A Comparative Study on 3D/2D Visual Search Performance on Different Visual Display Terminal

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Abstract Visual search tasks are mainly test methods of user performances for electronic visual displays, which was usually used to assess the subjective quality of the visual display terminal. This study investigated the effect of different 3D styles on static 3D/2D visual search performance. A 2 (search environment: 3D versus 2D) × 2 (display styles: 3D polarization versus 3D switch) within-subject factorial design was used in this experiment. The visual search contents included static 3D/2D visual search performance, which the search target was hexagonal pyramid and the background was pentagonal pyramid. The experiment task was to find out one hexagonal pyramid from many five pyramid in a trial. The experiment was carried out in two 47-inch screen televisions and their matching 3D glasses. As the 47-inch screen televisions, one was a typical 3D polarization television, which used LG display panel; the other was a typical 3D switch television, which used the Samsung's display panel. Sixteen subjects participated in this experiment. The search time and accuracy of each participant were recorded. The difference in search performance between 3D polarization television condition and 3D switch television condition was not significant whereas that between static 3D visual search and 2D visual search condition was significant. Post hoc comparisons found that the search time under the 2D environment was significantly longer than the search time under the 3D environment. Those results revealed that search performance was sensitive to search environment and the performance was not sensitive to 3D display styles. The obtained results could be a reference for deciding the visual search efficiency on different 3D display styles.

Keywords 3D/2D · Visual search performance · Visual display terminal

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1 Introduction

Visual search is very common in everyday life [1]. In visual search tasks such as Medical operation, security checking, military detection, 3D game are required to find certain subjects among background objects. In the past, the targets and background objects or the display were usually 2D, searches had to find targets in 2D searching area. With the development of display manufacturing technology, 3D display production technology is increasingly mature and cheaper, and they could be applied to various fields, which included medical operation, military detection and 3D game etc. But is the visual search performance in 3D display environment better than that of 2D display environment? There is no relevant literature description.

In addition, the mainstream 3D manufacturing technology mainly included switched mode and polarized mode, produced by Samsung Company and LG Company respectively. Moreover, which is better or worse about the two kinds of manufacturing technology for the user's visual search performance? The problem is a hot issue about which the manufacturers and consumers concerned. Researcher had did a comparison experiment on different 3D television displays produced by different 3D manufacturing technology in the dynamic visual search performance on 2D environment, but there was no significant difference of visual search performance and visual fatigue degree [2]. However, is there significant difference of visual search performance and visual fatigue between two kinds of 3D display manufacturing technology in static visual search task? The problem is also the questions concerned and focused on by the researcher.

This study intends to investigate the effect of watching visual displays produced by different 3D manufacturing technology though 2D and 3D visual search task paradigm and subjective survey. The study was expected to provide evidence to evaluate the efficiency of different types of 3D displays and different 2D or 3D visual environment. According to ISO international standard [3] about the user performance test methods for electronic visual displays, we adopted a visual search task paradigm [4] to evaluate the fatigue degree of different displays. We had tested the static visual search task performance, user experience and the visual fatigue degree of two kinds of displays, which provide the reference for the consumers, fans and gamers buying 3D displays. The specific evaluation indicators include the effectiveness, efficiency, comfortable and satisfaction etc. The visual fatigue perception scale developed by James et al. [5] was used to evaluate the eye and mental fatigue degree.

2 Method

The experiment was designed referencing to [6, 7]. The experiment task was to find out one hexagonal pyramid from many five pyramid in a trial. A within-subject factorial design was conducted to investigate the different performance of visual search on the different visual display terminals. A 2 (image types: two dimensional

image vs. three dimensional image) × 2 (visual display format: 3D switch TV or 3D polarization TV). In this experiment, the visual search time and search accuracy were measured to assess and compare which condition is better.

2.1 Participants

Sixteen ordinary adults from 18 to 30 years old (8 male and 8 female, mean age = 26.56, standard deviation of age = 4.43) were recruited and paid to participate in the experiment. All of them had more than 1.5 normal or corrected-to-normal visual acuities and healthy physical conditions, without ophthalmic diseases. They did not have any history of neurological and mental diseases.

