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A Study on Stress Levels when Using Head-Mounted Display Virtual Reality for Learning Spatial Shapes in Mathematical Education

1. Introduction

Studies in several fields have shown various positive educational effects of head-mounted display virtual reality (HMD-type VR) environments (Okamoto et al., 2024). However, negative results have also been reported, such as learning with no educational effects and VR sickness (Bermejo et al., 2023; Okamoto et al., 2024). Understanding whether learning environments using HDM-type VR causes more stress compared to traditional learning environments is important for implementing HDM-type VR in educational settings. VR environments can induce a variety of stress levels (Cho et al., 2017), although there is little analysis of such stress levels by learning with HDM-type VR.

The authors assumed that a situation in which HDM-type VR could be easily utilized in schools is when thinking about spatial shapes in mathematical education. When learning spatial shapes, it is easier for students to imagine these shapes in a three-dimensional space like actual solid objects, rather than in a two-dimensional space like drawn on paper, so that better learning effects can be expected. However, preparing real material objects is time-consuming and expensive. If material objects can be manipulated in a VR space, such problems can be solved because the material objects are just data and can be easily copied or downloaded. However, as mentioned earlier, few studies have analyzed the stress levels when learning using HDM-type VR. Therefore, in this study, a stress analysis is conducted using a three-dimensional mental rotation task. In addition, the effects of using HDM-type VR on users' spatial perception based on the rate of correct answers and the speed of decision making is also examined.

2. Method

This study used Garmin's vivosmart 5 and analyzes the gained data using software (Fitrockr) that can analyze physiological data on stress levels. In addition, the effects of VR sickness on stress were considered and investigated using a questionnaire (Kennedy et al., 1993). In addition, a survey was conducted on their impressions of using VR.

In: L. Schick, M. Platz & A. Lambert (Hrsg.),
Beiträge zum Mathematikunterricht 2025.

58. Jahrestagung der Gesellschaft für Didaktik der Mathematik. WTM.

<https://doi.org/10.37626/GA9783959873307.0>

In this study, mental rotation tasks were applied to simulate situations of imagining three-dimensional objects in mathematical education. The method of examining the survey is based on Kondo et al. (2022). There are 14 questions in total. A rest period of 1 minute was allowed for each task. The subjects were seated and allowed to move only their heads so that they could not change their viewpoint significantly while solving the tasks. In addition, they were not allowed to touch the 3D objects in the VR space. The subjects were divided into two groups. The first group was surveyed in VR to 2D (the task on a paper) order. The second group was surveyed in 2D to VR order. The content of the tasks and the order of the tasks were the same for both 2D and VR. Furthermore, the subjects were asked if they still want to continue solving the tasks after taking the survey in 2D. Similarly, they were asked if they want to continue solving the tasks after completing the survey in VR.

The VR device used was Meta Quest 3S made by Meta. The subjects were Japanese university students (N = 5, male 2, female 3, age 20-24).

3. Results

The table below shows the results of the survey. Each of the five students is labeled as S1-S5. S1, S2 and S4 were surveyed in VR to 2D order. S3 and S5 were surveyed in 2D to VR order.

	S1	S2	S3	S4	S5
Accuracy rate under 2D (Unit: %)	92.6	85.7	92.6	92.6	78.6
Accuracy rate under VR (Unit: %)	85.7	100	100	100	100
Average, Max and Min of heart rate during the answer under 2D (Unit: times)	76 65-90	81 69-91	79 73-87	90 76-113	87 72-116
Average, Max and Min of heart rate during the answer under VR (Unit: times)	79 70-99	84 69-93	78 66-99	93 76-110	83 71-100
Average, Max and Min of stress value during the answer under 2D (Range: 0 - 100, The closer to 100, the higher the stress level)	35 8-67	77 57-88	39 28-63	87 72-99	63 24-96
Average, Max and Min of stress value during the answer under VR (Range: 0 - 100, The closer to 100, the higher the stress level)	44 21-84	80 53-93	36 5-82	90 74-97	50 24-84

The averages are found at the top of each cell on the table above. The value at the bottom of each cell is a range of minimum value on the left and maximum value on the right.

This stress value is calculated by Fitrockr from HRV.

A Wilcoxon signed-rank test was used to analyze whether there were significant differences when comparing 2D and VR. The results showed that there were no significant differences in the percentage of correct responses, the average heart rate, and the average stress value ($p > 0.05$). In addition, a survey using a questionnaire to assess VR sickness (Kennedy et al., 1993) was conducted, and all five students did not show any symptoms of VR sickness. Notable comments from students on their use of VR include the following:

- I could see VR more three-dimensionally, so it was easier for me to think than with paper.
- It was interesting to see it three-dimensionally by VR, and I wanted to continue more.
- I felt no weight or resistance when I put on the VR, which bothered me.
- I felt that the range of vision became narrower with VR.
- It was easier to see without VR (2D).

4. Conclusion

This study investigated whether there is a difference in stress levels when HDM-type VR was used and when it was not used. There was no finding that the use of the HDM-type VR caused significant stress. Since this was the first time for all subjects to use HDM-type VR, it is assumed that the effect of unfamiliarity on stress may be low. Furthermore, during the mental rotation tasks, four out of the five subjects increased the percentage of correct answers when using HDM-type VR, and these four subjects solved all tasks correctly. This suggests that it may be easier to accurately capture spatial shapes within the VR space. In other words, we believe that it is effective in supporting the imagery of complex figures when learning spatial shapes in mathematical education.

There are several limitations to this study. The number of subjects is still small and only university students were included in the study. In addition, the tasks used were mental rotation problems, not 3D learning from a textbook. Moreover, there is a rest period for each task. This is a different environment from the usual class time (approximately 40 to 50 minutes). Furthermore, the environment is set up in such a way that the students cannot touch and move the three-dimensional objects in the VR space.

The subjects found it enjoyable to solve tasks in HMD-type VR in this study. In addition, no student wanted to continue solving tasks in 2D, but 4 out of 5 students wanted to continue answering tasks in VR. This time, we focused on stress evaluation, but in the future, we would like to focus on positive aspects of HMD-type VR, such as its playfulness, and begin research on the enjoyment of learning spatial shapes in mathematical education by using VR. As mentioned in the comments of the subjects, some students felt that HMD-type VR completely blocked and narrowed their field of vision. We will also consider the use of AR glasses that do not completely block the field of vision, and conduct a comparative verification by adding AR glasses. Furthermore, we would like to conduct the same study in an actual educational setting with students from a secondary education stage as the target group instead. Finally, based on the results of this study, we would like to examine the use of VR in mathematics classes and cross-curricular learning, and propose effective teaching materials or curriculum.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number JP24K22786.

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