Research on the Cabin’s Local Orientation Cues of Space Station Oriented to Navigation Enhancement

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Abstract. The large and complex interior space of multi-cabin space station makes the astronauts easily happened to navigational disorder during the travel. With the need to enhance the navigation ability of the astronauts, based on a method study on space station intra-vehicular navigation simulation including both VR visual simulation and physiological HDBR simulation, multiple different sets of sample scenes are designed for the axial orientation cues of non-node cabin and the local orientation cues of node cabin. Through the experimental data analysis, the influence law of the cabin’s local orientation cues of the space station on the navigation task performance and related physiological effects in the cabin are obtained.

1. Introduction

The multi-cabin space station has a complex three-dimensional axial space structure, and the astronauts are prone to navigation problems in the cabins, the astronauts mainly use visual cues to conduct space navigation [1], one of the visual environmental factors affecting intra-vehicular navigation is the whole station’s interior orientation cues. In this article, the whole station’s interior orientation cues refers to the orientation information which is provided by the various elements in the environment, especially the elements that are composed and implied in the space station interior, one of which is the cabin’s local orientation cues, mainly refers to local visual vertical cues and axial orientation cues in the cabin.

In 2001, NASA planned the interior colors of American cabin on the International Space Station in the <International Space Station Interior Color Scheme>, clearly pointing out the main purpose was to provide visual orientation cues [2]; In 2010, NASA proposed that establishing a stable cabin local visual vertical orientational clue could shorten the adaptation time of spatial orientation [3]; in addition, the stable cabin’s local visual vertical orientation cues has been used as the default condition in the intra-vehicular navigation related research [4-7].

It can be seen that, NASA has formed a relatively complete solution through relevant documents and practical applications for the non-node cabin’s local visual vertical orientation cues. However, for the non-node cabin’s axial orientation cues and the node cabin’s local orientation cues, the current approach adopted by NASA is relatively single and lacks relevant basis. Therefore, based on a system of space station intra-vehicular navigation simulation including both VR visual simulation and physiological HDBR simulation, this paper studies the influence law of the non-node cabin’s axial orientation cues and the node cabin’s local orientation cues on the intra-vehicular navigation task.
performance and associated physiological effects, thus to provide an effective reference for enhancing the intra-vehicular navigation capability of astronauts.

2. The space station intra-vehicular navigation simulation system

In related studies, the VR simulation method is used to simulate the astronauts’ visual navigation in multi-cabin space station’s interior [4-7], and the physiological HDBR simulation is a mature method for simulating physiological effects of weightlessness [8-9], therefore the VR visual simulation and physiological HDBR simulation are combined as the space station intra-vehicular navigation simulation system, as shown in Figure 1. This system is composed of the graphics workstation computer 1, the wide-field head-mounted display 2, the three-dimensional mouse 3, and the angle adjustable experimental bed 4.

![Figure 1. Schematic diagram of the space station intra-vehicular navigation simulation system](image)

The simulation system’s scenario of the virtual space station refers to the structure of the international space station and is slightly modified, as shown in Figure 2. The virtual space station consists of two cubic node cabins (Node1, Node2) which are 2×2×2m^3 in size and seven rectangular non-node cabins which are 2×2×6m^3 in size. The interior surface of the cabin is mapped with pictures of the international space station interior, each cabin is distinguished by different visual signs and given unique name.

![Figure 2. Virtual space station scenario](image)

The layout and visual signs of the space station cabin remain unchanged but the internal visual design is different. The whole orientation cues in the interior decoration of each cabin are arranged in the gap position of the wall cabin.

3. The experiment

3.1. The experimental subjects

A total of 60 (18-28 years old) subjects participated, all without visual or auditory impairment. The subjects were asked to participate in the mental rotation test and visual rotation ability test before the experiment. All the subjects were divided into 6 groups, with 10 people in each group. The distribution of gender and test scores in each group of subjects was balanced.
3.2. The experimental process

3.2.1. The preparation stage of experiment. The subjects were placed on a supine position with the -6° head-down posture and wore a wide-view helmet-mounted display, kept this pose for a period of time; then, the simulation program of the virtual multi-cabin space station scene in the graphics workstation was started. The subjects operated the three-dimensional mouse to realize the roaming in the multi-cabin space station and to check the equipment availability.

3.2.2. The navigation training stage of experiment. In the training part, the subjects firstly followed the simulated astronauts walking along nine preset path in the space station, they went through three rectangular cabins and two node cabins that required the observation orientation of the subjects be consistent with the simulated astronaut. The subjects secondly passed through each cabin of the virtual space station, they must used the keyboard or handle to switch the orientation to complete the corresponding task. The subjects were asked to select one of all the paths on the screen and to go to the cabin on their own under the guidance of the simulated astronaut. After reaching the destination, the subjects needed to return to the starting point, if it was wrong, they were asked to try it again. The subjects visited each cabin three times (except for the American laboratory in the middle of the space station—all paths would pass through it).

3.2.3. The navigation testing stage of experiment. In the testing part, the subjects were asked to perform orientational and path-finding task, they were asked to indicate the orientation of their destination firstly, then to move as fast as possible to complete the path-finding task, and then to indicate the location of the starting point. There were two parts in this testing part, and each part had 9 tests. In each test, the wrong type r indicating the orientation, the response time indicating the destination and the operation time of completing the evacuation task were recorded. In the orientational task, if the orientational was correct, r=r0; or else r=r1.

