Overview of research on the application of virtual reality to spatial cognitive ability

An Bao, *Qiang* Wei*, and *Y*an Sun

Jianghan University, 430056 Wuhan, China

Abstract. The experimental environment created by the virtual reality technology for the Spatial Cognitive Ability Research Institute cannot be replaced by the traditional experimental environment. Given this, this study reviews the research on spatial cognitive ability using virtual reality technology from the aspects of concept development and application category of virtual reality spatial cognitive ability. On this basis, this study summarizes the shortcomings of current research and proposes the direction of future research to provide ideas and references for researchers of spatial cognitive ability of virtual reality.

Keywords: Spatial cognitive ability, Virtual reality, Spatialorientation capability, Spatial visualization capability.

1 Introduction

1.1 Spatial cognitive ability and virtual reality technology

Spatial cognitive ability refers to people's ability to encode, represent, store, recognize, combine, decompose, summarize, and abstract objects or spatial graphics in their minds[1]. Cognitive ability is the main component of people's intelligence. Many scholars who study spatial cognitive ability believe that spatial cognitive ability is not a single skill, but is composed of many factors[2]. Different scholars hold different views on the constituent elements of spatial cognitive ability in academic circles.

So far, the constituent elements of spatial cognitive ability have not been discussed clearly. Some parts of spatial cognitive ability can be verified by testing methods, but no unified conclusion has been reached. At present, the recognized and widely studied elements of spatial cognitive ability are spatial orientation ability and spatial visualization ability.

Spatial orientation ability, which is also equivalent to the mental rotation ability referred to by some scholars, refers to the ability to correctly distinguish objects from different angles. Spatial orientation ability includes the ability to understand the arrangement relationship of visual graphic stimulus elements and the ability to maintain correct judgment when the direction changes in the presented spatial configuration[3]. Spatial visualization ability, i.e. spatial representation ability, refers to the ability to visually rotate,

* Corresponding author: 2602093745@qq.com

control, reverse and fold two-dimensional or three-dimensional graphics. It is one of the main components of spatial cognitive ability. Spatial visualization has been widely concerned by researchers in the fields of art design, engineering, mathematics, and other educational fields and professional fields related to flight[4].

Virtual reality (VR) is an immersive interactive environment based on simulation technology, sensing technology, and multimedia computer technology. It is generated by a computer and acts on users through multi-sensory stimuli such as sight, hearing, touch, and smell to provide users with an immersive feeling[5]. Although this virtual situation is generated by a computer, it is also a true reflection of the real situation. VR is the crystallization and reflection of the application of highly developed computer technology in various fields. Its application research covers a wide range of disciplines, including psychology, artificial intelligence, computer science, and so on.

VR has three remarkable characteristics. First, it is immersive. VR enables the experimenter not only to feel the virtual three-dimensional environment visually but also to perceive the simulated real environment in terms of smell, touch, hearing, taste, etc., so that the user can have an immersive feeling in the whole process. The ideal virtual environment should be the reproduction of the real-world environment, which can make people seem to be in the real world. Second, it is interactive. This is the natural degree of users' operability of objects in the virtual environment and instant information feedback to the virtual environment. When users enter the simulation environment, VR enables users to interact with the environment. When users operate, the surrounding environment will also respond. For example, users can touch the table in the virtual environment with their hands and feel the feeling of grasping the table. Third, conceptualization. VR can not only make the experimenter get real experience in the virtual environment, but also give play to the subjective initiative and form new concepts. Using the conception of VR can expand users' spatial cognitive ability, which is of practical significance for their testing and training.

1.2 Putting forward the cognitive ability of virtual space

As the main component of people's intelligence, spatial cognitive ability should have certain spatial knowledge whether in scientific research or daily activities. It is a basic ability to help people adapt to survival. At the same time, it is also a subject of great concern in the field of social spatial cognition.

