Research on Binding Memory of Icon Features Based on Event-related Potential

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Abstract. The visual characteristics are important factors influencing the cognition and memory of the icon. In order to study the process of memory coding of feature binding in working memory of icon, the experiment requires 20 subjects to remember whether the icon features or feature binding are consistent and response quickly by pressing buttons, and the behaviour data and ERP data of the subjects are recorded. The experiment results show that compared with single feature memory of an icon, the accuracy under the icon-color feature binding memory condition is lower and the reaction time is longer while the P300 brain electric component with larger amplitude can be triggered. Studies have shown that the binding of visual features in icon memory requires additional cognitive resources. Compared with the other three memory conditions, the latency of the P300 under icon semantic-color feature binding is more significant, indicating that the task of semantic coding of icon is more difficult to complete and the cognitive load is greater.

1. Introduction

Icons are important ties between human-computer interaction in digital interfaces [1]. Design and use of icons could optimize the design and layout of the digital interface. The rich design expression of the icon can beautify the interface and improve the user's pleasure when interacting with the interface. Icon also has its unique cognitive advantage in the digital interface [2] which can improve the user's cognitive efficiency, the universality of the interface, and enhance the user's memory effect [3]. Therefore, it is important to study the impact of icon design on working memory in interface design and evaluation stage.

The visual features of object are important factors affecting working memory [4]. The visual features of icon have multiple dimensions, including shape, color and texture. According to the feature binding theory, these features are stored in the working memory in a bundled form. After the visual information of icon is input through the visual pathway, users' brain processes those icon in two different stages. The first phase is pre-attention phase, the features of each dimension of the icon are roughly bundled to form an object with an overall image. Then, in the process of visual perception, the shape, color and other features of the icon are bundled into an individual with a rough outline. The second stage is to after-attention binding stage. The detailed features of the icons, such as the details

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on the icon graphics, color matching, texture will be further bundled at this stage with the participation of attention resources. Combined with the contour image that has been formed in the first stage, the final complete image of the object is processed [5].

At present, researchers at home and abroad mainly use physiological measurements [6], eye tracking [7-9] and EEG analysis [10] to study the evaluation of the availability of digital interface elements. The multi-dimensionality of the icon itself has a significant impact on digital interface. Domestic and international scholars have done research based on visual cognitive model of the icon [11], visual search efficiency [12], and human-computer interaction efficiency [13]. There are few studies on icon feature bundling, and there are always divergence and controversy such as if the characteristics of each dimension of the object are stored in different brain region and do not affect each other, or will they compete for resources among each other in the buffer zone [14]? In this paper, event-related potential (ERP) technology is used to study the influence of color characteristics of icons on user's working memory, in order to explore the influence of color features on working memory of icon features.

2. Experiment Methods

2.1. Subjects

The subjects of this experiment were 20 students in the Department of Industrial Design of Southeast University, including 10 males and 10 females. All subjects were between 25 and 27 years old with an average age of 26 years old. None of the 20 subjects were color-blind, with a corrected visual acuity of 5.0, and were all right-handed. None of the subjects had a history of mental illness or trauma to the brain.

2.2. Experiment materials

Before the experiment, using Photoshop design 200 icons, the matching semantic word length is mainly two words, using the standard meaning of the icon. Then redesign these 200 icons in a linear icon design style to keep them in a same design style. The familiarity, specificity, visual complexity, and semantic distance of the 20 subjects were scored by 5-level Richter scale. As shown in Figure 1, we select 16 concrete icons with high familiarity, semantic distance, and specificity as sample icons. Six of these 16 icons are taken as experimental memory items in each memory task. There are 6 colors of icons, red (RGB: 255, 0, 0), orange (RGB: 255, 153, 51), purple (RGB: 204, 102, 255).

2.3. Icon and color used in memory experiment.
2.3. Procedure
The experiment uses a change-aware paradigm of single-stimulus detection. The experiment is a single factor design, which is divided into four conditions according to the type of memory: single graphic feature memory, single color feature memory, binding memory of color and icon, and binding memory of color and icon semantics. In the formal experiment, memory experiments under four memory conditions were performed in sequence. For each condition, 40 trials will be performed, 50% of which will not in the memory sequence, and 50% of the detection items are in the memory item. Under the condition of binding memory, there are three possible cases that the detection items are not in the memory sequence: the picture is in the memory column, the color is not; the color is in the memory column, the icon is not; the color and the icon are in the memory column but match wrongly.