2.2 Stimulus and Apparatus

The experiment task was to find the hexagonal pyramid among the pentagonal pyramids. There was only one target in each trial and the gap may be at left upper, right upper, left under or right under. The size of the background pyramid and target pyramid were same. Targets and background objects was green(R 255, G 0, B 5), blue (R 0, G 12, B 255) and red(R 30, G 255, B 95) that were balanced in all experiment conditions. Moreover, the background was black(R 255, G 255, B 255). The resolutions of all the display stimulus pictures were 1280 × 768, which the size of the space on the screen occupied by the shape in each picture is same. The order of pictures presentations was completely random. Considering that the experiment time should not too long, the search number of 2D image condition was reduced. In order to make the targets appear evenly in the different area of the screen, the screen was divided for four regions. According to mathematical plane right angle coordinate system rules, the upper right section of the screen was defined as region 1, the upper left section of the screen was defined as region 2, the lower left section of the screen was defined as region 3, and the lower right section of the screen was defined as regional 4. If the targets were showing near the fixation point or the boundary position, the subjects will be easy to find out the target. In order to avoid the impact on the experimental results, we will set the location of the target in the middle position of each region. And the searching area can be divided into 64 × 40 boxes with the size of 20 × 20 pixels (see Fig. 2). The background objects and targets were arranged as shown in Fig. 1. And the beginning of the task, the target didn't appear in 1st–7th rows, 34th–40th rows, 1st–12th columns and 53rd–64th columns in order to avoid extremely long search time. In addition, to avoid too short search time, the target didn't appear in 15th–25th rows and the intersection area of the 11th–29th rows and the 20th–44th columns. The area that the target did not appear was shown in Fig. 2(the dark area).

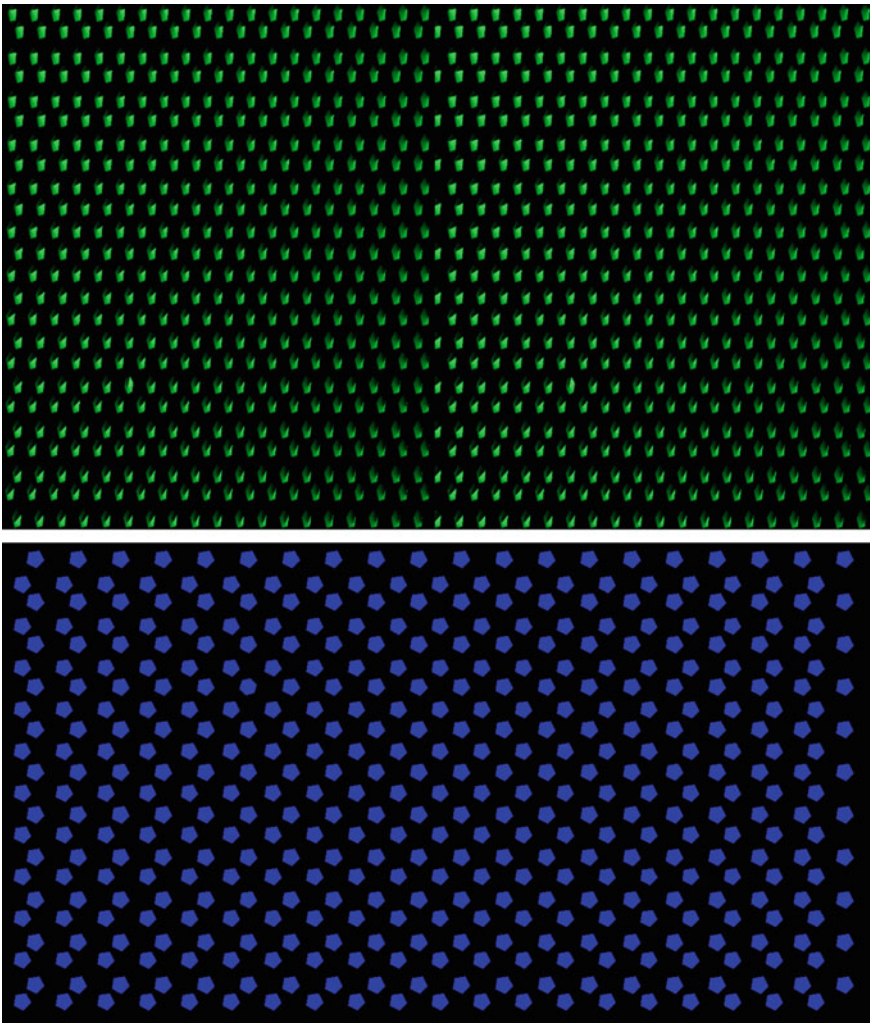

Fig. 1 Experiment pictures. The above picture is the *green* 3D picture, and the under picture is the *blue* 2D picture

