A Study of Multi-target Visual Search by Eye Movement Behavior

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Abstract. The purpose of this study is to probe the characteristics of search time and eye movement behavior to the multi-objective search. Ten subjects participated in the experiment and they were asked to search three target characters at the same similarity degree among the distraction characters which displayed on a 24 in. computer display. The results of search time showed that the first target character was the longest and the second target character was the shortest when the similarity degree between target characters and distraction characters was smaller; The search time to the third target character was the longest and the second target character was the shortest while the similarity degree between target characters and distraction characters was larger; It could been seen from the eye movement data that the search time was longer of the group of the higher similarity degree. It also could be found from the video playback of eye movement data that there were three kinds of visual search patterns for the subjects that they were parallel search, serial search, and parallel-serial search. The subjects who used parallel-serial search pattern made shorter time in founding the target. Conclusions can be made from the results: the order that the targets presented can significantly affect the search time; the similarity degree between target characters and distraction characters also has significant effect to the search time; the parallel-serial search pattern has the best search efficiency among three search patterns.

Keywords: Multi-target · Visual search · Eye movement · Cognition · Ergonomic

1 Introduction

Visual search is an important way for human to obtain information and it refers to that the people make a series of saccadic and fixation to the stimulus to complete the information processing [1]. Visual search has a widely application in industrial inspection, medical, security and military field. It is an important research focus to the people of physiology, psychology and ergonomics.

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Most of the present studies of visual search were for the single target that people need to search the target in the distracters and respond to the target when it was found [2]. But in the daily life and work, people often need to search more than one target. All hazardous articles must been found in a short time when the airport make security check; defect is likely to be more than one place in the industrial inspection; Several fire points of enemy may be dispersed in an area in the military reconnaissance; Pilots need to search, lock and attack for multiple targets of enemy. Therefore, multi-objective visual search research has the vital significance that can understand the characteristics of the person scanning pattern, look for ways to improve search performance, so as to make better scanning training to operation worker and guide the design to the display interface.

In studies to the multi-objective visual search, as well as to the single objective search, the search pattern was one of the focuses of the researchers. Chan and Yu [3] made a visual search experiment of two targets. They summarized that the searchers adopted a random search strategy when the space proportion of search target is small and target search time is less than 30 s. Through the study of the multi-objective visual search, Hong and Drury [4] confirmed that the subjects tend to take the system search strategy to the front objectives while take the random search strategy to the latter objectives. It has been pointed in the study of Morawski et al. [5] that actual search performance is usually between random search and system search or these two search patterns are lower bound and upper bound of the search performance. In the studies of Hong and Drury [4], Chan and Chan [6], Chan and Yu [3], they all indicated that people tend to adopt the strategy of random search when the background is much greater than the target number.

The study of visual search model of multi-objective search was another concern to researchers. Hong and Drury [4] expanded the single objective random search model to the multi-objective random search model. They assumed that when each target search in the search area is independent of each other, it can be seen as multiple independent joint distribution function of a random variable, so that the detection probability of each target and the search time can be calculated. Yu and Kong [7] thought that targets are not independent of each other, but influence each other. Based on return and inhibition theory, they introduced a concept of effective search area and built the correction model of the above model. Morawski [5] studied system search model of multi-objective. He found that the system search model cannot be directly developed from that of the single target search model. When making multiple target search, he assumed that the target must be seen as long as the target fall within the field of vision of each fixation. That is to say, all targets can be found if the whole area be searched. At this time, search time of each target only depended on its location. If the target was randomly distributed, the average search time of each target was the same. Hong and Drury [4] expanded the model of Morawski's and studied system search model of multi-objective when $P_0 = 1$ and $P_0 < 1$.

Eye movement measurement technology can objectively record scanning behavior in the process of visual search. Current visual search theory and model were established on the basis of assumptions and mathematical calculation and lack of the support of eye movement data. The aim of this study is to study the characteristics of multi-objective search time and eye movement behavior with the help of eye movement measurements, so as to reveal the cognitive processing and eye movement patterns of multi-objective search. Results will provide theoretical basis and data support for layout design of information display in practical engineering.

