Assessing Mental Rotation Ability in a Virtual Environment with an Oculus Rift

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Many studies have found gender differences in mental rotation ability in young adults when completing mental rotation tests on paper and pencil (e.g., Peters et al., 1995; Vandenberg & Kuse, 1978). Two previous studies have been unable to replicate these findings when testing mental rotation ability inside of a virtual environment (Parsons et al., 2004; Rizzo et al., 2001). We created a new virtual mental rotation test (VMRT) based on a full, validated test of mental rotation ability (MRT-A; Peters et al., 1995) that 128 participants (79 females) completed while wearing an Oculus Rift DK1. Our data replicate previous findings of paper and pencil tests of mental rotation ability: men scored approximately one standard deviation higher (d = .90) than women.

The ability to manipulate objects in space has been well-studied. The original work measuring mental rotation of three-dimensional objects by Shepard and Metzler (1971) has been cited over 4000 times and spurred a wealth of follow-up research. Indeed, many studies have shown gender differences in mental rotation ability (e.g., Peters et al., 1995; Vandenberg & Kuse, 1978) with males scoring approximately one standard deviation higher than females in tests of mental rotation.

Although a number studies have found the gender effect using paper and pencil tests (e.g., Peters et al., 1995; Vandenberg & Kuse, 1978), initial findings suggest that the gender differences disappear inside of a virtual environment (VE). Specifically, Parsons and colleagues (2004) and Rizzo and colleagues (2001) did not find gender differences when participants completed a virtual mental rotation task.

There are a number of possibilities that could have led to the lack of replication inside of a VE. For example, it is possible that the gender differences do not exist in VE. Additionally, the task itself may have differed from a validated paper and pencil version. Lastly, the VE technology of the time of these studies most likely produced poorer resolution and quality compared to today's VE technology.

Both Rizzo and colleagues (2001) and Parsons and colleagues (2004) used an ImmersaDesk 3D projection display system to deliver their virtual mental rotation tasks (see Czernuszenko et al., 1997 for a more detailed review of the ImmersaDesk platform). Although this technology is now approximately twenty years old, it was considered advanced at the time.

Additionally, in both studies, a base stimuli was presented and then replaced with a working stimuli. The dependent variable in these studies was the time it took to successfully rotate the working stimuli to correctly match the base stimuli. However, most of the traditional mental rotation tasks showing the gender effect use a comparison-based test where a base stimuli is presented simultaneously with multiple working stimuli that may or may not match the base stimuli.(e.g., Peters et al., 1995; Vandenberg & Kuse, 1978). In these studies, participants must then identify which stimuli are correct (i.e., accuracy).

Therefore, the goal for this research was to explore the gender effect for mental rotation ability in a VE using a comparison-based test while using newer VR technology (i.e., Oculus Rift DK1). To do this, we created the Virtual Mental Rotation Task (VMRT), based on the Peters et al. (1995) validated paper and pencil Mental Rotation Test, Version A (MRT-A). The MRT-A is an updated and redrawn version of the original mental rotation tests designed by Vandenberg and Kuse (1978).

We hypothesized that on average, men would score higher than woman on the VMRT. This would be in line with previous research using comparison-based paper and pencil tests of mental rotation.

METHOD

Participants. One hundred twenty-eight students (*M* = 21.1 years old, *SD* = 2.1, 79 females) with normal or corrected-to-normal vision from George Mason University participated for course credit.

Virtual Mental Rotation Task. The Virtual Mental Rotation Task (VMRT) is a replica of the Peters and colleagues (1995) Mental Rotation Test Version A (MRT-A) that was based on the original Vandenberg and Kuse (1978) mental rotation test. The primary difference between VMRT and MRT-A is that the VMRT was displayed using an Oculus Rift instead of paper. Additionally, instead of marking the correct answers using pencil, participants selected the correct answers using the computer keys *F1, F2, F3,* and *F4.* Each key corresponded to one of the four possible answers per problem (see Figure 1).