By the E-prime software, the stimulus pictures were presented and the time of visual search time and the accuracy data of the every trial was recorded in the software. The experiment task was carried out in two kinds of 47-inch LED screen televisions and their matching 3D glasses, which one is 3D polarization TV and the other is 3D switch TV. The resolutions of all the display terminals were 1280×768 and their refresh rates were 60 Hz. The image mode of all the LED televisions sets exactly the same standard mode. Moreover, the Dell workstation host computer was connected with the LED by a data line. Participants were asked

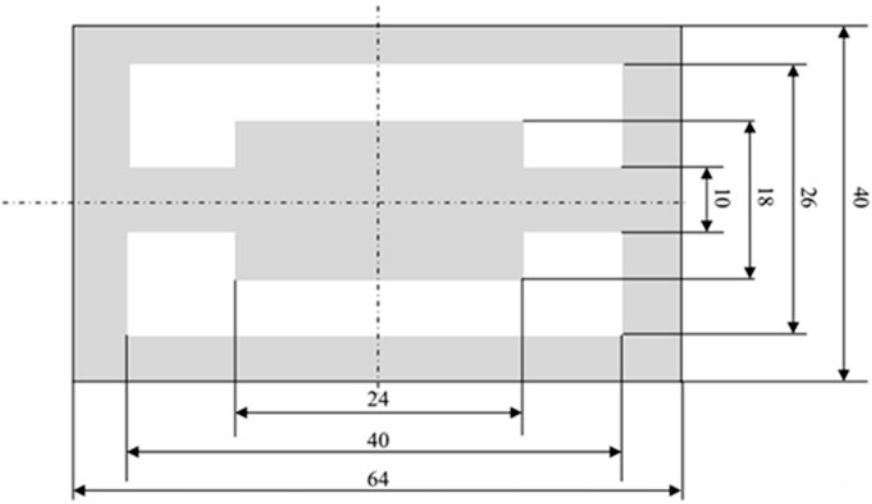

Fig. 2 The area that the target did not appear in each task

to seat on an adjustable chair before the screen at a distance of 2500 mm. The height of the chair was adjusted so that the participants' eyes were at the same height as the center of the screen.

2.3 Procedures

Experiments were conducted in a quiet laboratory environment that simulated home condition. It was installed in Human Factors and Ergonomics lab in China National Institute of Standardization. The visual search tasks were displayed on the LED TVs. After arriving at the laboratory, participants signed the informed consent and completed a general survey about their demographic information about name, sex, age, education, eye health condition, etc. Participants were asked to sit into the simulator to get ready for the test. First, the experimenter explained the procedure of the experiment and showed how to do the experiment task. Then participants began practice trials under the instructions of the experimenter to ensure participants understand the instruction and conduct the visual search task correctly. The practice trials were the same as the actual experiment trials except that there was no time pressure. If participants do not know the experimental process, then let him/her do practice again until him/her do practice proficiency. Then, they entered the formal experiment. Before each task, there was a red dot on the center of the screen. Participants were required to gaze at the dot and then clicked any key after which the task interface appeared. Once the target was found, the participants were required to click any key. Then a dialog appeared to let the participants choose the direction of

the target's location (i.e. upper left, upper right, lower left or right under) by click the direction key. There were 6 groups of experiment trials in one single display to complete, and there was a five minutes break between each group. After completing the visual searching task, the participants were required to fill out the visual fatigue questionnaire. The same procedures have done on each displays. In order to avoid the impact of visual fatigue on the experimental results, the participant were asked to complete the experiment for two times, that is, one time was for completing one display test, the other time was to complete another display test, and the test order was balanced. Moreover, in each display testing, participants need to complete different color 2D and 3D image searching task and the presentation order of different color 2D and 3D image were balanced in different displays.

