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Are the warning icons more attentional?

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The rapid growth of attention to visual warnings is a representation of the adaptive behavior of humans. However, the ways warning icons attract attention in the cognition context has yet to be clarified. This research aims to investigate cognitive mechanism of warning icons under various perceptual loads. The results of Experiment A, whose average attentional capture effect of the warning icons (69 ms) was significantly higher than that of the ordinary icons (35 ms), show that compared with ordinary icons, warning icons are prioritized in processing under both high and low perceptual loads. Besides, the attention capturing abilities of non-target warning icons are the same under high and low perceptual loads. To isolate the effects of salient visual features and semantics, warning icons in Experiment B are replaced with transposed icons with saliency but no semantics. The attentional capture effect of warning icons is found to be significantly smaller under high load than under low load, so the effect in Experiment A can be attributed to the semantics of warning icons. In Experiment C the icons of negative and neutral semantics without salient frames are used as interfering stimuli, and the RT to the negative icons (823 ms) was longer than both the RT to the neutral icons (780 ms) and to the no interference icons (743 ms) ($P < 0.001$), which show that negative icons have stronger attention capturing ability than neutral icons. This research verifies that the semantics of icons is vital, and icons with salient visual features and negative semantics can enhance attentional capture effect.

1. Introduction

Visual stimuli with warning or threatening information can generally capture people's attention more easily and rapidly than ordinary icons (Deng et al., 2010). For instance, people become increasingly attentive when they find themselves in the presence of animals that pose a threat, from large ones such as crocodiles, tigers, and snakes, to small ones such as spiders and centipedes (Carretié et al., 2009; Van Bockstaele et al., 2013; Weymar et al., 2013; Fox et al., 2001; Yiend and Mathews, 2001; Öhman et al., 2001a). When an individual is conducting a visual search for emotional faces, the search for scared faces is much quicker than that of neutral and happy faces (Mu and Wan, 2014; Yao et al., 2014; Nahum et al., 2012; Yokoyama et al., 2015; Bekhtereva et al., 2012, 2015; Todd et al., 2012). In daily life, red buttons can immediately attract attention from people because of their warning function. Unlike ordinary dialogues, dialogues in web pages with red error marks or red exclamation marks clearly present strong hints of warning. Prohibition icons, deceleration strips with alternating red and yellow labels, and highly bright yellow uniforms of transportation officials on roads easily attract the attention of drivers, who consequently become vigilant in their driving process. These conditions are indicative of the capability of warning icons to quickly and easily capture people's attention (Zhao et al., 2006; Schmidt et al., 2015; Zhang et al., 2011a; Young, 1991). These warning icons are prioritized over ordinary icons in the information processing of the human brain. However, the reasons for these tendencies are still unclear.

Young, Soto, and Bzostek et al (Young, 1991; Soto et al., 2006; Bzostek and Wogalter, 1999) found that the salient features of visual materials, such as colorful geometric figures and strings, can automatically direct people's attention from the bottom up, and this condition is vital in the recognition of icons. The exotic stimulus paradigm formulated by Theeuwes (1992, 1994) can best illustrate the bottom-up mode of attention capture. In the experiment, the participants were required to find a visual stimulus with a unique appearance from among many non-target stimuli (for

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instance, to find a round shape among many squares), while a salient non-target color stimulus appeared in half of the tests. The participants reacted to the target at a significantly slower speed in the presence of salient color stimuli than in the absence of salient color stimuli. Thus, non-target color as an interfering stimulus causes a postponing effect in human reaction, in which case salient color stimuli capture attention from bottom to top. A series of studies (Young, 1991; Turatto and Galfano, 2000; Theeuwes, 1992; Yantis and Jonides, 1984, 1996; Kiss et al., 2012; Bai et al., 2011; Yeshurun et al., 2009) has indicated that attention resources can be unconsciously attracted by non-target salient stimuli and that highly salient visual features (e.g., shape, color, and degree of thickness) significantly contribute to the priority gained by the marked stimuli in processing. However, semantic information has been found to perform important functions in the human recognition of icons (Zhang et al., 2011a; Biggs et al., 2012; Nordfang et al., 2013; Xie et al., 2011). Under different types of searching tasks, the brain can freely choose strategies of visual representation, semantic information, or a combination of the two. Another explanation of the priority gained by warning icons in processing is that when the semantic information is consistent with or similar to memories, the brain tends to choose the stimulus with the highest degree of relevance to the task to activate attention capturing and processing from bottom to top (Soto et al., 2005; Folk et al., 2014; Zhang et al., 2011b, 2013). Verifying the above-mentioned explanations is important because of their varying predictions with regard to improving the influence factors of warning icon recognition. If visual saliency leads to the prioritization of warning icons in attentional capture, then visual saliency can be enhanced by optimizing the visual features of warning icons. If semantic information leads to the prioritization of warning icons in attentional capture, then the icon whose semantics is more easily understood by users, should be designed. The present study aims to investigate the functions of visual features and semantic information in the attentional processing of warning icons under different perceptual loads to reveal the cognitive mechanism of warning icons.

