Holomental: Improving Mental Rotation Ability with Mixed Reality

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ABSTRACT

Mental rotation ability is a type of spatial skill that is important in many aspects of life. With technological advancements, 3-D visualizations are more frequently used for addressing this spatial ability. In this study, we investigated the effectiveness of a Mixed Reality-based training module, Holomental, on Microsoft HoloLens 2 in improving the mental rotation ability of 22 undergraduate students. The results showed that the training improved the accuracy of the students' responses by approximately 33%. Gender difference present before the training seemed to disappear after the training. The study contributes to our understanding of performance in Mixed Reality-based training.

CCS CONCEPTS

• **Computer-assisted instruction**; • **Virtual Reality**; • **Mixed/Augmented Reality**;

KEYWORDS

spatial ability, cognitive load, immersive experience, mixed reality, Microsoft HoloLens 2

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1 INTRODUCTION

In this study, we investigated the effectiveness of Mixed Reality-based mental rotation training, Holomental, in terms of mental rotation performance and explored the effect of gender in the amount of improvement. Mental rotation ability (MRA) refers to the visualization of two or three-dimensional objects in the human mind. It is critical for tackling many everyday tasks and is also a strong predictor of success in STEM fields [1]. There is evidence that females typically show lower mental rotation performance than males [2]. Nevertheless, targeted interventions can help educators address this gender difference; therefore, studies are needed to find which type of training can support students in improving their spatial ability [3].

Mental rotation ability has been trained using various tools including paper-based tools, solid models, video games, CAD and other computer software and in recent years Extended Reality technologies. AR-based mental rotation training applications were used for the rehabilitation of the elderly [4]. A holographic display was employed that enabled viewing by multiple people. The training they developed involves opening a holographic chest by rotating a 3-D key in which using hand gestures enhanced mental rotation ability and increased learner interest. Other researchers merged a physical manipulative and its virtual projection on the computer screen using a sensor board attached to the physical model [5]. The orientation of the virtual manipulative responded to the manipulations made to the physical model in real-time. A VR-based training on HTC Vive was created by modifying the items in the Mental Rotation Test and providing feedback [6].

Mixed Reality technology is a type of immersive system that locates virtual objects in the real world of the user which is often used interchangeably with AR [7]. With their ability to show the coexistence of virtual objects and real-world surroundings, AR-based training tools were found more effective in enhancing spatial ability than VR [8]. The use of 3-D visualization is effective in enhancing mental rotation ability in different training environments including computer software, and desktop-based and Head Mounted Display-based Augmented Reality/Virtual Reality applications [9].

In the present decade, immersive technologies have been increasingly employed for training different types of spatial abilities. The representational and interactional affordances of these devices allow for rich learning experiences enhanced by situated immersion, multimodal interaction and a sense of embodiment [7]. According to previous studies, immersive technologies can improve spatial ability and increase learner interest. Considering these studies, we aimed to explore in this study whether a holographic display can improve mental rotation ability in short training sessions. To cultivate a realistic experience, the Mixed Reality-based training module in this study allows users to interact with the holographic

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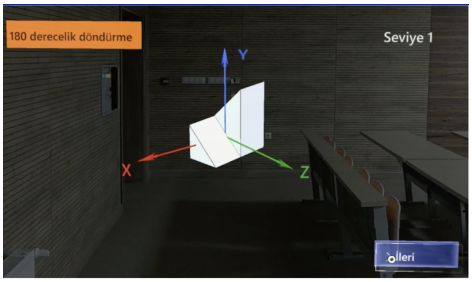

Figure 1: Example training screen

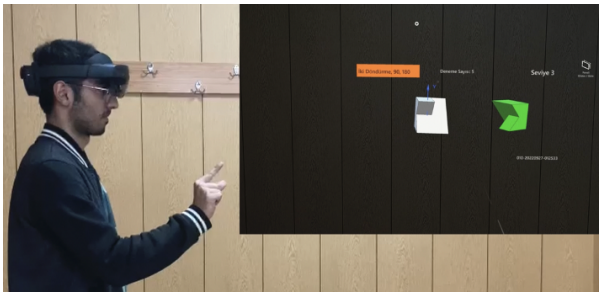

Figure 2: Interaction with the Training Module

content using their hand gestures and explore the rotation tasks with free navigation in the immersive environment.