The research of spatial cognitive ability needs VR technology. At present, the traditional methods used in the study of spatial cognitive ability have low ecological validity, and cannot meet the experimental study of spatial cognitive ability. VR technology can simulate the dangerous, inaccessible, and stressful environments of subjects in real life. In these virtual environments, subjects will have more sense of security and understand that they will not be punished or hurt because of mistakes or improper behaviors. Therefore, subjects may break through the "no" limit in the real environment and have behaviors such as crossing the road. This hasn't been observed using traditional research methods.

In this paper, the spatial cognitive ability developed and designed by using VR technology to assist or replace the traditional paper pen test or physical instrument experimental research is called virtual spatial cognitive ability.

Compared with the experimental research based on traditional paper and pencil tests or physical instruments, the experimental system of virtual space cognitive ability has unique advantages:

First of all, virtual cognition does not have to pay the necessary and tangible material costs. Real cognitive activities always consume a certain amount of physical strength and energy, as well as a certain amount of material, energy, and time. VR technology can complete the process of interaction between substances in the experiment of spatial

cognitive ability research, which can save the material consumption in the experiment process and reduce the cost of cognition.

Secondly, the research efficiency is high. Once the research system of virtual space cognitive ability is set, the experimental parameters can be tested for the same test indefinitely, reducing the impact of the observer and the test environment on the subjects. At the same time, it can flexibly control and quantify the content of the stimulus and the behavioral response of the subjects and can record the relevant duration.

Finally, the cognitive ability of virtual space can realize the communication of distributed collaborative experiments on the research system platform. In this collaborative context, collaborative research, remote experiments, and other operations can be completed.

Therefore, virtualization can not only turn people's imagination into reality but also make the presentation of creation more diversified, which cannot be replaced by the traditional experimental environment. The experiment of virtual spatial cognitive ability can complement the experiment based on physical instruments, and jointly promote the realization of the research goal of spatial cognitive ability.

2 Spatial orientation ability

Spatial orientation is one of the most common spatial cognitive processes in human life, and its application is also the most extensive. The process of spatial orientation involves many cognitive processes, including motion perception, environmental cognition, and spatial information acquisition. Spatial orientation ability is also a basic component of spatial cognitive ability. Some scholars believe that mental rotation ability is equal to spatial orientation ability.

VR technology is a potential and powerful tool for the cultivation and training of spatial orientation ability. Lindeyi et al.[6] studied and tested the effect of VR on the space-based performance training of the elderly. 15 elderly people and 15 college students were selected to participate in the local hospital navigation emergency escape experimental task. The experiment designed three training media: pure VR demonstration, VR plus aerial view demonstration, and traditional 2D map demonstration as repeated measurement factors. The results showed that the older subjects had less advantage in identifying the correct turn leading to the emergency exit. Although it was also found that older subjects had difficulty in remembering route landmarks, for these two age groups, the spatial memory generated by 2D and VR plus aerial view presentation was much stronger than that of pure VR media. When evaluating mental rotation, if the emergency route is demonstrated and trained through VR and VR plus aerial view, the older subjects can achieve considerable performance. The application of VR technology provides an optimistic way for the elderly spatial orientation training, which can exercise their spatial ability confidently.

The neuropsychological evaluation method based on VR technology has high ecological validity and can provide subjects with multi-sensory channel feedback, to realize their daily interaction. The VR environment provides a new possibility for the ecological assessment and rehabilitation training of cognitive impairment of the elderly. Impaired spatial orientation ability often shows topographic disorientation, also known as topographic disorder, which is a common obstacle in patients with nervous system diseases. Morganti et al.[7] studied the virtual maze test, virtual circuit diagram test, and traditional pen and paper test on 10 healthy male subjects and 4 male patients with brain injury. The experimental results show that for all virtual tests, patients need a longer execution time and more errors than healthy subjects.

In a word, VR technology is a potential and powerful tool for the research of spatial orientation ability. It provides an effective way for the cultivation and training of spatial orientation ability and can exercise people's spatial ability confidently. VR technology

solves the interaction problem of traditional experimental neuropsychological evaluation and provides an environment with high ecological validity for the neuropsychological evaluation of spatial orientation ability.

