The Influence of Visual Angle on the Performance of Static Images Scanning

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Abstract. The present study addressed to explore the influence of visual angle on the performance of static images scanning with a 2 (scanning distance) × 2 (scanning type) × 3 (visual angle) mixed design. The results demonstrated significant effects of three factors on participants' performance. Stimuli at 5.5° and 8.4° rather than 2.7° could facilitate the performance of static image scanning. However, the effect of visual angle on mental image scanning was smaller than on retinal image scanning. These findings were interpreted in terms of the theory of working memory and the theory of mental image. The implication of these findings in human-computer interface was discussed at last.

Keywords: visual angle, image scanning, mental load, working memory.

1 Introduction

Picture is one of primary external representations of the world as well as word [8], however, it supplies people with information in a quite different way from word. Compared with word, picture has the advantages of being an intuitionistic form, more understandable, and less susceptible to the influence of cross-cultural differences and literacy proficiency [15]. An abundance of pictures were used in human-computer interface [8], advertisement [15], traffic signs [1], and multimedia learning [10].

1.1 Retinal Image Scanning and Mental Image Scanning

When a picture appears in front of one's eye, a retinal image is formed through the light rays reflects from the picture activating the cells on retina, people then encode it as a mental image on visual working memory [7]. Both retinal image and metal image can subsequently be taken as an input of further processes such as scanning or rotating [13].

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Correspondingly, the image scanning can be divided into retinal image scanning and mental image scanning.

Retinal image scanning is the systematic shifting of attention over the retinal image of object or a scene with the presentation of the original real object or scene [7]. It is an integral part of visual search processes involving computer or radar displays, head-up displays in aircraft, or attending to road traffic signs [11]. Several variables were reported to affect the performance of users on retinal image scanning, including color [14], spatial frequency of picture [8], visual complexity [11], and number of icons and luminance of environment [15].

Mental image scanning corresponds to the systematic shifting of attention over the mental image when the real object or scene is out of sight [7]. Mental image scanning is an important spatial ability [2] and is often used in visual thinking [5]. An experimental measure of mental image scanning was developed by Kosslyn in 1973 and modified by Dror and Kosslyn in 1993 [2]. Details of this image scanning paradigm will be expatiated in later experiment section. By this modified paradigm, a lot of research found that more time was required to scan a greater distance across a mental image as well as across a retinal image.

A series of experiments had been reported by Kosslyn et al. reflected the structural isomorphism of visual mental images with corresponding retinal image [2] [7]. They also found both the retinal image and mental image share much of neural machinery [6]. However, most of them failed to give enough consideration to the difference between them. This is one aspect we focused on in the present study. According to Kosslyn's theory of mental image, both of retinal and mental image scanning work on the visual buffer, which is a functional space being located in the visuo-spatial scratch pad of working memory [7]. Subjects have to refresh their mental image on the visual buffer after the picture disappears, while retinal image need not such step because of presentation of the actual object. So, we hypothesized that retinal image scanning and mental image scanning might differ in the working memory resources they use. Scanning across a mental image demanded much more mental resources than retinal image scanning. We expected that there was some difference between the performance of the two types of image scanning, with higher accuracy and shorter response time for retinal image scanning than for mental image scanning.

1.2 Visual Angle and Image Scanning

Visual angle is defined as the angle between the line joining the observer to one point of the diameter of object and the line to the other point of the diameter of object. It is a function of object size and the distance between eyes and object (stadia distance). Visual angle reported in most researches was taken as a controlled variable while object size or stadia distance was taken as an independent variable (e.g. [2] [7]). However, it is visual angle but not object size or stadia distance that determines the size of retinal image. One obvious example is that the perceived size of object does not generally equal its physical size [5].

Though less data is available to reflect the relation between visual angle and image processing, a recent study carried out by Niu, Qiu, and Fu addressed the relationship between visual angle and maintenance of static images [12]. In their study, subjects firstly studied a 5×5 matrix that was composed of white and black panes, and then they were required to recall the locations of black panes. The results showed that the matrix presentation with larger visual angle could promote the performance of short-term maintenance of static images. Given the fact that static image processing is based on the short-term maintenance of static images, we speculated in the present study that the performance of image scanning might also vary with visual angle.

To summarize, the current study was motivated by following questions. Firstly, was there a difference between the performance of retinal image scanning and mental image scanning? Secondly, whether visual angle could influence the performance of static image scanning? In order to answer these questions, Kosslyn's image scanning paradigm [2] and a variant of the paradigm were used to test the performance of mental image scanning and retinal image scanning respectively. Moreover, according to Huang et al's argument that acuity of vision was quite different among the three regions [0°, 5°], [5°, 8°], and [8°, 180°] [4], 2.7°, 5.5°, and 8.2° were taken respectively from these three regions.

