Measuring the attentional effect of the bottom-up saliency map of natural images

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textures because of their rich naturalistic low-level features that the human visual system is tuned to. Although these natural images were invisible, the difference of visual saliency (calculated by a famous computational saliency model [1]) between inside and outside a local region could attract attention to improve the performance of an orientation discrimination performance at the salient region. We use the degree of saliency to refer to the saliency difference in the paper. Then we could measure the attentional effect generated by different degrees of saliency. Investigating this topic not only provide evidence for the bottom-up saliency map in our brain, but also is helpful to many important applications, such as object detection.

1.1 Related work

The representation of the strength of the bottom-up attention attraction from our visual input [2] is a saliency map. It is constructed in our brain and can direct our attention along with top-down signals. Several studies had tried to measure the effect of visual saliency, and also found brain regions that realize the saliency map. For example, Geng and Mangun found that anterior intraparietal sulcus could realize the saliency map [3]. Mazer and Gallent found a goal-related activity in V4, which provided evidence that V4 could realize the saliency map [4]. However, these studies can not rule out the top-down attentional control, which makes it hard to identify the neural basis of the bottom-up saliency map. So it's important to probe the bottom-up attention attraction free from the top-down influence.

Several methods can be used to reduce the top-down signals influence, such as backward masking, binocular rivalry and continuous flash suppress (CFS). Zhang *et al*. had adopted the backward masking method to investigate the neural substrate of the bottom-up saliency map [5]. In their study, stimuli were presented so briefly and followed by a high contrast mask so that subjects could not perceive the stimuli. Similarly, we also used backward masking to make low-luminance stimuli invisible. Stimuli in our experiment were natural images collected from the Internet instead of simple pattern or texture, for natural images contain multiple and naturalistic low-level features [6]. Consider that some studies had used checkerboard to mask objects [7], random checkerboard was used as mask in our experiment.

In our experiment, we adopt a revised version of the cueing effect paradigm proposed by Posner *et al*. [8]. In this paradigm, a target appears in one of two locations randomly, and subjects need to finish a discrimination task about this target. Prior to this target, a cue indicates the location of the following target. Trials with a correct cue are called valid cue trials, while trials with an incorrect cue are called invalid cue trials. A classical result demonstrates that performance (response time or accuracy) in the valid cue trials is significantly higher than that in the invalid cue trials [9]. The salient region of a natural image was used as a cue in our experiment.

Many studies had also proposed a computational model to generate the saliency map of an image. An example can be seen in Fig. 1, the value of each

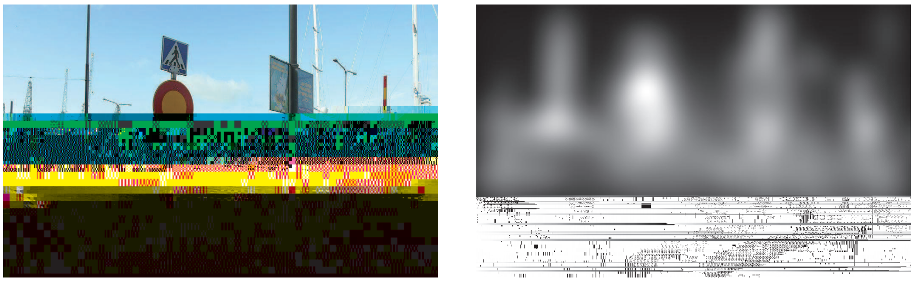

Fig. 1. An example of a color image (left) and its saliency map (right). White region in the right image indicate its salient region.

pixel in the saliency map ranges from 0 to 1, higher value correlated with more saliency. Itti *et al*. proposed a biologically-plausible saliency model based on a center-surround mechanism, by combining information from three channels: color, intensity and orientation [1]. According to the spectrum of natural images, Hou *et al*. compute the spectral residual of an input image and transform the spectral residual to spatial domain to obtain its saliency map [10]. By simulating the information transmitting between neurons, Wang *et al*. proposed a saliency model based on information maximization [11]. These saliency models can provide a prediction about the attentional effect of a bottom-up saliency map.