![Figure 2. Experiment flow.](image)

The experimental flow is shown in Figure 2. Before the start of each experiment, center of the screen will show a cross gaze point and a left or right indicator arrow above it. The presentation time is 1000 ms, and the subject is asked to remember the direction of the arrow. After that, 3×2 color icons are presented, and the presentation time is 2000ms. The subject is required to remember the characteristics or binding relationship of the three icon samples in the column indicated by the arrow according to the specific experimental task, and then the blank screen of 1000 ms appears, and finally the detection is performed. The user needs to determine whether the binding relationship of the feature or feature in the probe item appears in the three memory items of the memory sequence. Press A key if it appears, or L key if it does not appear. After the user makes a button response, the probe disappears on the screen and enters the next round after 1000ms. The formal experiment consisted of 4 sets of experiments, 40 memory tasks per group, a total of 160 memory tasks, and the subjects were allowed to rest between each group of experiments, which lasted about 20 minutes.

2.4. ERP data and process
Behavior data such as accuracy and reaction time was recorded using E-prime2.0. EEG data were collected and using ANT brain electrical equipment, and then the original EEG data was analyzed and processed using ASA4.1 software. Finally, SPSS was used to analyze the behavioral data and EEG data of the subjects in each group.

3. Experiment results
3.1. Behavioral data
As a result, it was found that the memory condition has a significant main effect, p = 0.000. Memory accuracy under graphic-color binding condition (0.789) is significantly lower than the accuracy under
a single graphic memory condition (0.925), p=0.000. Memory accuracy under graphic-color binding condition (0.789) is significantly lower than the accuracy under a single-color memory condition (0.938), p=0.000. The memory accuracy (0.795) under icon semantics - color binding conditions is significantly lower than the accuracy under a single graphics memory condition (0.925), p = 0.000. There was no significant difference between the single-color memory condition (0.938) and the accuracy under a single pattern memory condition (0.925), p=0.904. There was also no significant difference between the graphic-color binding condition (0.789) and the icon semantic-color binding condition (0.795), p=1.000.

There was no significant difference between icon memory task and color memory task in reaction time, p=0.475. The icon-color binding memory task reacts significantly longer than a single icon memory task, p=0.000, and is significantly longer than a single-color feature memory task, p=0.000. The semantic-color binding memory task is also significantly longer than a single icon memory task, p=0.000, which is significantly longer than a single-color feature memory task, p=0.000. The semantic-color binding memory task is significantly longer than the graphics-color memory task, p=0.000.

**Table 1. Accuracy rate and Reaction time.**

| Detective item         | Sample | ACC  | Standard deviation | RT   | Standard deviation |
|------------------------|--------|------|--------------------|------|--------------------|
| Icon                   | 20     | 0.925| 0.264              | 779.820| 201.368           |
| Color                  | 20     | 0.938| 0.242              | 728.440| 229.291           |
| Icon color binding     | 20     | 0.789| 0.408              | 879.170| 327.920           |
| Semantic color binding | 20     | 0.795| 0.404              | 1023.080| 408.573           |

**3.2. ERP data**

According to the EEG waveform, there are obvious p300 EEG components in the brain regions such as the central region and the top region in the memory experiment. At the same time, according to the existing research on the P300 neurogenic source [15-16], the six central electrodes (CP1, CP2) and the top region (POz, Pz, P3, P4) were selected for P300 EEG component analysis.

![Figure 3. Icon feature binding memory experiment map.](image-url)
In order to study whether there are significant differences in the four groups of characteristic memory tasks on these six electrodes, one-way ANOVA was performed on the average amplitude of the P300 components on each electrode. It can be seen from Table 5-16 that the amplitudes on the CP1, P3, P4, and POZ electrodes are significantly different among the memory tasks of each group (CP1: F=4.591, p=0.006<0.05; P3: F=4.504, p=0.007<0.05; P4: F=4.833, p=0.005<0.05; POz: F=9.863, p=0.000<0.05). There was no significant difference in P300 amplitude between groups CP2 and Pz (CP2: F=1.429, p=0.245>0.05; Pz: F=1.507, p=0.223>0.05).

Table 2. Significant effect of 4 feature memory task p300 electrode amplitude

| Electrode | Sum of square | df | Mean square | F    | Sig. |
|-----------|--------------|----|-------------|------|------|
| CP1       | 14.097       | 3  | 4.699       | 4.591| .006 |
| P3        | 11.993       | 3  | 3.998       | 4.504| .007 |
| CP2       | 2.857        | 3  | .952        | 1.429| .245 |
| P4        | 10.995       | 3  | 3.665       | 4.833| .005 |
| POz       | 23.557       | 3  | 7.852       | 9.863| .000 |
| Pz        | 3.660        | 3  | 1.220       | 1.507| .223 |

Figure 4 is a graph of ERP brain electrical waveforms formed by four sets of characteristic memory tasks at the P4 electrode position. It could be observed from the figure that the graphic-color binding and icon semantic-color binding have more volatility than the P300 EEG component generated in the single feature memory task. It can also be seen from the P4 electrode waveform diagram that there is a significant difference in the appearance time of the P300 between the graphic-color binding and icon semantic-color binding memory task. The latency of P300 component of the color semantic-color binding memory task is significantly later than the other three memory tasks.

Figure 4. P4 electrode amplitude in 4 memory experiment.