2 Method

2.1 Participants

Ten undergraduate students were recruited from the Beihang University. Their ages ranged from 22 to 25 (Mean age = 23.5). Each was tested by a standard near-visual chart to ensure that they had a near fovea acuity that was normal. Participants provided informed consent and received RMB 100 yuan for their participation. Three participants who performed the fastest search will have a bonus of RMB 50 yuan.

2.2 Apparatus

Eye movement measurement system of SMI iViewX RED desktop was used in this experiment. It was made up of a laptop which was operated by the host to control the experiment process, a 24 in. monitor which presented stimulus materials to the participants and eye tracking module. The eye tracking module was installed below the monitor. It can track and collect the line of sight of subjects position in real-time and transmit the collected signal to the laptop. After the calculation and processing of that eye movement signal, eye movement data of fixation, saccade, pupil and blink can be acquired. Sampling rate of the system was 120 Hz, the resolution was 0.03°, and gaze position precision was 0.4°.

2.3 Stimulus Material

Participants were asked to find three target characters among the distraction characters or background characters that presented in 24 in. monitor. The size of the target and the background characters were both 20 pound and the characters density was 13*13pixel. Both the target and background characters were Chinese characters and they all appeared at the same time. In the whole experiment process, the background characters were kept the same Chinese character as “再”. There were three groups target characters: the first group was “天、木、未”, the second group was “贪、贫、贤” and the third group was “墓、慕、幕”. There were different complexity between three groups target characters and the three target characters in the same group had the same similarity. Also there was different similarity between each group target characters and background characters in each group. The complexity of the characters was determined by the number of strokes of Chinese characters which the more strokes was with the higher complexity. The calculation method of Chinese character similarity was as formula 1 [8].

$$S = K \times (A + B) = K \times (E/F + C/D) \tag{1}$$

K structure similarity coefficient if the topology structure was the same of the two Chinese characters the K = 1 and the two Chinese characters are the same similarity while K = 0 if the topology structure was different and two characters were not similar
A proportion of stroke of the differences between characters
B proportion of similar structure blocks between characters
C the structure and blocks number of the consistent strokes in phase between characters
D the structure number of the full word
E the common stroke counts both similar and close position between characters
F the number of strokes of the biggest difference with the stroke number of nearly form word

Similar structure blocks ratio was defined as B = C/D and the similarity ratio of the difference part was defined as A = E/F. The value of the similarity was 0 ~ 1。 "1" represented the highest similarity while "0" was the lowest similarity.

The results of the target characters similarity calculated by formula 1 were shown in Table 1. The similarity between target characters and background characters was shown in Table 2

Table 1. Similarity between target characters (TC)

Group	TC	TC	TC	Similarity
1	天	木	未	0.87
2	贪	贫	贤	0.89
3	墓	慕	幕	0.90

Table 2. Similarity between target characters (TC) and background characters (BC)

BC	TC	TC	TC	Similarity
	天	木	未	0
再	贪	贫	贤	0.67
	墓	慕	幕	0

2.4 Procedure

When the participants came he will do as the following procedure.

(1) To practice 10 min to the experiment tasks.
(2) Adjust the position of the participants and sitting posture, make the participants' eyes 40 cm distance from the screen.

(3) Adjust the height and Angle of the screen, make the sight line of participants near the center of the screen, and the angle between sight line keep about 90° with screen (Fig. 1).

(4) The calibration of eye movement measurement system.

(5) Present the interface of experimental stimulus and the participant began to search the targets. When participants found the first target, he quickly pressed the "1" key on the keyboard, the "2" key for the second target, and the "3" key for the third target.

(6) When the all three targets were found, the three target characters turned to red in order to make participants to check the correctness of search location (Fig. 2). The experiment data would not be recorded if he make the wrong search.

