Analysis of Simulator Sickness and Performance in Virtual Training

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Abstract. Simulator sickness is inevitable during virtual training. At the process of missile lifting task, the problem “how long and how to train” is presented in virtual training of troop, crossed and uncrossed parallax stereoscopic display are set up as different virtual training environment. To analysis the change rules of sickness and performance along with time and different parallax types, subjects are asked to operate the box loading vehicle for 1 hour, and the score of simulator sickness questionnaire is recorded every 10 minutes. The result shows performance is better in crossed environment than which in uncrossed. There is no significant difference in operational performance over time; all subjects feel slight simulator sickness after 10 min training and obvious feeling after 30min. Suggestions are proposed that virtual training should be in crossed parallax environment and keep in 30 min.

1. Introduction

With the development of virtual reality technology, virtual training has attracted widely attention in military, traffic, medical treatment, entertainment and education owing to its safety and economy. Virtual training plays an important role due to the strict security requirements and exorbitant fees of actual military equipments. Virtual training has many advantages, and also many problems, of which the most common is simulator sickness. Exposed in 3D virtual environment for a long time will lead people to dizziness, vertigo, nausea, vomiting and other symptoms of motion sickness, called simulator sickness.

In most cases, people have a better performance of location estimation, object recognition, spatial memory etc. in the 3D virtual environment than in 2D[1], but it will cause more visual fatigue[2]. Continuous operating in the virtual environment, operational performance will decline with the onset of simulator sickness[3-4], the human body will be damaged. Article [5] shows that when keep driving operation on the car simulator for 10 minutes, the participants will feel sick and the operating performance will decrease significantly. If exposed to virtual 3D environment for more than 1 hour, human eye will gradually adapt to the contradictions between regulation effect and convergence effect, resulting in esotropia[6], although it helps to adapt to the virtual environment, it is harmful in the real environment.

For 3D virtual display, many researches focus on visual fatigue and comfort. The study on virtual training also focuses on the performance and despise fatigue, which can not guide the practice of "how long and how to practice" in virtual training. In this paper, we study the relationship between operational performance and simulator illness in different parallaxed (cross and non-cross) virtual 3D
environment, and find the best virtual training duration and training method under the condition of simulator illness disturbance.

2. Causative factor analysis of simulator sickness

Domestic and overseas scholars have done a lot of researches from the aspects of visual imaging principle, EEG, virtual object movement about the causative factor analysis of simulator sickness[5,7,8], one of the most important factors is contradictions between binocular regulation and convergence[6,7,9,10,11]. More than 80% of external information is received by eyes, and about 90% of the brain energy is used to deal with external information and form awareness[12], article [13] argued that the nature of stereopsis fatigue is the brain fatigue caused by brain cognitive overload. When human sensory conflict exceeds the body central physiological tolerance limit, it will lead to a series of vegetative nervous disorder, resulting in a variety of short-term symptoms[7], that is, simulator sickness.

In addition, simulator sickness is also associated with a variety of factors: The ability of people to perceive the depth information of objects is different, there are about 12% of people who are weaker in the depth perception[14]. Individuals with better stereo vision ability will have better performance in the virtual environment, but more likely to emerge symptoms of simulator sickness [10], and similarly, the elder are less likely to emerge symptoms of simulator sickness than young people because of eye movement system recession [15]; article [16]shows that the faint shaking of virtual images caused by head shaking will lead to adverse reactions in human body. The sensitivity of different gender to simulator sickness is also different, and women are more likely to feel discomfort in virtual environments [10, 15, 17]; human reading speed and object recognition ability are better in a bright virtual environment than low-brightness environment[18]. Parallax variation frequency can affect visual fatigue more than parallax size, vertical movement of virtual image is more likely to cause fatigue than horizontal movement. Distance is also an important factor, it is comfortable to watch 3D TV when viewing distance is 3 times as large as the screen height[6]. Besides these reasons, simulator sickness is also affected by a number of equipment factors. At present, 3D display technology is varied, the most widely used is the optical perspective helmet display (HMD), computer screen display and projection display. Among them, helmet display technology is the earliest and has been widely used in various virtual reality (VR) fields, such as virtual maintenance and fault diagnosis. But researches show that helmet display is the most likely way to cause visual fatigue[19]. Computer screen display, such as 3D TV, is the most closest to the civilian, but 3D immersion is not as good as the other two ways and cannot give a good solution to the problem of visual fatigue, this technology has not been applied widely; projection stereoscopic display technology is most likely to achieve, such as 3D movie, but is susceptible to the polarized glasses. In addition, the images mutual crosstalk between left and right eye, screen resolution, image delay, flicker, etc. can also lead to visual fatigue.

3. Stereo vision and the virtual stereo vision

We can see the three-dimensional views, the most important foundation is physical structure of the eyes. When observing the same object there will be a slight angle difference due to the distance between two eyes, the retina will receive the same object with two different images, and then the brain will integrate two different images into a stereoscopic vision, form three-dimensional visual perception.