2.4 Data Analysis

The changes value of visual search and visual fatigue data was analyzed by IBM SPSS 20 Statistics software (IBM-SPSS Inc. Chicago, IL). The method of repeated-measure ANOVA analysis and t test were applied to the experiment data. The experiment was comparing the differences of 3 factors from 3 quantitative indicators, namely: search time, response accuracy and subjective report data. In the subsequent sections, P was test significance. When the significance standard was 0.05, P was less than 0.05, the results are obvious, and otherwise, they are not.

3 Results and Analysis

3.1 Visual Research Time

With regard to the search time, a repeated-measure ANOVA was applied to the search time data of the different conditions, a significant main effect of 2D/3D factors was found ($F(1,15) = 213.43$, $P < 0.001$), the main effect of displays was not significant ($F(1,15) = 0.73$, $P = 0.405$), and there was no significant interaction, $F(1,15) = 1.45$, $p = 0.248$. It indicated that under the 2D/3D search environment, search time was obviously difference, but it was no variation on various TV displays. The T test analysis showed that the average search time under 2D environment (41898 ms) was remarkably longer than the search time under 3D environment (6674 ms), $t(15) = 14.609$, $P < 0.001$ (see Fig. 2). The average search time of switch display under 3D environment was 6483 ms, and that of the polarization displays was 6866 ms, the result of T test analysis was $t(15) = 0.744$, $P = 0.468$; and under 2D environment, the former was 43384 ms,and the latter was 40314 ms, the result of T test analysis was($t(15) = 1.035$, $P = 0.317$). So it further showed that there was no significant difference whatever under 2D or 3D visual

Table 1 Comparison of averages and standard deviation about search time among different conditions

Types		Search time	Standard deviation
Switch display	3D	6483.38	449.86
	2D	43483.56	3117.32
Polarization display	3D	6866.19	524.90
	2D	40314.27	2819.68

search environment. The results indicate that there was no difference for various displays under the different search environment of 2D and 3D. Comparison of average search time under different conditions was as follows (see Table 1):

3.2 Accuracy

A repeated-measure ANOVA was applied to the search accuracy data of different conditions, a significant main effect of 2D/3D factors was found ($F(1, 15) = 5.76$, $P < 0.05$), and the main effect of displays was not significant ($F(1, 15) = 0.628$, $P = 0.441$), and there was no significant interaction, $F(1, 15) = 0.73$, $p = 0.407$. The results indicate that there was significant difference in search accuracy data under the 2D/3D search environment, and there was no significant difference of the search accuracy on different 3D displays. Further T test analysis showed that the average search accuracy under 2D environment (0.93) was remarkable lower than that of the 3D environment (0.96), t (15) = 2.40, $P = 0.030$ (see Table 2). Under 3D environment, there was no significant different between the average search accuracy of switch display(0.96) and that of the polarization display (0.96), t (15) = 0.094, $P = 0.923$; and there was also no environment under 2D environment between the Switch display (0.94) and the polarization display(0.92), $t(15) = 1.195$, $P = 0.238$. It indicates that no matter under the 2D or 3D visual searching circumstance, there is no significant difference. The results show that there was different about the search accuracy indicator between 2D and 3D search environment, but there was no difference about the search accuracy indicator between the two kinds of displays.

Table 2 Comparison of averages and standard deviation about response accuracy among different conditions

Types		Search time	Standard deviation
Switch display	3D	0.961	0.007
	2D	0.936	0.021
Polarization display	3D	0.960	0.013
	2D	0.917	0.022

3.3 Subjective Report

There were two sections of subject report data. The first part was visual fatigue, which including 9 aspects, namely eye burning, ache, strain, irritation, tearing, blur, double vision, dryness and headache, and the other part was comfort data, it contained evaluation of 4 aspects, namely task comfort, glasses comfort, difficulty of visual searching task and total satisfaction about the displays.

