereas the visual search efficiency of the medium complexity coding in three tests were lowest. According to these two kinds of target-stimuli in different complex levels, the visual cognitive performance for lower complexity level from higher level was significantly better.

To investigate this problem between the target-stimuli and interested distractors, the heat map of nine high complexity coding materials in the correlation test were used to analysis the interested areas. As shown in Fig. 11, the red dots in the heat map

Table 2. TVD and MVC in three tests

Familiarity test	Low Complexity	Medium Complexity	High Complexity			
TVD (ms)	1333.33	1553.33	1436.67			
Mean Visual Clarity	3	4	4			
Correlation test	Low Complexity	Medium Complexity	High Complexity			
TVD (ms)	1728.75	1898.75	1746.25			
Mean Visual Clarity	5	4	4			
Similarity test (stimuli-target)	Low-Medium	Low-High	Medium-Low	Medium-High	High-Low	High-Medium
TVD (ms)	1153.33	1226.67	1013.33	1663.33	1173.33	1343.33
Mean Visual Clarity	3	2	5	4	5	2

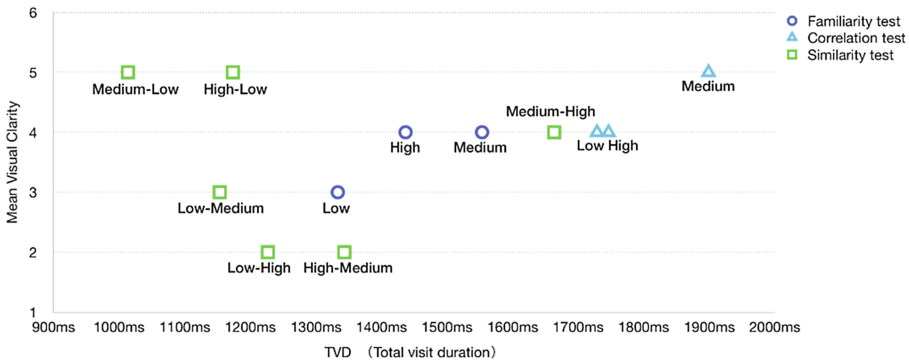

Fig. 10. Scatter diagram of the relationship between visual clarity and TVD in three complexities

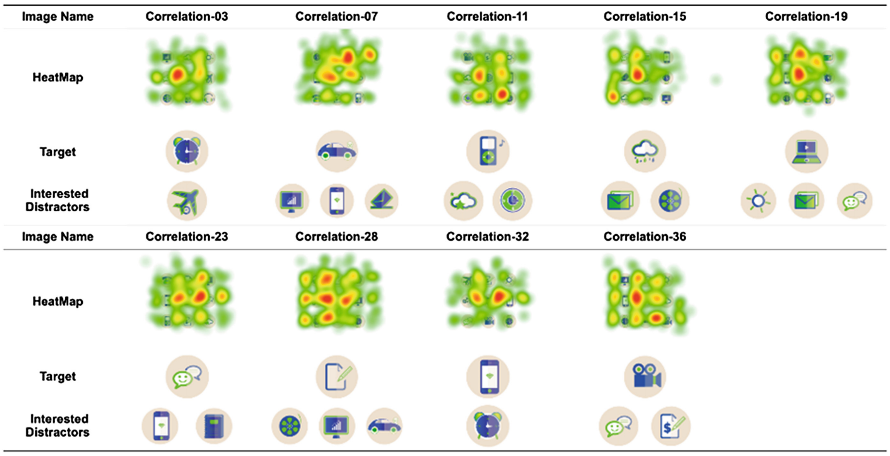

Fig. 11. The heat map, targets and interested distractors in similarity test

represent the most concentrated icons and the results suggested that the most interested distract icons were composed of sharp angles, square shape, circular shape or in similar semantic contour.

5 Discussion

1. The experiment validated the icon complexity of CP and CM in matches the icon complexity, as visual cognitive performance for lower complexity level from higher level was significantly better than from higher level, which prove the perceptual layering decoding processes from easy complexity (CP) to high complexity (CM) was a visual dimensionality reduction.
2. The results in TVD and MFD demonstrated a better cognitive re-identification in familiarity and a worse performance in correlation, suggesting the low complexity has an excellent coding advantage in semantic familiarity with small amounts of information.
3. Comparing the relationships between visual clarity and TVD in three tests, the cognitive efficiency of medium complexity with color-coding was worst, suggesting the main visual noise was the color texture and these pointed out some direction of research in the future.
4. Seen from the interested distract icons, icons composed of sharp angles, square shape, circular shape or in similar semantic contour was easy to be visual captured, these characteristics indicated that the outline of icons was the first step to analysis the semantic memory.

The scope of this paper is limited to the different uses of semantic memory for icon complexity for a meaningful information transmission. The scope of semantic memory can be expanded as there may be some other relevant factors can enhance the cognitive performance. Based on the experimental conclusion, questions are raised about the findings. The color selections in medium complexity coding are limited to a small number, but an infinite number of possible color combinations exist in actual applications. In the design work, the hue, lightness, spacing, and graphic structure are inconsistent. Determining how these additional variables influence the icon complexity and cognitive performance is then needed. Given the favorable findings of this study, additional research is reasonable and compulsory. Additional factors need to be identified, clarified and evaluated for further testing.

6 Conclusion

This paper aims at effects of the semantic memory on icon complexity and the combination of CP and CM. It is validated that the semantic memory in the memory component directly affects comprehension as recognition is enhanced when stimuli are processed in a semantically meaningful way. As the different excellent coding advantages of CP and MP were established in familiarity test, similarity test and correlation test, some icon design points about semantic memory could be clarified by the current study. The two kinds of icon complexity can guide the icon design separately, as users' cognitive efficiency of high complexity coding can be increased in a familiar way, which broke the traditional view that RT is growing by the increased complexity. The data analysis and conclusion of this thesis can provide a novel and valuable efficiency guidance for icon design factors, so as to effectively improve the use efficiency of information icon complexity design in reality.

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