Depth perception of objects in stereoscopic vision is mainly determined by the parallax. As shown in Figure.1, assuming M is the fixation point, the M point is clearly imaged by the cooperative action of binocular regulation and convergence, although point A and point B (farther away from the fovea) is not clear, it can still be imaged. In order to see objects clearly, eyes will adjust the refractive power, it’s known as regulation effect, refers to the phenomenon of adduction or extorsion of both eyes when looking near or distant targets[9]. View angles form the basis of depth perception, and the angle difference between them is called parallax, when $\alpha - \beta > 0$, it is called cross parallax; $\gamma - \beta < 0$, it is called uncross parallax.
Figure 1. Crossed and uncrossed parallax

We do not notice unclear objects beyond the eyes focus because our eyes move continuously at a speed of 3 times per second, putting focus on the surrounding environment objects selectively. In this case, the regulation and convergence effect of eyes is consistent, namely the adjustment will increase along with the increase of convergence, decrease with the decrease of convergence. But in the virtual environment, adjustment and convergence will appear inconsistent in some cases. The principle of virtual 3D vision is the two cameras show different images to left and right eyes respectively in order to meet the three-dimensional visual perception. Finally, the image will be displayed on the screen, in order to see the image, the eyes will focus on the screen, but the virtual 3D object is presented in front of the screen or behind the screen, convergence located on the virtual 3D Object. In Figure. 1, we assume that point M is the screen position, A and B is the virtual 3D object, and the accommodation acts at point M, the converge acts at point A or B. Therefore, there is a phenomenon of inconsistent between regulation and convergence, leading to visual fatigue.

Studies have shown that cross parallax causes more visual fatigue than uncross parallax[20]. However, some studies have also shown that the effects of different parallax types have no significant differences[21]. There is few studies focus on the effect of different parallax types on operational performance. Article [22] argued that cross-parallax can stimulate people's stress reaction and raise the cortical arousal level to pay more attention to virtual scene, but whether this can improve operational performance need further research.

The movement of virtual objects includes two-dimensional motion and depth motion, depth motion refers to movement that virtual object close to or away from the observer, depth motion is more likely to lead to visual fatigue than two-dimensional motion, and the faster the speed of depth movement, the easier the eyes feel fatigue[9,14], fast depth motion means the rapid change of the parallax, and the rapid change of parallax and frequent change in the direction of depth movement are easy to cause visual fatigue[6]. Research [23] shows that the comfortable scope for parallax is 35' - 40', and when the variation exceed 1 degrees, it will be unbearable. In this paper, we take virtual training system of box loading as background and focus on the depth of movement.

4. Virtual training experiment

4.1. Subjects
Subjects are eight male soldiers, corrected visual acuity were 1.0 or more, at the age of 22 to 23, scatter plot stereoscopic examination shows that subjects have passed the 60 "parallax test, belonging to the normal parallax crowd. Before the experiment, all participants have involved in different missile lifting training with actual equipment, but haven’t operate in the simulator before, all subjects can be regarded as novice.
4.2. Experiment design

Optoma LC1 stereoscopic projector matched with stroboscopic polarized glasses is used in the experiment. The distance between subjects and the screen is 2.5m, and the sight distance between subjects and the virtual equipment is set as 10m. The projection area is shown in Figure 2, taking the eye spacing of 0.06m as the benchmark, the maximum parallax of 3D virtual image is 5.5 degrees, the minimum is 0, maximum speed of swing arm is 9 degrees per second, and the maximum parallax change rate is about 0.04 degrees per second by calculation.

Figure 2. Sketch map of virtual images

Subjects were asked to hoist the missile launch box from one vehicle to another vehicle. During the hoisting process, the main task of the participants was to control the crane to place the hook in the specified position, and the auxiliary staff would perform the grasping operation. The experimental performance index is the depth error between the position of the parking hook with the standard position, as shown in Figure 3.

Figure 3. Schematic map of depth deviation counting

When training for ten minutes, pause for one minute to conduct Simulator Sickness Questionnaire (SSQ). The questionnaire was mainly used to check the adverse symptoms of the subjects, includes nausea, Ophthalmic discomfort, lost direction, and further refined into 16 kinds of index, each index has 4 different degrees (no, mild, moderate, severe), corresponding to the weight coefficient from 0 to 3 respectively, the indexes and weights shown in Table 1, The final score is calculated as a weighted sum of two weights.
### Table 1: Details of simulator sickness questionnaire

| number | index | Nausea(N) | Ophthalmic discomfort(O) | Lost direction(D) |
|--------|-------|-----------|--------------------------|------------------|
| 1      | General discomfort | 1 | 1 | 0 |
| 2      | Fatigue | 0 | 1 | 0 |
| 3      | Headache | 0 | 1 | 0 |
| 4      | Visual fatigue | 0 | 1 | 0 |
| 5      | Difficulty focusing | 0 | 1 | 1 |
| 6      | Salivation increase | 1 | 0 | 0 |
| 7      | Sweating | 1 | 0 | 0 |
| 8      | Nausea | 1 | 0 | 1 |
| 9      | Difficulty concentrating | 1 | 1 | 0 |
| 10     | Fullness of the head | 0 | 0 | 1 |
| 11     | Blurred vision | 0 | 1 | 1 |
| 12     | Dizziness eyes open | 0 | 0 | 1 |
| 13     | Dizziness eyes closes | 0 | 0 | 1 |
| 14     | Vertigo | 0 | 0 | 1 |
| 15     | Stomach awareness | 1 | 0 | 0 |
| 16     | Burping | 1 | 0 | 0 |