3 Spatial visualization capability

In the research of spatial cognitive ability, the research on spatial visualization ability is more, but the research on spatial visualization using VR technology is less. They mainly study the professional fields related to spatial visualization ability, such as pilots, astronauts, etc.

Many studies have shown that the visualization ability of virtual space can be improved through learning and training, or its decline speed can be slowed down. In terms of occupational characteristics, the decline of spatial visualization ability of professionals who are closely related to spatial visualization ability is slower than that of those who are not engaged. Oman et al.[8] conducted several experiments focusing on the physical orientation problem at the node module of the space station, using a large number of methods of virtual simulation and physical simulation. Under the same experimental conditions, the subjects were trained in physical orientation using a virtual simulation environment. The results show that the subjects with strong spatial visualization ability can achieve better training results than those with weak spatial visualization ability. The application of VR technology in spatial visualization has also been studied in other fields. Luhuaiyu[9] studied the impact of the virtual Lego course on the mental rotation ability and spatial visualization ability of middle school students. The students in Grade 7 of Shanghai school a and school B were taught a 90-minute virtual Lego expansion course once a week, and the number of students should not exceed 30, Before the first and after the last course, the students will be tested for their spatial visualization ability and mental rotation ability. The experiment shows that the students who have studied the virtual Lego course have improved their mental rotation ability and spatial visualization ability to a certain extent.

However, in different research fields, the impact of virtual space visualization ability on performance cannot be agreed. Wangyonggang et al.[10] conducted experiments to explore the changing trend of pilots' safety performance and the relationship between pilots' space capabilities and their safety performance, and found that the space visualization capability had no significant impact on the prediction effect of pilots' safety performance level. Limengyu et al.[10] conducted tasks such as universal visualization and psychological deployment of rotation test explored the impact of spatial visualization ability on the performance of subjects in the space station virtual environment pathfinding task and found that spatial visualization ability has a positive effect on pathfinding performance.

To sum up, the virtual space visualization ability is mostly studied in the professional fields related to spatial visualization ability. The virtual space visualization ability can be improved or slowed down through learning and training. However, in different research fields, the visualization ability of virtual space cannot agree with the research results of performance.

4 Summary and prospect

4.1 Research summary

Spatial cognitive ability is an indispensable ability in human life. It is a subject of great concern in the field of spatial cognition in today's society. VR technology is a powerful tool for the study of spatial cognitive ability.

It can be seen from the relevant research described above that the virtual simulation research environment created by VR technology as new technology and new tool not only has the incomparable nature of the traditional research methods of spatial cognitive ability but also allows people to use both visual thinking and logical thinking in the process of experiments to improve people's perception of spatial information. This also makes VR technology a pioneering technical means to realize the prediction, testing, training, and rehabilitation of spatial cognitive ability. VR technology meets many experimental needs that can not be implemented or difficult to implement in the research of real space orientation ability and provides an optimistic way for the cultivation and training of space orientation ability. At the same time, it solves the interaction problem of traditional experimental neuropsychological evaluation and provides an environment with high ecological validity for the neuropsychological evaluation of spatial orientation ability. Some studies have also proved the positive role of VR technology in the research of spatial visualization ability. The virtual spatial visualization ability can be improved through learning and training or slow down the decline of spatial visualization ability. However, the research on the application of VR technology in the field of spatial visualization ability is in the development period, and the previous related research is less, and the virtual spatial visualization ability cannot be agreed in the performance research results in different directions.

4.2 Future direction

The research on the cognitive ability of virtual space needs further research and discussion in theory and technology.

Theoretically, for the research on the cognitive ability of virtual space, we also need to learn more from the theoretical essence of our predecessors. For example, constructivist learning theory is an important theoretical support for the research on the cognitive ability of virtual space, which requires that the research on the cognitive ability of virtual space should follow some principles: the user-centered design idea should regard the user as an active constructor; Based on interaction, the need for assistance and cooperation should be fully considered. Situational Cognition Theory is also the theoretical support for the research on the cognitive ability of virtual space. Situational Cognition Theory also emphasizes the subject as the center and requires a close combination of knowledge and practice. The virtual environment created by VR technology places the subjects in a scene that cannot be realized by the real experimental environment to deepen the subjects' perception of this special environment. The training and practice of cognitive ability in virtual space can promote an in-depth understanding of knowledge.