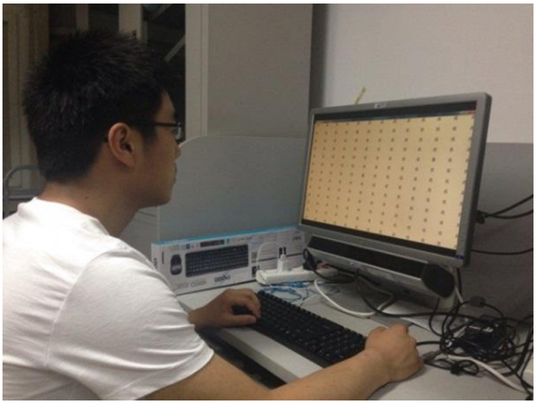

Fig. 1. Multiple target search experimental scene

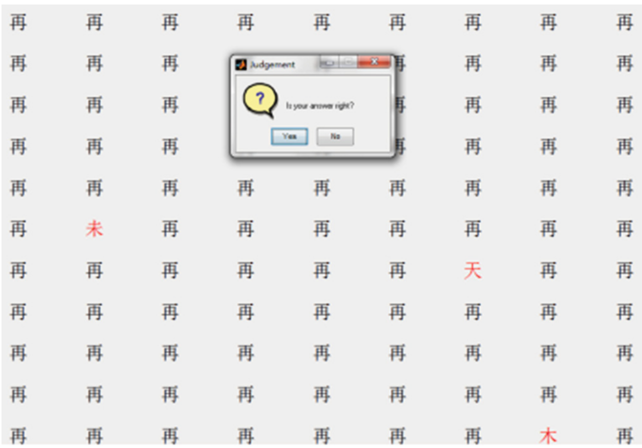

Fig. 2. Stimulus interface

2.5 Single Target Search Experiment

The search time of the single target within the same group selected according to formula 1 should be close equal or approximate. And because of the difference of similarity and complexity between groups, the average search time of single target should have some degree of difference between groups. In order to verify the difference of search time, the single target character experiment (Fig. 3) was done and the search time of above target characters was abstained (Tables 3, and 4).

Fig. 3. Single target search experiment

Table 3. Search time (ST) of single target

Group 1	ST(s)	Group 2	ST (s)	Group 3	ST (s)
天	1.25	贫	1.78	墓	1.27
木	1.29	贤	2.10	慕	1.39
未	1.35	贪	2.19	幕	1.28

Table 4. Average search time of each group

Group	1	2	3
Average search time(s)	1.30	2.02	1.31

The results of search time were tested with the one-way ANVOA method. The search time of single target of the same group had no significant difference ($P > 0.05$), the cause of this was the close similarity between the target characters in the same group and the background characters. While the average search time of each group reached significant difference ($P < 0.05$). The difference of the search time was significant ($P < 0.05$) between the first group, the third group and the second group, but there was no significant difference between the first group and the third group. These differences were caused by the similarity of three groups of target characters and background and complexity between three groups of target characters, so it proved that the selected characters by formula 1 were reasonable.

3 Result

Table 5 was the results of the search time of three groups target characters. The results of search time were tested with the one-way ANVOA method. The first group of target characters “天”, “木”, “未” reached significant level ($p < 0.05$) and the comparison results of search time between characters also reached significant level ($p < 0.05$). The second group of target characters “贫”, “贤”, “贪” reached significant level ($p < 0.05$) and the comparison results of search time between “贫”, “贪” and “贤” reached significant level ($p < 0.05$) while it was not significant between “贫” and “贪”($p > 0.05$). The third group of target characters “墓”, “慕”, “幕” reached significant level ($p < 0.05$) and the comparison results of search time between characters also reached significant level ($p < 0.05$).

Table 5. Search time(ST) of target characters of three group

Group 1	ST(s)	Group 2	ST (s)	Group 3	ST (s)
天	1.379	贫	1.556	墓	1.376
木	0.685	贤	1.108	慕	0.827
未	1.000	贪	1.609	幕	1.141

Table 6 was the results of the average search time of target characters of each group. The test results with the one-way ANVOA method showed that the comparison of search time between three group target characters reached significant level($p < 0.05$) and the comparison results of search time between the first group, the third group and the second group of target characters reached significant level ($p < 0.05$) while it was not significant between the first group and the third group ($p > 0.05$).

Table 6. Search time(ST) of each group target characters

Group	1	2	3
ST(s)	3.069	4.375	3.345

Figure 4 was the scan path recorded by eye movement measurement system. Table 7 showed the fixation point number of target characters of each group. The test results with the one -way ANVOA method showed that the comparison of fixation point number between three group target characters reached significant level ($p < 0.05$) and the comparison results of fixation point number between any two groups l ($p < 0.05$).