Only a few studies have explored the cognitive mechanism of warning icons, but numerous scholars have conducted extensive studies in other related fields (Zhang et al., 2011b; Öhman et al., 2001b; Kiefer et al., 2012; Olivers et al., 2006; Eriksen and Eriksen, 1974). Zhang et al. (2011a) conducted a study on the influence of semantic information on the attentional capture effects of negative stimuli under various perceptual loads using the classical perceptual load paradigm. In Experiment A, six non-target letters formed a circle. The target letter (N or X) stood in the visual center as the target stimulus, and negative faces appeared with small probabilities at random in the visual periphery as interfering stimuli. Six different non-target letters were used under high perceptual load. One non-target letter and five letter O's were used under low perceptual load. To clarify the effect of saliency and semantic information on the test results, the authors replaced the negative-face stimuli in Experiment B with salient color-lump stimuli without semantic information. The participants were required to judge whether the target letter was N or X through their reactions and to subsequently press the corresponding button. In Experiment A, no significant difference was found in the abilities of attentional capture of the negative faces under high and low perceptual loads, whereas in Experiment B, the attentional capture effect of the color lumps under high perceptual load was significantly lower than that under low perceptual load. Hence, the effect in Experiment A was attributed to the semantic information of the negative faces. However, in the experiment by Zhang et al., the same visual saliency could not be guaranteed in their two experiments successively. In Experiment A, negative faces in black and white with semantic information (with visual saliency) were used. To separate the saliency and semantic information of the stimuli, color lumps without semantic information (with saliency of colors) were used in Experiment B. In these two experiments, the saliency and semantic information of the same test material were not separated; two unrelated test materials were used instead.

The most significant problem in previous research involves the improper selection of test materials, which causes the invalid separation of visual saliency and semantic information, thus failing to either integrate saliency and semantic information in semantic representation or completely separate semantic information and visual stimulus features. Therefore, the individual effect and mechanism of the two factors in the attentional processing of warning icons is very difficult to explore. In the present work, the test materials are used to separate the functions of the salient visual features (from bottom to top) and semantic information (from top to bottom) of the warning icons successfully, which helps to study the "real" role of visual saliency and semantic information in the warning icon recognition. Ordinarily placed warning icons (with salient visual features and semantic information) and transposed warning icons (with salient visual features) are used as the experimental materials and the classical perceptual load paradigm (Lavie and Tsal, 1994; Lavie and Cox, 1997; Forster and Lavie, 2008a, 2008b; Liu et al., 2014) is adopted. A study on the cognitive processing mechanism of warning icons is also conducted. Experiment A is focused on testing the attentional capture effects of warning icons with semantic information under high and low perceptual loads. In Experiment B, transposed icons without semantic information are used as interfering stimuli, and the function and effect mechanism of semantic information and salient visual features in warning icon recognition are verified. In Experiment C, warning icons without frames are used as interfering stimuli, and the effect of semantic information on warning icon recognition is verified.

2. Experiment A

2.1. Method

Ethics Statement. The procedure in this study was approved by the Institutional Review Board of China University of Petroleum. Participants signed a written consent form before the participating in the experiment.

Participants. 21 college students, 11 boys and 10 girls(20–27, SD = 3.11), average age of 23, participated in this experiment for monetary compensation. Not informed of the experimental intent, all the subjects are voluntary and have never participated in similar experiments before.

Materials and Design. An experimental picture was used as the search set comprising six gray letters that were uniformly distributed on an invisible circle (Fig. 1). The angle of view along the diameter of the invisible circle was 5.8°, and that of the letters was $1.0° \times 1.2°$. At the center of the invisible circle was a gray "+," which served as the fixation point measuring $0.7° \times 0.7°$. The six letters were target and non-target letters. The former was denoted by X or N while the latter was denoted by A, E, F, K, H, and M. The interfering stimuli were the warning or ordinary icons presented at six possible positions on the large invisible circle with a diameter of 8.7° (corresponding to the six letters on the small invisible circle). Each warning icon was composed of a thick outer border (line width of 2.25 pounds) and a negative graph containing danger or warning semantics. The ordinary icons were composed of a thick outer border (line width of 0.75 pounds) and neutral graphs without negative or pleasurable semantics. The two categories of icons are common abstract icons (Fig. 2) with explicit connotations and consistent gray scale. Twenty warning icons and twenty