2 Method

2.1 Participants

Thirty-six undergraduates participated in the experiment (18 men and 18 women), with a mean age of 22.5 years and an age range from 18 to 26 years old. All of them were right-handed and had normal or corrected-to-normal vision ability. All subjects were volunteers paid for their time.

2.2 Materials

As illustrated in Figure 1, a ring was constructed from twenty squares; with 6 squares on each side (two squares of them were blackened). A 0.5-cm-long arrow, corresponding to 0.6°of visual angle, appeared within the inside of the ring after the subject pressed the space bar (under mental image condition, this arrow was presented after the ring removed); the arrow pointed either north, east, south, or west. In addition, the arrow was positioned at two kinds of distances from the target square, either 0.4 cm away from it, or 0.8 cm away from it, which corresponded to 0.5° and 0.9°of visual angle, respectively. Totally 192 test trials were constructed, 96 for each

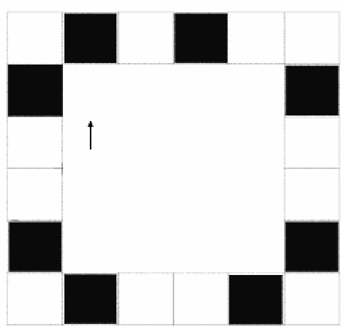

Fig. 1. Example of the stimuli used in retinal image scanning task

distance. On half of the trials at each distance, the arrow pointed to a black square, and on half it did not. The orientation of the arrow was counterbalanced within each condition. We also prepared 24 additional practice trials under each scanning condition.

2.3 Apparatus

The stimuli were displayed on a TCL17-in. monitor with a 70-Hz refresh rate at resolution of 1280 × 1024 pixels, connected to a Pentium IV computer. The experiment was programmed with E-Prime software (version 1.1). Participants positioned their heads on a chin located at a distance of 50cm from the center of the screen. Visual angle is calculated according to the formula as follows (α: visual angle; l: the diameter of the picture; d: stadia distance; $\pi \approx 3.14$):

$$a = 2\times \mathrm{arctg}\,(1 / 2\,d) \times 180\,\pi. \tag{1}$$

The sizes of the rings presented under the three visual angle conditions were 7.2 cm×7.2 cm, 4.8 cm×4.8 cm, and 2.4 cm×2.4 cm respectively with an unvarying stadia distance of 50 cm.

2.4 Procedure

First of all, the 36 participants were randomly allocated to each scanning condition, half of them for the retinal image scanning, and the other half for the mental image scanning. All the subjects were tested individually. Under the retinal image scanning condition, a trial began with a fixation point "+" at the center of the screen for 500 ms. Then the fixation was replaced by a blank screen for 250 ms. Following this, a square-ring stimulus with an arrow appeared at the center of the screen for 50 ms, and then the arrow disappeared leaving the square-ring on the screen. The subjects were required to scan from the pit of the arrow to the ring and pressed the yes key if the target square of the ring which the arrow pointed to was black or the no key if the target square was white. After the response, a cross appeared immediately, and a new trial began.

Under mental image condition, the subjects were shown a ring and were asked to study it until they could visualize it. Once they could visualize the ring, they pressed space bar and then the stimulus was replaced by a blank screen for 250 ms, following this, an arrow appeared for 50 ms. At this point, all the stimuli were removed. The subjects press the yes key if the arrow pointed to one of the black squares or the no key if it did not. After their response, a new trial would begin.

A 2 (scanning distance: 0.8 cm and 0.4 cm) × 2 (scanning type: retinal image scanning and mental image scanning) × 3 (visual angle: 2.7°; 5.5°, and 8.2°) mixed design was employed. The scanning type was a between-subjects factor, and the other two were within-subjects factors. All the trials were presented in random order; the same square-ring could not appear twice in consecutive trials. All subjects were asked to respond as quickly as they could while being as accurate as possible.

3 Results

Prior to analysis, response time 2 standard deviations away from the mean was omitted as outlier, which occupied 1.6% of all data. We did not include incorrect responses when calculating mean response time. Separate analyses of variance were performed on RT and ACC.

3.1 The Test of Speed-Accurate Trade-Off Effect

The analysis of Pearson's correlation between response time and accuracy rate was conducted to test whether there was a speed-accurate trade-off effect in the experiment. A significant negative correlation was obtained, $r = -0.615$, $p < 0.05$, suggesting less reaction time was associated with higher accuracy, so there was no significant speed-accurate trade-off effect in this experiment.