At present, VR pays more attention to immersion and has strong performance in visual and auditory aspects, but there are still deficiencies in dynamic reality. Researchers should select high-quality and suitable developers before the development of the virtual system, and select a small number of users to experience feedback during the development process, to avoid the problem that the lack of dynamic reality of the system will reduce the ecological validity and affect the experimental results. VR technology has its advantages in the expression of spatial information. However, due to individual differences in practical applications, sometimes users will have illusions and incorrect mental maps in the study of cognitive ability in virtual space. This also requires researchers to screen the subjects before the experiment, and exclude the inappropriate objects through scale tests, to ensure good experimental data. In addition, personalized mapping tools with different reference points can be provided according to the characteristics of the subjects, which can help the subjects complete the processes such as mental rotation, spatial orientation, and so on. These problems still need to be solved in the current research.

In terms of technology, the technology of establishing a high-quality virtual environment is expensive, and there are still great difficulties at present. The experimental instruments of virtual space cognitive ability still need to be further improved to expand the application scope of VR technology; There is still a gap between the interactive function of VR and human's natural interactive function. Immersive VR will bring people fatigue, dizziness, and other phenomena, so it needs to be further improved.

In a word, VR technology will become a particularly important experimental tool in the research of spatial cognitive ability, and it will also be an indispensable part of its large-scale spatial cognitive ability research. The cognitive ability of virtual space has huge research space and potential, whether in technical research or theoretical research. It needs to carry out innovative research and reserve new technologies to maximize the efficiency of VR technology. Whether in a commercial application or in educational practice, it is necessary to carry out policy and commercial promotion, expand the scope of application, speed up the update speed, and realize the popularization of the application of cognitive ability in virtual space.

Fund Project: Philosophy and social science research project of Hubei Provincial Department of Education (21G078)

References

1. Jiangxia Zhou, Jingbin Zhang, Zhen Zhou.Review on the relationship between cognitive style and spatial cognitive ability [J] Journal of Mathematics Education. 2007,(3):68-71
2. Lin MC, Petrosen AC. Emergent and an chochatrization of sex differences in spatial ability: A mete-analysis [J] . Child Development. 1985:1479-1498
3. Humphreys G. Disorders of visuo-spatial cognition [J]. Neurocase. 2005, 11(2): 146－147
4. Potter RB. Consumer behavior and spatial cognition in relation to the extraversion-introversion dimension of personality [J]. The Journal of Social Psychology. 1984,123(1):29－34
5. Jianwu Zhang, Hongju Kong. Application of virtual reality technology in practical training teaching [J]. e-Education Research. 2010, (4): 109-112
6. DyiYih Michael Lin,PoYuan Darren Yang. The Use of Virtual Reality to Train Older Adults in Processing of Spatial Information[C]. Universal Access in Human-Computer Interaction. 2007
7. Morganti F. ,Gaggioli A. ,Strambi L. ,Rusconi M. L,Riva G. A virtual reality extended neuropsychological assessment for topographical disorientation:a feasibility study[J]. Journal of NeuroEngineering and Rehabilitation, 2007,4(1):26
8. Oman CM,Shebilske WL,Richards JT, et al. Three dimensional spatial memory and learning in real and virtual environments [J]. Spatial Cognition and Computation. 2000,2(4):355-372
9. Huaiyu Lu.Research on the influence of virtual Lego on middle school students' mental rotation and spatial visualization.[D]. Shanghai Normal university. 2019
10. Yonggang Wang, Li Miao.Research on the relationship between pilots' space capability and their safety performance.[N]. China safety science news. 2015,25 (8): 141-05
11. Mengyu Li. Design and Research on the simulation system of space station in cabin path finding based on VR technology [D]. Harbin Institute of Technology, 2013