Visual Fatigue. The visual fatigue data was get by averaging the nine aspects of visual fatigue. A repeated-measure ANOVA was applied to the visual fatigue data of different conditions, a significant main effect of 2D/3D factors was found ($F(1, 2) = 17.997$, $P < 0.001$), and the main effect of displays was significant ($F(1, 2) = 5.066$, $P = 0.040$), and there was no significant interaction, $F(1, 2) = 0.128$, $P = 0.726$. The results showed that the degree of visual fatigue feeling under two visual search environment 2D and 3D was remarkable significant, and there was significant different subjective visual fatigue feelings on different displays. The planned comparisons revealed that the subjective visual fatigue of 2D visual search environment (34.5) was remarkable higher than that of 3D visual search environment (21.5), so it mean that the subjective visual fatigue feeling of 2D environment was far higher than the 3D visual fatigue. Furthermore, the visual search time of 2D environment was longer than that of 3D environment. When subjects finished visual search tasks on switch display, their subjective visual fatigue feeling value was 31; but when they finished the tasks on polarization display, they reported that the subjective visual fatigue feeling value was 25. Therefore, it indicated that a greater degree of visual fatigue feeling was caused by switch display. The subjective visual fatigue feeling values of different conditions were shown in the follow table: (Table 3).

Comfort. The comfort data was get by averaging the comfort values of task comfort, glasses comfort, visual comfort, visual searching task difficulty and total satisfaction about the displays (values of visual search task difficulty was reversed). A repeated-measure ANOVA was applied to the comfort data of different conditions, a significant main effect of 2D/3D factors was found ($F(1, 2) = 35.487$, $P < 0.001$), and the main effect of displays was significant ($F(1, 2) = 15.604$, $P < 0.001$), and there was no significant interaction, $F(1, 2) = 0.665$, $P = 0.428$. The results showed that under 2D and 3D visual search environments, subjects' subjective comfort feelings were different, and their subjective comfort feelings about various displays were different too. The planned comparisons revealed that the subjective comfort feeling value of 3D visual search environment (40.5) was

Table 3 Comparison of averages and standard deviation about the subjective visual fatigue feeling values among different conditions

Types		Visual fatigue	Standard deviation
Switch display	3D	25	13.40
	2D	37	17.54
Polarization display	3D	18	12.57
	2D	32	17.40

Table 4 Comparison of averages and standard deviation about the subjective comfort feeling among different conditions

Types		Comfort	Standard deviation
Switch display	3D	36	9.89
	2D	18	14.10
Polarization display	3D	45	12.92
	2D	31	16.83

significantly higher than that of 2D visual search environment (24.5). Therefore, it showed that the visual search task under 3D visual environment was more comfort than that of 2D visual environment, and visual search time of 2D visual search environment was longer than that of 3D visual search environment. On switch display, the subjective comfort feeling of visual search task was 27, and that of the visual search task on polarized display was 38. Therefore, it mean that subjects' subjective comfort feeling of polarized TV display was higher than that of the switch display. The contrast about subjective comfort feeling of different displays and 2D/3D was as shown in Table 4:

4 Conclusion

The research mainly tested subjects' visual search performance and subjective feeling of two indicators from two aspects about display types and 2D/3D visual environment. The statistical analysis results showed that there were significant differences of visual search task performance (search time and accuracy) between 2D and 3D visual environment, which the visual search performance of 3D visual environment was significantly higher than those of 2D visual environment. Therefore, it mean that the visual search tasks of 3D environment were finished quickly and accurately than those of 2D environment, and the different 3D displays did not affect the same visual search task performance. From the subjective feeling results, there were significant differences about subjective feeling (such as visual fatigue, comfort and satisfaction) of 2D and 3D visual search task. The planned comparisons showed that the subjective feeling of 3D environment was much better than that of 2D environment, and the subjective visual fatigue feeling degree of 3D environment was lighter and the evaluation of 3D environment was comforter than 2D environment. The subjective feeling of polarized 3D TV display was better than that of the switched 3D TV display. What's more, the degree of subjective visual fatigue and comfort feeling of polarized displays was better than switched 3D displays. The study provided the evidence that 3D visual search performance was better than 2D visual search performance, and meanwhile, it proved that different 3D display manufacturing technologies from different manufacturers did not affect the visual search performance, but it might affect the user's subjective visual fatigue and comfort feeling.

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