3.2 The Main Effect of Visual Angle and Scanning Type

The RT data were analyzed by repeated measure ANOVAs, which included scanning distance, scanning type, and visual angle of stimulus presentation as independent variables. In this analysis, as well as in every analysis reported in this article, all results not mentioned were not significant, $p > .10$.

As illustrated in figure 2a, subjects did require more time to scan a greater distance (with means of 859ms and 898 ms for near and far distances, respectively), $F(1, 34) = 5.49$, $p < .05$. The main effect of visual angle was found, $F(2, 34) = 21.315$, $p < .001$. Post hoc comparisons with LSD method revealed that this effect was due to large and medium visual angle conditions taking a significant less time to scan the same distance, $p < .01$. In addition, the difference between the two larger visual angles was not significant, $p > .10$. The main effect of scanning type was also in significance, less time was needed to complete the retinal image scanning task than mental image scanning task, $F(1, 34) = 25.00$, $p < .001$.

We also performed the corresponding analysis of the accuracy rates with the same independent variables. Consistent with the response time data, the subjects made more errors when a greater distance had to be scanned (with means of 86.1% and 73.8% for near and far arrow distances, respectively), $F(1, 34) = 163.07$, $p < .001$. The accuracy rates increased with increasing visual angle, $F(2, 34) = 5.80$, $p < .05$. Post hoc analysis indicated that only the difference of accuracy rates between the large visual angle condition and the small visual angle condition approached the significance, $p < .01$. The main effect of scanning type was also in significance, $F(1, 34) = 161.71$, $p < .001$. The mean accuracy rate of retinal image scanning was much higher than that of mental image scanning.

3.3 The Difference of Effect of Visual Angle Between the Two Types of Scanning

In the repeated measure ANOVAs, the most interesting findings were that the interaction between the visual angle and scanning type also approached significance,

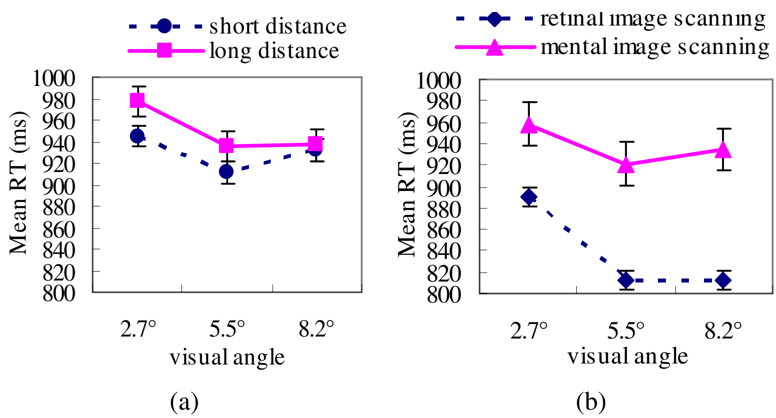

Fig. 2. Mean RT for each level of scanning distance (a) and scanning type (b)

F (2, 68) = 5.43, p < .01. A simple effect test showed the effect of visual angle was significant under both retinal image scanning condition and mental image scanning condition, F (2, 68) = 28.74, p < .001 for retinal image scanning and F (2, 68) = 5.11, p = .009 for mental image scanning.

In order to investigate the difference of effect of visual angle between the two types of image scanning, we calculated the mean decrease of RT when visual angle increased from 2.7° to 8.2° for each scanning type and compare the differences of mean decrease of RT between the two types of scanning. A one-way ANOVA revealed that the mean decrease of RT was larger under retinal image scanning (mean decrease = 77.28 ms) than under mental image scanning (mean decrease = 23.92 ms), F (1, 34) = 10.34, p = .003. When the visual angle increased from 2.7° to 5.5°, the mean decrease of RT was also larger under retinal image condition (mean decrease = 77.88 ms) than that under mental image condition (mean decrease = 37.28 ms), F (1, 34) = 5.00, p < .05. That is to say, there was a diminishing effect of visual angle from retinal image scanning to mental image scanning. The results were shown in Fig. 2b.

4 Discussions

The experiment reported here replicated the standard hallmarks of image scanning: scanning time and errors increased with increasing distance. We could have confidence that performance in these tasks did in fact reflect the efficacy of image scanning processes. In addition, we correlated the response time with accuracy rate of image scanning which revealed no speed-accurate trade-off effect in the experiment, so both response time and accuracy rate could be valid dependent variables. However, because of the sensitivity of RT, we took it as the main dependent variable as most studies on scanning task did [2] [7].

