Visual Hierarchy Design of Map Site Information in Thematic Meteorological Interface

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Abstract. The visual map elements of the thematic meteorological interface have an essential impact on the user's processing efficiency. Based on the different visual hierarchies of map site information, including shape, colour, and area, this paper explored the influence of site information's visual hierarchy change mechanism on user behaviour performance. The results were as follows: 1) The greater the number of shapes, the more difficult it was to complete the task. Therefore, the shape of map sites could be formulated according to the type of meteorological disaster. 2) Under the same comparison level, when the number of colours for multiple map sites was 6, the user's task operation efficiency was best. 3) The area of map sites was reasonably enlarged within a specific range that could improve the operation efficiency of interface tasks and balance the information complexity of map sites. The results have certain reference value for the visual hierarchy design of map sites in the meteorological interface.

1. Introduction

The meteorological map interface displays multi-level information such as spatial distribution, category attributes, quantitative characteristics and time changes based on actual weather information\cite{1}. As the most important information carrier in the meteorological interface, the map site can convey the weather status of different locations in real time. Therefore, the sites with a clear visual hierarchy plays an indispensable role in expressing weather information for the meteorological map interface, especially in emergencies or meteorological disasters. Generally, the visual hierarchy refers to the level at which the user perceives the different functional information of the interface, which is characterized by a progressive pyramid structure\cite{2}. Building a stable and orderly visual hierarchy in the map interface can help users quickly understand the logical path of target information, thus reducing the cognitive cost of visual search process. In recent years, some progress has been made in the related research on visual hierarchy. Wen et al. found the influence mechanism of visual selective attention ability\cite{3}. Finlayson et al. discussed the different patterns of 2D location and depth decoding in the visual hierarchy\cite{4}. And likewise, Harvey et al. investigated the similar transformation of visuospatial representations induced by visual movement throughout the visual hierarchy\cite{5}. Furthermore, Li et al. explored the influence of colour coding on the level of visual perception\cite{6}.

The visual hierarchy design for the weather map interface can be distinguished from two aspects: set element and individual element. Specifically, the visual hierarchy of map information can be divided into various functional modules for the set element, such as background, navigation bar, toolbar, regional site, pop-up window, etc. For the individual element, the visual hierarchy can be divided into different attributes of a single element, such as shape, colour, transparency, lightness, etc. For example, Wang et
al. conducted a visual design for the map site information of the emergency public opinion monitoring interface and optimized the display efficiency of thematic maps from the distribution of scatter points [7]. As for the visual design of the epidemic thematic map, Xin analysed the difference in processing efficiency of map information from two aspects of representation form and colour coding [8]. Besides, according to the visual parameter system (size, hue, orientation, etc.) explored by predecessors, Liu et al. explored the user performance of the position and shape change process of dynamic sites in the map interface [9]. To sum up, the current research on the information design of map sites is still scarce, lacking sufficient definitions to discuss the boundaries of multi-site visualization from the perspective of individual elements. Therefore, according to the application background of multi-site representation in the meteorological map interface, this study explored the design strategy of map sites in the visual hierarchy.

2. Methods

2.1. Participants
Twenty-five volunteers participated in the experiment (12 females aged 20 to 27 years with a mean age of 23.60, SD = 2.59). All participants, who were right-handed and had the normal or corrected-to-normal vision, gave informed consent after receiving the explanation of the experiment content. Before the experiment, participants performed 10 exercises on an HP computer monitor with a resolution of 1920px × 1080px to familiarize themselves with the experimental rules and procedures and then entered the formal experiment.

2.2. Materials
This study conducted a behavioural experiment on the design strategies of multiple site information levels in the meteorological map interface and analysed the changes in users' visual search efficiency under different combination schemes. Meanwhile, the visual hierarchy scheme of multiple map sites matching the mental needs of users was summarized based on the previous research on the hierarchical elicitation approach (HEA) [10].