It can be seen from playback of eye movement video data that there were three patterns in the process of participants’ visual search: parallel search (Fig. 5), serial search (Fig. 6), and parallel-serial search (Fig. 7). Some participants used more parallel

Table 7. The fixation point number of each group target characters

Group	1	2	3
Fixation point number	1624	3418	1811

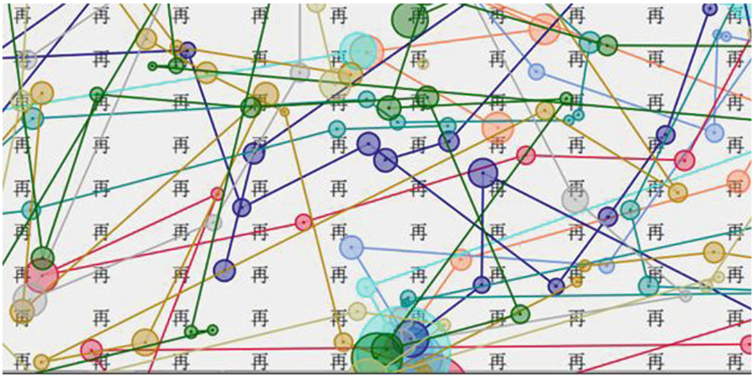

Fig. 4. The participant's scan path

search pattern. Some participants used more serial search pattern, and some participants used more parallel-serial search pattern. Table 8 was the search time for the participants who had different preference search pattern to find three target characters.

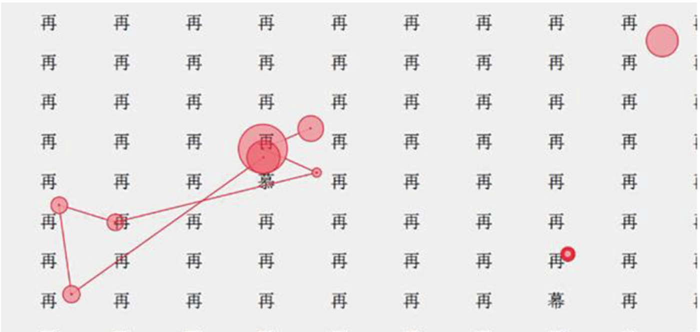

Fig. 5. Parallel search pattern

4 Discussion

It could be seen form Table 5 that the search time of the second target character was the shortest and the first target character was the longest when the similarity between target characters and background characters (e.g. the first group and third group) was lower. The search time of the second target character was the shortest and the first character and the third character was closer when the similarity between target characters and background characters (e.g. the second group) was higher. The search time of the second target character was the shortest whatever the similarity between target characters and background characters was. Klein [9], found that working memory would temporarily store the detected items (or location) in the process of visual search has been tested project (or location) to prevent these items (or location) from searching