4.1 The Effect of Visual Angle

The results of the experiment demonstrated that the visual angle of stimulus presentation during the image scanning had a considerable effect on subsequent task performance. The two larger visual angle conditions facilitated the performance of both the retinal image scanning and mental image processing. These results were consistent with a previous study on the impact of visual angle on the short-term maintenance of static images [12], which found that larger visual angle could promote short-term maintenance of mental images. Huang, Cai, and Chen argued that the vision acuity would be maximal at the visual angle of about 5° according to the physiological structure of eye [4]. This was also in accordance with our results. In our experiment, best performance of image scanning tended to appear at 5.5° of the stimulus presentation, though there was no significant difference between 5.5° and 8.2°. However, since only three visual angles were used in our experiment, it was difficult to conclude that the larger the visual angle was the better image scanning task was performed. Future studies should be aimed to explore how visual angle influence the processing of different static images, and determine which visual angle will be the best to facilitate the performance of static image scanning.

4.2 The Difference Between Retinal Image Scanning and Mental Image Scanning

Clear differences between the performances of two types of scanning were also revealed by both the analyses of RT data and ACC data. Subjects under the retinal image scanning condition accomplished task with a much less response time and higher accuracy rate than those in mental image scanning. Previous studies paid more attention to the functional equivalence between the retinal image and mental image [2, 6, 7]. However, our experiment demonstrated that the retinal image and mental image were of some differences. Since we had excluded the contribution of extraneous variables by keeping the same color and shape of stimuli, the same orientation of the arrow and the same spatial frequency under the two conditions, it was easy for us to claim that the differences between retinal image scanning and mental image scanning was due to different mental load of the two kinds of scanning held. According to the theory of mental image raised by Kosslyn [7], all kinds of image scanning work on the visual buffer (which is a spatial mediate being located in the visuo-spatial scratch pad of working memory), so they are restricted by the visual working memory's limited capacity. Under mental image scanning condition, subjects had to refresh their mental image on the visual buffer after the picture disappeared, while in retinal image scanning the picture didn't disappear until subjects made a response, subjects only needed to maintain the orientation of the arrow. Hence, it was obvious that mental image scanning put a much greater mental load on subjects than retinal image scanning did.

Interestingly, the response time also revealed an unexpected interaction of scanning type and visual angle. Though simple effect test showed that the effect of visual angle existed on both the retinal image scanning and mental image scanning, we took a further analysis to test the difference of the decrease of response time from 2.7° to 5.5° or to 8.2° between retinal image and mental image scanning. The results indicated that the effect of visual angle was rather larger under the retinal image condition than that under mental image condition. In other words, as the visual angle increased from 2.7° to 5.5° or 8.2°, a larger increase of performance appeared in retinal image scanning than in mental image scanning. One explanation for this interaction is the fact that retinal image, as a low level visual process, has a more direct relation with visual angle. Kosslyn's theory claims that mental image is a high-level visual process. Mental image scanning relies on such high-level mechanisms which typically operate on the output from low-level processes. It is possible that the influence of visual angle can be modified by a higher-level cognitive process. Further study should be taken to verify this hypothesis.

4.3 The Implications in Human-Computer Interface Design

These results may have important implications for human-computer interface design. For one thing, this study extends the visual factors which can influence the performance of image processing. In the realm of human-computer interface design, there are very few studies about the role of visual angle from psychology perspective. Though the effect of visual angle is similar to the effect of size [7], which refers to that a larger image could facilitate the processing of mental image, the effect of visual angle is of more practical applications and leaves a broader decision space for the designers of human-computer interface and computer & software manufacturers. Once a visual angle is fixed, the stimulus size can be altered flexibly with corresponding change in stadia distance. Secondly, icon search, one basic interaction between human and computer [8], is actually constructed by retinal image scanning. Many factors which can affect the performance of icon search have been reported, such as the number of icons and the contrast of icon [3]. Our research extends past studies by taking visual angle into consideration. The performance of icon search will be impaired if the visual angle of the stimulus presentation is too small. Lastly, not all the scanning tasks can be completed at the presentation of original stimulus, sometimes we have to complete some tasks by visualizing the original object. For example, designers often take three or four pictures to indicate successive procedures when they compile training procedures [10]. Only by mental image transformation such as mental image scanning can people make connection between one picture and the next one. So it is necessary to classify the scanning tasks into retinal image scanning tasks and mental image scanning tasks, and designers should pay more attention on the fact that some factors (like visual angle) may affect the two types of image scanning tasks in different ways.

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