A 2 (bundle type: graphic-color bundling, semantic-color bundling) × 6 (electrodes: CP1, P3, CP2, P4, POz, Pz) repeated measures analysis of variance was performed on the P300 latency data of the two different methods of the binding memory experimental group. It can be found that the main effect of the electrode is not significant, p=0.160>0.05. The main effect between the bundled memory types presented a significant edge, p=0.057>0.05, the interaction between the electrode and the feature type was not significant, p=0.191>0.05.

The six electrodes are further divided into three brain regions: left region (CP1, P3), right region (CP2, P4), and midline (POz, Pz). After the two sets of bundled memory experiment EEG data 2 (bundle type: graphics - color bundling, semantic - color bundling) × 3 (brain area: left zone, right zone, midline) repeated measurement analysis of variance can be found, the interaction between brain zone and the group was not significant, F=2.280, p=0.123. The significance of the main effect of the brain area was significantly improved, F=4.122, p=0.028<0.05. A paired sample T test under the two bundled memory conditions was performed on the left, right, and midline brain regions. It was found that there
was a significant difference between the two bundled memory tasks only in the midline of the brain region, \( p = 0.035 < 0.05 \). The paired sample T test under two bundled memory conditions was continued for the POz and Pz electrodes in the midline brain region. Only on the POz electrode the latency of the graphics-color binding memory task is significantly earlier than the semantic-color binding memory task, \( p = 0.030 < 0.05 \). POz electrodes can be used as a focus for further analysis.

**Figure 5.** POz electrode amplitude in 2 memory experiments.

Figure 5 is an EEG waveform graph of the POz electrode in two binding memory experiments. The latency of the P300 component in the graphics-color bundle memory task is significantly earlier than the semantic-color bundle memory, indicating that the cognitive load generated by the participants in the semantic-color bundle memory task is greater. This is consistent with the analysis of behavioral data.

### 4. Discussions

#### 4.1. Behavioral data results analysis

In this experiment, it can be obtained from the behavior data that the feature binding memory task is longer than the single-feature memory task with lower accuracy, indicating that the feature binding memory task is more difficult than the single-feature memory task. In the weak object storage theory, the concept of subsystems is no longer used, but that there is only one shared memory storage system, and all features and objects in working memory need to compete for cognitive resources in this shared storage system [17]. The behavioral data results in this experiment verify the correctness of the weak object storage theory in the icon feature binding memory. Icon semantics-color binding memory reacts longer than graphic-color binding memory experiment. According to the synchronous multi-encoding theory proposed by Wickens, in working memory, the object information is simultaneously encoded by both speech and visual encoding [18]. The significant difference between Icon semantics - color binding memory and graphic – color binding in response in react time is caused by differences in user's memory coding. In the graphic-color binding memory task, the double-coded memory was used by the participants, while the semantics-coded memory was mainly used in the icon semantic-color binding memory, indicating that the task of semantically encoded memory is more difficult and the cognitive load is greater.

#### 4.2. P300 results analysis

P300 is currently the most widely studied ERP component in the field of working memory, and its incubation period is around 250-600ms. P300 is affected by many types of tasks, such as type of task, the importance of stimulation, attention, working memory, decision-making, and emotion. From the data of the P300 brain electrical component, it can be found that P300 mainly appears in the top and central regions of the brain. The P300 waveforms of each electrode in the single-color feature memory, the single-color feature memory, and the graphic-color binding memory test are roughly similar. And
the P300 generated by graphics-color bundling and icon semantic-color binding has a larger amplitude than it in the single feature memory task, indicating that the subject has a larger cognitive load in the feature-bound memory task. Comparing with the behavioral data of the subjects, it can be found that the graphics-color bundle memory and the icon semantic-color bundle memory are significantly lower than single graphics feature memory and the single-color feature memory in accuracy. At the time of the reaction, the graphics-color bundling and icon semantic-color bundling memory tasks are significantly lower than the single graphical feature memory and the single-color feature memory. At the same time, the P300 latency in the semantic-color-bound memory experiment is significantly later than the latency in the other three tasks, indicating that the feature-bound memory task is more difficult than the single-feature memory. Behavioral data is consistent with the analysis of EEG data which support the conclusion that with larger cognitive load comes later P300 volatility [19].

5. Conclusions
In this paper, ERP is used to study the influence of the color characteristics of icons on the working memory of icons from the perspective of feature binding memory. The research shows that there are significant differences in the response time, accuracy rate and P300 composition of the icon under the single feature memory and the feature binding memory condition of the icon. The feature binding memory of the icon generates a larger cognitive load than the single feature memory. Bundling of features requires additional cognitive resources. The research results could be the scientific guidance and has reference value for revealing the characteristics of icon binding memory rules, enhancing the usability of icons, and exploring more effective icon design methods. In following research, the feature binding relationship in same dimension of multicolor icons and its impact on icon memory will be explored.

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