In addition, the subjects were asked to dictate oral the space station cabin layout after the completion of all tasks, the staff drew a virtual space station layout map according to the description of the subject and confirmed with the subjects whether it matched the description, the error type e in this layout was recorded. If it was exactly true, e=e0; if the cabin sequence (structure) described by the subjects was correct, but the cabin interior orientation was wrong, e=e1; if the cabin sequence (structure) was wrong, e=e2.

In the process of simulated navigation and autonomous navigation, the head of the subjects received EEG continuous real-time monitoring on the head. Before and after the experiment and related nodes, they also received the head resting FMRI scan to obtain the objective information of the physiological state of the brain. Finally, the staff also asked and recorded the symptoms of motion sickness such as dizziness during the experiment.

3.3. The design of experimental sample scenes

3.3.1. Sample scene design of the non-nodal cabin’s axial orientation cues. Three sets of sample scenes were designed, and each group showed different setting strategy for the non-node cabin’s axial orientation cues, as shown in Figure 3. The C1 scheme reflected the absence of any non-node cabin’s axial orientation cues setting strategy, the C2 scheme reflected the node cabin’s landmark setting strategy, and C3 reflected the whole orientation setting strategy. Before the experiment began, the subjects were informed of the orientation meaning represented by every setting strategy of the non-node cabin’s axial orientation cues.

3.3.2. Sample scene design of the node cabin’s orientation cues. Three sets of sample scenes were designed, and each group showed different setting strategy for node cabin’s orientation cues. The D1 scheme reflected the absence of any node cabin’s orientation cue setting strategy, the D2 scheme
reflected the node cabin’s vertical orientation cues setting strategy, and D3 reflected the node cabin’s axial orientation cues setting strategy. Before the experiment began, the subjects were informed of the orientation meaning represented by every setting strategy of the node cabin’s axial orientation cues.

![Figure 3. A sample scheme showing different non-node cabin’s axial orientation cues setting strategies](image)

3.4. The experimental results and analysis

3.4.1. The experimental results of the sample scenes which reflect the non-nodal cabin’s axial orientation cues. Through the statistics of the obtained experimental data, we can obtain the comparison chart of the accuracy rate of orientational task, the average time of path-finding task, the accuracy rate of psychological map task and the proportion distribution of symptoms of motion sickness for different sample scenes which reflect the non-nodal cabin’s axial orientation cues.

![Figure 4. Comparison of the accuracy rate of orientational task for different samples](image)

In Figure 4, the accuracy rate of orientational task corresponding to C1 (no setting) was significantly lower than others (P<0.05); the accuracy rate of orientational task corresponding to C2 (cabin landmark setting) was significantly higher than C3 (whole orientation setting) (P<0.05).

![Figure 5. Comparison of the average time of path-finding task for different samples](image)

In Figure 5, the average time of path-finding task corresponding to C1 (no setting) was significantly higher than others (P<0.05); the average time of path-finding task corresponding to C2 (cabin landmark setting) was significantly lower than C3 (whole orientation setting).
Figure 6. Comparison of the accuracy rate of psychological map task for different samples

In Figure 6, the accuracy rate of psychological map task corresponding to C1 (no setting) was significantly lower than others (P<0.05); the accuracy rate of psychological map task corresponding to C2 (cabin landmark setting) was significantly higher than C3 (whole orientation setting) (P<0.05).

Figure 7. Comparison of the proportion distribution of symptoms of motion sickness for different samples

In Figure 7, there was no significant difference in the proportion of mild, moderate and severe motion sickness symptoms in all samples.

Conclusion and analysis: compared with the situation of no local cabin’s orientation cues, the setting of the non-node cabin’s axial orientation cues can improve the navigation task performance to some extent, but the symptoms of motion diseases such as dizziness have not been significantly improved; the setting strategy of the node cabin’s landmark can improve the navigation task performance more effectively than the whole orientation cues.

3.4.2. The experimental results of the sample scenes which reflect the node cabin’s orientation cues.

Through the statistics of the obtained experimental data, we can obtain the comparison chart of the accuracy rate of orientational task, the average time of the path-finding task, the accuracy rate of psychological map task and the proportion distribution of symptoms of motion sickness for different sample scenes which reflect the node cabin’s orientation cues.

In Figure 8, there was no significant difference in the accuracy rate of orientational task in all samples.

In Figure 9, there was no significant difference in the average time of path-finding task in all samples.

In Figure 10, there was no significant difference in the accuracy rate of psychological map task in all samples.

In Figure 11, there was no significant difference in the proportion of symptoms of mild, moderate and severe motor diseases in all samples.
Figure 8. Comparison of the accuracy rate of orientational task for different samples

Figure 9. Comparison of the average time of path-finding task for different samples

Figure 10. Comparison of the accuracy rate of psychological map task for different samples

Figure 11. Comparison of the proportion distribution of symptoms of motion sickness for different samples

Conclusion and analysis: compared with the case of no cabin’s local orientation cues, the setting of the node cabin’s vertical orientation cues or axial orientation cues can not significantly improve navigation task performance or symptoms of motion sickness.
4. Conclusion
With the need to enhance the navigation ability of the astronauts, based on a method study on space station intra-vehicular navigation simulation including both VR visual simulation and physiological HDBR simulation, multiple different sets of sample scenes are designed for the axial orientation cues of non-node cabin and the local orientation cues of node cabin. Through the experimental data analysis, the influence law of the cabin’s local orientation cues of the space station on the navigation task performance and related physiological effects in the cabin are obtained. The research could provide reference for the space station interior design engineering in the orientation of the cabin visual navigation capability.

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