![Figure 1. Experimental factor design for multiple map sites.](image-url)
The visual hierarchy of multiple regional sites can be distinguished by the coding of information attributes, such as shape, colour, area, style, etc. Therefore, according to the operating environment of multiple site information in the interface of the weather map, three site attributes were selected to design stimulus materials in this study, including shape, colour, and area (see Figure 1). It should be noted that the original size of map sites was limited to a rectangular frame with an area of 10px × 10px (A). The site areas were doubled sequentially, defined as A, 2A, and 3A, respectively. Besides, the site shapes were divided into three levels according to the quantity, defined as S3, S6, and S9. Similarly, the site colours were C3, C6, and C9.

2.3. Procedure
In this study, a 3 × 3 × 3 (shape, colour, area) three-factor mixed experimental design was adopted based on the visual search paradigm. The combination scheme of multi-site representation design in the meteorological map interface was shown in Figure 2. Each level was repeated four times for a total of 108 trials. The experimental material was based on the grayscale-processed map as the background image, and 36 site stimuli were randomly presented in a fixed area. All materials were designed through Photoshop and Adobe XD software.

In the formal experiment, the target site picture and the multi-site picture were presented to the participants in sequence, and the presentation duration was 1000ms and 3000ms, respectively. It should be pointed out that the presentation process of all experimental stimuli was realized by the E-prime 2.0 software. Participants were asked to search through the multi-site picture (36 map sites) and judge as quickly as possible whether the target site appeared in the map. If the target appears, press the J key. Otherwise, press the F key. The entire experiment took about 20 minutes to complete, and participants were allowed to take short breaks at any time during the experiment according to their mental and physical state. In addition, participants were told that reaction time was more important than accuracy during the experiment.

3. Results
The user's reaction time and accuracy rate of searching for the target site were recorded by the E-prime 2.0 system. Through statistical data visualization, the user search performance under different combination schemes was intuitively compared, as shown in Figure 3. It should be noted that the behavioural data were processed by repeated-measures analysis of variance (ANOVA) and mean value analysis (MVA) based on SPSS 26.0 software. All the statistical tests were conducted by two-sided tests, P-value less than 0.05 was as the statistically significant difference test. In addition, the behavioural data that violated the spherical assumption were corrected by the Greenhouse-Geisser method.
The results showed that the shape, colour, and area of map sites did not satisfy the spherical hypothesis test in reaction time ($P < 0.001$) and accuracy rate ($P = 0.000 < 0.05$). After data correction using the Greenhouse-Geisser method, it was found that the shape, colour and area of the sites were significant in reaction time [$F (3.917, 94.002) = 2.715, P = 0.035 < 0.05$] and accuracy rate [$F (4.306, 103.342) = 5.016, P = 0.001 < 0.05$]. The simple-simple effect was used to analyse the interaction of different shape factors on the combination of colour and area factors (see Table 1).

Table 1. Simple-simple effect analysis for reaction time and accuracy.

| Analysis items | Effect size (RT) | Sig. (RT) | Effect size (ACC) | Sig. (ACC) |
|----------------|-----------------|-----------|-------------------|-----------|
| A-C3           | 0.23            | 0.796     | 2.21              | 0.120     |
| A-C6           | 5.99            | 0.005     | 2.02              | 0.144     |
| A-C9           | 3.60            | 0.035     | 2.55              | 0.089     |
| 2A-C3          | 0.34            | 0.716     | 5.76              | 0.006     |
| 2A-C6          | 2.26            | 0.115     | 1.71              | 0.844     |
| 2A-C9          | 0.30            | 0.740     | 12.53             | 0.000     |
| 3A-C3          | 2.19            | 0.123     | 3.97              | 0.025     |
| 3A-C6          | 2.90            | 0.065     | 3.97              | 0.025     |
| 3A-C9          | 1.67            | 0.198     | 6.48              | 0.003     |