2 METHOD

This study measured the effectiveness of Mixed Reality-based mental rotation training with Purdue Spatial Visualization Test: Rotations (PSVT:R). The Revised PSVT:R was used in this study [10]. The gain score in PSVT:R was calculated by subtracting the pretest score from the post-test score.

The mental rotation training in this study was developed for Microsoft HoloLens 2. Importantly for holographic object rotation, it supports six degrees of freedom that allow users to move their bodies as well as their heads for interaction.

The training module in this study was designed to train mental rotation ability using 3-D virtual representations. Usability studies were conducted with 7 participants in two iterations. In the immersive environment, participants have the opportunity to interact with 3-D visualizations using gestures and navigate around the content. Animations realistically demonstrate the mental rotation processes. Feedback is provided both verbally and visually. To avoid negative effects on cognitive load, a simple "screen" design was adopted for the 3-D training module. An example screen is seen in Figure 1.

The study participants (13 female, 9 male) were undergraduate students. Since the training is for individual use, the training and measurement sessions were carried out individually. The training environment was a lab with sufficient navigation space and the lighting was adjusted carefully to avoid poor visibility. Figure 2 presents a user interacting with the training module.

Participants first took a demographic questionnaire and the online PSVT:R. After familiarization with the device, the participants started training. The training consisted of three sessions that lasted approximately 10-25 minutes. After the third session, participants took the online PSVT:R again.

3 RESULTS

Due to the non-normal distribution of pre-test scores, we used the non-parametric Wilcoxon signed-rank test to investigate training effectiveness. The mental rotation ability (MRA) of the participants was higher after completing the Mixed Reality-based mental rotation training (Mdn = 21.00) than before the training (Mdn = 14.00) ($z = -3.814$, $p < .01$, $r = .57$).

The non-parametric Mann-Whitney U test was done to compare the baseline MRA levels for the two genders since the pre-test scores were not normally distributed. Males (Mdn = 18.00, M = 18.56 , SD = 5.36) had higher MRA than females (Mdn = 13.00, M = 14.15, SD = 5.04) at the beginning of the study. To investigate the effect of the Mixed Reality-based training on the gender difference in mental rotation ability, an independent samples t-test was conducted. After the training, male and female mental rotation ability levels were not significantly different from each other, $t(20) = .87$, $p = .39$. MRA gain was higher in females than in males to the degree that the difference between the MRA scores was no longer statistically significant after the training.

4 DISCUSSION AND CONCLUSION

The results indicated that mental rotation ability can be improved with Mixed Reality-based training. In our training, students interacted with the holographic content to solve the mental rotation tasks, which engaged them in an interactive experience that involved both the virtual content and the physical surroundings. 3-D presentation of content and gesture-based interaction may be factors contributing to mental rotation ability improvement [9]. Practice with holographic objects may have facilitated the construction of more complete mental models of the rotations, allowing learners to wander around the holograms if they had difficulty comprehending the stimuli.

At the outset, males had higher mental rotation performance than females. Importantly, the improvement of females was to the degree that it was equal to male performance after the training. Thus, this study showed that with short but targeted sessions it is possible to eliminate the gender difference in mental rotation performance.

Future studies can further investigate whether such disappearance of gender difference prevails in similar training environments with variations of 3-D mental rotation tasks. Furthermore, value-added comparisons can be made to reveal the training methods that benefit individuals from different genders or other characteristics differently. Finally, spatial ability should be investigated with longer training durations, larger samples and different learner groups.

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