Moreover, the underlying neural mechanism of the bottom-up saliency map has been subject to debate. A dominant view assumes that saliency results from pooling different visual features (e.g. [2], [12]), thus could be realized by higher cortical areas such as parietal cortex. However, Li proposed the V1 theory which claimed the saliency map was created by V1 (e.g. [13], [14]). It was completed via intra-cortical interactions that are manifest in contextual influences [15]. By combing psychophysical data and brain imaging results, Zhang *et al*. found that neural activities in V1 could create a bottom-up saliency map of simple texture [5], which supported the V1 theory. But evidence on natural images is still lack.

The rest of this paper is organized as follows. In Section 2 we introduce the one subject who was one of the authors. They were given written, informed consent in accordance with the procedures and protocols approved by the human subjects review committee of Peking University.

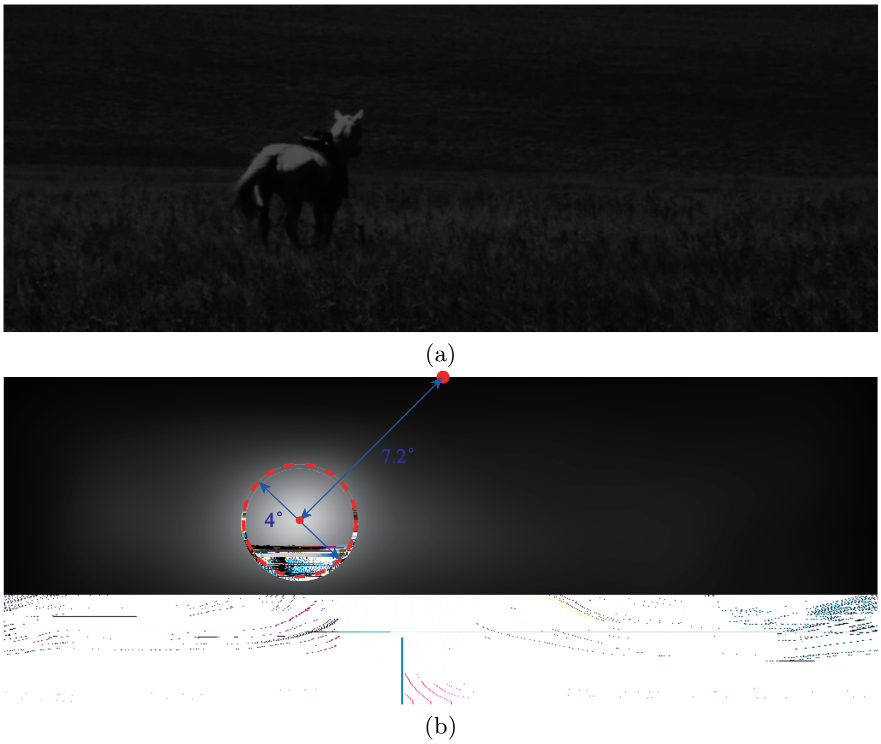

Fig. 2. (a) A sample of a low-luminance image used as our stimulus. (b) The averaged saliency map of left-salient images, a circle-like local salient region can be seen on this map.

their head position was stabilized using a chin rest and a head rest. A white fixation cross was always present at the center of the monitor, and subjects were asked to fixate the cross throughout the experiment.

We adopt a modified version of the cueing effect paradigm proposed by Posner to measure the attentional effect of the visual saliency of invisible natural images. Each trial started with a fixation. A low-luminance (2.9 cd/m^2) image was presented on the lower half of the screen for 50 ms, followed by a 100ms mask at the same position, and another 50ms fixation interval. The bottom-up saliency map of the image served as a cue to attract spatial attention, and the mask could ensure that the image was invisible to subjects. Then a grating orientated at about $\pm$ 1.5° which centered at about 7.2° eccentricity from the fixation was presented randomly at either the lower left quadrant or lower right quadrant with equal probability for 50 ms. The location of the grating was either at or symmetric with the salient region of the previous image, thus indicated the valid cue condition or the invalid cue condition. The grating had a spatial frequency of 5.5 cpd (cycle per degree) and its diameter was 2.5 with full contrast. Subjects

3 Experimental Result

3.1 Images Invisibility

The purpose of the 2AFC experiment was to evaluate whether those natural images used as the cue in the attentional experiment were indeed invisible. High salient images and low salient images were counterbalanced in this task. Subjects had to report whether they can see an image before the mask (details can be found in Section 2.3.