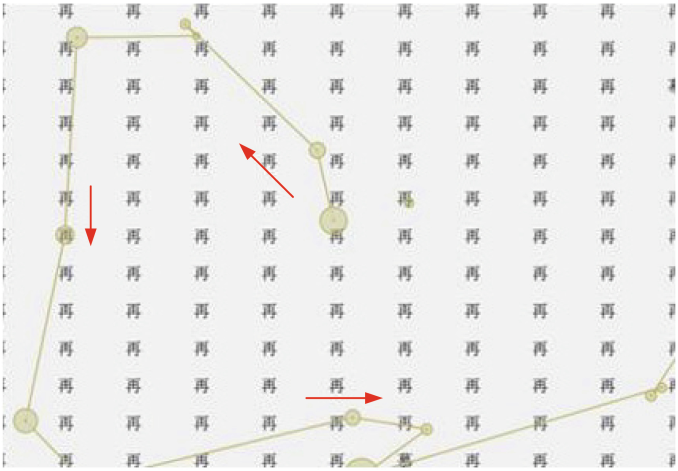

Fig. 6. Serial search pattern

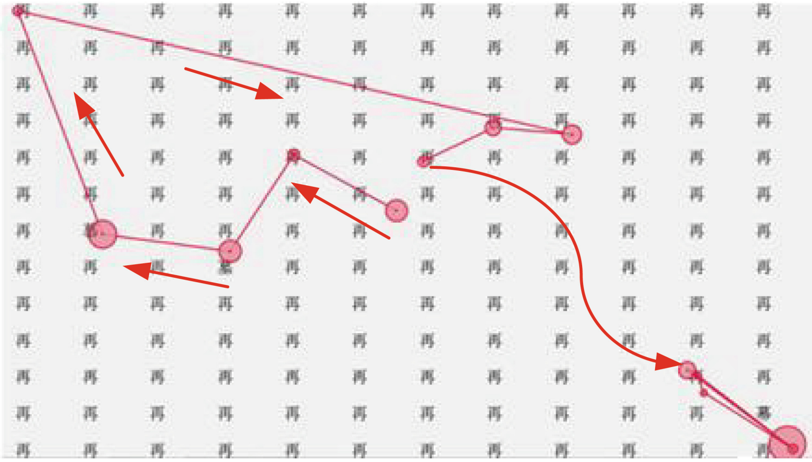

Fig. 7. Parallel-serial search pattern

Table 8. Search time (ST) of different search pattern

Search pattern	Parallel search	Serial search	Parallel–serial search
ST (ms)	4704	5163	4195

again. In this study, the participants had remembered the detected locations due to the existence of working memory effect when they had found the first target character, so they would not to search these locations again when they search the second target character, and the search space was minished and the search efficiency was improved. Eye movement data also reflected the effect of working memory. Seen from the playback of video data of eye movement, the most of the participants' scanning was in the remaining space, while occasionally scanned the detected area again once. Some of the other researchers also found the support of eye movement data in the eye movement research of visual search. For example, in the process of visual search, Klein and MacInnes [10] found that saccade made more deviation from the previously noticed items, and the deviation effect can be traced back to the three items before the current fixation. The role of working memory in visual search can explain the cause that the search time of the second target was shorter than the first target. The search time of the third target should be shorter than the second target according to the working memory effect, but the experiment result was not conforming to that. How to explain that result? It was perhaps due to the stimulus. In this experiment, the target and background characters were all Chinese word, the similarity between target and background, word shape and word structure might all lead to that result.

Seen from the Table 6, the search performance could be affected obviously by the similarity degree. The longer the search time was the more similar between target characters and background characters. The result was accordance with Duncan and Humphreys [11]. They think that similarity between target and distraction could significantly affect the visual search performance and the easier local contrast was with the less similar between target and distractions. In addition to that, it could be seen form Table 6 that complexity could affect search performance to some degree. When the similarity between target characters of Chinese word and the background characters was close, the search time would be longer with the higher complexity of target characters of Chinese word. It might be due to that the increasing stroke of Chinese word increase the difficulty for participants' confirmation to targets, and so the confirmation time increased. Seen form Table 7, the fixation point number of the first group was the least and the second group was the most, so the eye movement data could also indicate that the higher similarity between target characters and the background characters increased the difficulty of search and reorganization of target and participants need to spend more scanning in finding target.

It could be seen from the scanning results of Table 8, the search performance of parallel-serial pattern was the best. It indicated that parallel-serial search pattern is a flexible and efficient mode of scanning, and in the actual target search, the efficient scanning habit could be developed to the operator by conducting the specialized training in scanning.

5 Conclusion

Based on the visual search experiment of three group target characters of different similarity and complexity, the conclusion could be made as the following:

(1) The presence of the target sequence will significantly affect the search time in the multiple target search. The search time of the second target character is the shortest when there are three search targets. The search time of the first target character is the longest when the similarity between target Chinese word and background Chinese word is lower. The search time of the third target character is

the longest when the similarity between target Chinese word and background Chinese word is higher.

(2) The similarity between target Chinese word and background Chinese word takes a significantly effect on search time. The search time will be longer with the higher similarity and the shorter the vice. In addition to that, the complexity of target Chinese word also has a slightly effect on search time.

(3) The participants show three visual search patterns in the multiple target search that they are parallel search, serial search, and parallel-serial search, and the search performance of parallel-serial search patter is the best.

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