Score

A = N × 9.54
O = B × 7.58
D = C × 13.92

Simulator sickness degree = (A + B + C) × 3.74

Each experiment was conducted for 1 hour, with an SSQ test and an error recorded every 10 minutes. 4 people were asked to take part in cross-parallaxed (animation out the screen) experiment, and the other 4 were asked to take part in uncross-parallaxed (animation in the screen) experiment. During the experiment, keep the curtain closed, to prevent the background light from affecting the experiment.

5. experiment results and analysis

5.1. Experiment results

The average operational error of 8 subjects is shown in Figure 4. The degree of simulator sickness is shown in Figure 5 and Figure 6.
As shown in Figure 4, Operational performance of cross-parallax and uncross-parallax is significantly different. Analysis of variance shows that there is no significant difference between four subjects in two groups (Fin (3, 20)=0.547, P=0.655; Fout (3, 20)=0.728, P=0.547), the operational performance in two groups has no significant difference over time (Fin(5, 18)=1.49, P=0.241; Fout(5, 18)=0.926, P=0.487). There are significant differences in the operational performance of the two groups (F(1, 46)=86.0, P<<0.01).

The longer the training time, the higher the SSQ scores of the eight subjects, that is, the simulator sickness became more and more serious. The analysis of variance shows that the time effect of SSQ scores is significant (Fin(5, 18)=24.973, P<<0.01); Fout(5, 18)=18.212, P<<0.01). ANOVA of SSQ scores between animation in and out at different timing are shown in Table 2. We can see that there are no significant differences in two groups at all timings.
Table.2 ANOVA of SSQ scores between animation in and out the screen at different timing

| Timing (Min) | F(1, 6), | P  |
|--------------|----------|----|
| 10            | 0.711    | 0.431 |
| 20            | 0        | 1   |
| 30            | <0.001   | 1.0 |
| 40            | 0.760    | 0.417 |
| 50            | 2.288    | 0.181 |
| 60            | 1.130    | 0.329 |

After training for 10min, there were two in cross-parallaxed experiment, one in uncross-parallaxed experiment appeared the symptoms of lost direction such as head bilge and vertigo. After training for 20min, all subjects appeared the symptoms of lost direction, two subjects appeared ophthalmic discomfort symptom in each group. After training for 30 min, only one subject didn’t appear ophthalmic discomfort. 50 min later, there is one subject appeared nausea symptom (sweating) besides lost direction and ophthalmic discomfort.

5.2. Experiment analysis

Although the virtual training of cross-parallax and non-cross-parallax increases visual fatigue with training time, the effect of the two types of parallax on operator fatigue is not very different, which is consistent with the conclusion of article [20], and inconsistent with article [21]. Experiment simulate the real load training process, the emphasis is focused on the analysis of the effects of different types of parallax on the fatigue of virtual training, so the maximum rotational angular velocity of the boom is set at a slower value (9°/s) for real safety reasons. So for the operator, the two main factors (parallax amplitude and parallax change rate) that affect the simulator sickness are invariant in the two groups and the main operating area is set in the proposed comfort range. The results show that the effect of parallax type on the fatigue of virtual training is not significant.

There is significant difference in the operation performance of two groups. The article [22] suggests that the human eye is much more sensitive to 3D effects in cross parallax than uncross parallax, which can be interpreted as cross-parallax makes people feel more immersed, that is, people in a virtual environment mentally while the body is in real environment[24]. Some researches show that the enhancement of immersion can improve the emotional arousal level and it will further improve the operational performance [24], but it will increase more fatigue[15].

6. Conclusions

In this paper, the following conclusions are obtained by setting up the virtual training of cross parallax and uncross parallax:

(1)In the process of virtual training, the training time has great influence on fatigue of the trainee. Although the operating performance will not be reduced significantly after 30 minutes, fatigue will increase rapidly due to simulator sickness. Mild degree simulator sickness takes 1 to 2 hours to disappear gradually, and there are extreme cases need 48 hours to eliminating [25]. So it is suggested that the virtual training time is less than 30min.

(2)Cross-parallax makes people feel more immersed. In this paper, we focus on the effect of depth motion of virtual objects on operation performance and fatigue. In order to achieve better training effect, stereo vision should be set as cross parallax in virtual training with a large number of depth motion.

At present, the influence of the parallax amplitude and parallax change rate on the fatigue and the operation performance in the 3D virtual environment is a hot research topic. Because of the large number of simulation diseases, the various hardware devices, the experimental variables are difficult to control, and the experimental research background is different, resulting in a lot of uniform conclusions. In this paper, there are some variables do not be effective controlled, such as the
environmental brightness is controlled by closing the curtain in natural light conditions, and experiment takes the loading process of a certain kind of box as background, which is highly targeted, universality needs to be further studied.

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