Different levels of shape factors were selected for simple-simple effect analysis, and significant differences in reaction time were found in both A-C6 and A-C9 groups compared to the other groups. According to the mean value statistics of reaction time, the corresponding specific combinations were as follows: CS2 ($M = 2310.73$, $SD = 984.27$), CS3 ($M = 3202.23$, $SD = 709.35$), CS11 ($M = 1940.89$, $SD = 1050.24$), CS12 ($M = 2964.21$, $SD = 980.94$), CS20 ($M = 3068.88$, $SD = 1807.65$), CS21 ($M = 2546.85$, $SD = 1043.18$). It was found that the CS11 level (shape S6, colour C6, and area A (10px × 10px)) had the shortest reaction time and the best operating efficiency. In terms of accuracy rate, the intra-group comparison showed significant differences in 2A-C3 groups ($P = 0.034$), 2A-C9 groups ($P$...
Therefore, the corresponding specific combinations in terms of accuracy are shown in Table 2. The results found that users had the highest average accuracy and the best operation efficiency at the CS8 level (shape S3, colour C6, and area 3A).

Table 2. Statistical analysis of accuracy for corresponding combinations.

| Combinations (Level) | ACC (M ± SD) | Combinations (Level) | ACC (M ± SD) |
|----------------------|--------------|----------------------|--------------|
| CS4                  | 0.933 ± 0.136| CS17                 | 0.893 ± 0.230|
| CS6                  | 0.680 ± 0.180| CS18                 | 0.933 ± 0.215|
| CS7                  | 0.960 ± 0.111| CS22                 | 0.933 ± 0.167|
| CS8                  | 0.987 ± 0.067| CS24                 | 0.827 ± 0.218|
| CS9                  | 0.893 ± 0.267| CS25                 | 0.867 ± 0.236|
| CS13                 | 0.787 ± 0.270| CS26                 | 0.920 ± 0.174|
| CS15                 | 0.907 ± 0.181| CS27                 | 0.773 ± 0.230|
| CS16                 | 0.893 ± 0.159| -                    | -            |

4. Discussion

Through a three-factor mixed design study on the shape, colour and area of map sites, it was found that there were significant differences between colour factors and between area factors on reaction time and accuracy, but no significant difference between shape factors. In terms of overall performance, colour and area factors mainly affected participants' reaction time and accuracy rate. By comparing the behavioural performance under colour factors, the reaction time was the shortest, and the accuracy rate was the highest in C6 groups, while the reaction time was the longest and the accuracy rate was the lowest in C9 groups. A reasonable number of site colours can effectively integrate the same category information and filter non-target information. The results showed that it was reasonable to set the number of site colours to 6. However, when the number of colours was increased to 9, the information capacity exceeded the cognitive load of the participants processing the number of colours in a short time.

In addition, when the area of map sites was set to 3A, the reaction time was the shortest, and the accuracy rate was the highest, followed by the area of 2A. The site areas affected the user's selective attention ability through the visual proportion, and the area size was inversely proportional to the reaction time and directly proportional to the accuracy. Therefore, designers should increase the area ratio of map sites as much as possible within a reasonable range, thereby improving the efficiency of visual search and selective attention. It should be emphasized that the shape factors did not show significant differences at different levels. The possible explanation is that the limitation of area size fails to reflect the difference between shape factors. By further analysing the influence of shape factors on behavioural performance, the results showed that the reaction time was the shortest in S6 groups, the accuracy rate was the highest in S3 groups, and the overall performance was the worst in S9 groups. Given the multi-dimensionality of meteorological disaster information and the urgency of emergencies, the shape design of map sites can be formulated according to the types of weather disasters. Especially when the number of meteorological disaster categories exceeds 6, the complexity of visual information on the map should be balanced by increasing the site areas or reducing the number of site colours.

By exploring the map site information at different visual levels, this study revealed the user's visual cognitive characteristics and behavioural rules. The research results can effectively improve the user's interactive efficiency in the meteorological interface and provide some important references for the visual representation design of map sites.
5. Conclusion
This paper studied the visual hierarchy perception of multi-site information in the meteorological map interface. The visual combination schemes were designed through the shape, colour, and area of map sites to compare the difference in participants' reaction time and accuracy rate. The results showed that the increase in the number of site shapes would correspondingly increase the difficulty of task completion. When the number of site colours was 6, the operation efficiency of task completion was the best. In addition, it was possible to increase the efficiency of task operation and balance the complexity of task information by reasonably enlarging the area of map sites.

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