We found that percentages of correct detection (mean $\pm$ std) were $48.6 \pm 6.0\%$ and $50.9 \pm 5.7\%$ for high salient and low salient images respectively. Paired t-test results showed that the percentages of correct detection were statistically

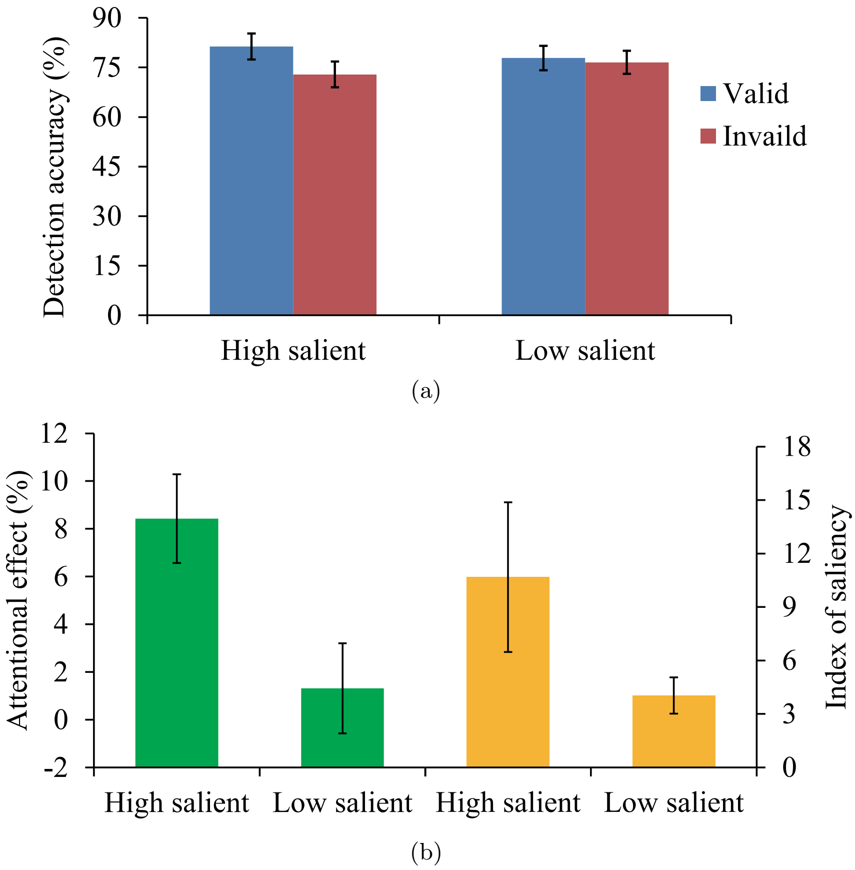

Fig. 4. Results of our experiment. (a) The performance of the grating orientation discrimination task for high salient images and low salient images. (b) The left two green bars indicate the attentional effect of bottom-up saliency maps in high salient and low salient groups. The right two yellow bars indicate the predication of the attentional effect in two groups.

4 Conclusion and Discussion

In this paper, we proposed a method to measure the attentional effect of bottom-up saliency maps. By using backward masking, we could eliminate the contamination of top-down signals. We selected natural images which had a local round salient region and found that even those natural images were invisible, the salient region could attract attention to improve the orientation discrimination performance on a grating in the cueing effect paradigm. Furthermore, we found that the attraction of attention increased with the degree of saliency.

In our experiment, we assume that the absence of awareness to the whole image could maximally reduced top-down signals, even if it did not completely abolish them [5]. These top-down signals may include feature and object perception, as well as subjects' intentions [16]. Compared to previous studies, such manipulation could help us observe the attentional effect based on a relatively pure bottom-up saliency signal. Our findings may suggest that the bottom-up saliency map of a natural image could be generated at a very early stage of visual processing.

In the future, we will extend our study to find the neural substrate of bottom-up saliency maps of natural images. Moreover, consider it's difficult to modulate the degree of saliency on the same content, we will also extend our work on synthesized textures so that we could quantitatively change the degree of saliency on one image.

5 Acknowledgement

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