Each question has one base stimulus and four working stimuli that may or may not match the base stimulus when rotated (i.e., two objects that when rotated are identical to the base stimuli and two objects that cannot be rotated to match the base stimuli). For every question, there are exactly two matching answers and two non-matching answers. To successfully answer the problems, participants needed to identify both of the matching stimuli.

Equipment. The Oculus Rift DK1 was used to present the VMRT. This device has a 1280 x 800 screen resolution, a 50-60 ms latency, a refresh rate of 60 Hz, and a 110 degree visual field.

Questionnaires. The Simulator Sickness Questionnaire (Kennedy, Lane, Berbaum, & Lilienthal, 1993) was used to determine whether participants exhibited symptoms of simulator sickness including: nausea, eyestrain, headache, etc. Participants rated each of the 16 questions as none, slight, moderate, or severe. Participants that identified any one-item as severe were asked if they would like to be excused from the study based on discomfort.

A modified Presence Questionnaire (Witmer & Singer, 1998) was used to determine the level of presence (i.e., subjective experience of being in an environment, even if not physically at that location) for each participant. Since the VMRT did not include any auditory metrics, all questions assessing sound-based presence were excluded.

Design and Procedure. Participants read and signed an informed consent form at the beginning of the experiment. They were then equipped with an Oculus Rift. To gain familiarity with the device and images displayed, the participants practiced moving inside a virtual environment entitled *Tuscany*, a default environment created by Oculus. Participants moved around the environment using a keyboard and mouse for two to three minutes to ensure they were comfortable and could see well using the device. Participants then completed the SSQ. Participants then began the VMRT. The instructions were displayed inside the virtual environment and were also read aloud by the experimenter. After completing four practice problems to ensure the participants understood the test and how to answer each question, they completed all 24 test problems. Participants then completed the SSQ again, the PQ, and a demographics questionnaire.

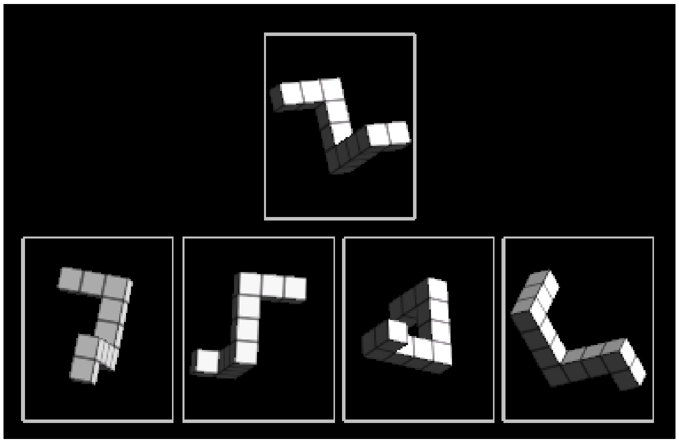

Figure 1. Sample question from VMRT. The base stimulus is on the top row while the working stimuli are on the bottom row. In this example, the middle two working stimuli are the correct answers.

RESULTS

We were interested in determining whether the gender effect would be present in the VMRT. An independent samples *t*-test of scores on the VMRT (i.e., the number of problems correctly solved) between male (M = 13.04, SD = 4.40, n = 49) and female (M = 9.37, SD = 3.74, n = 79) participants revealed a significant main effect of gender, $t(126) = 5.048$, $p < .001$, $d = .90$ (see Figure 2). These data are consistent with findings from paper and pencil tests of mental rotation (e.g., Peters et al., 1995) and not consistent with two previous studies assessing mental rotation inside VE using older virtual reality technology (Parsons et al., 2004; Rizzo et al., 2001).

Additionally, a correlation between scores on the VMRT and the PQ revealed a significant positive relationship between presence and scores on the VMRT, $r(127) = .20$, $p < .05$, $r^2 = .04$.

Examining the SSQ revealed that no participant listed a severe rating for any item. Three participants answered moderate to questions regarding eyestrain and blurred vision.

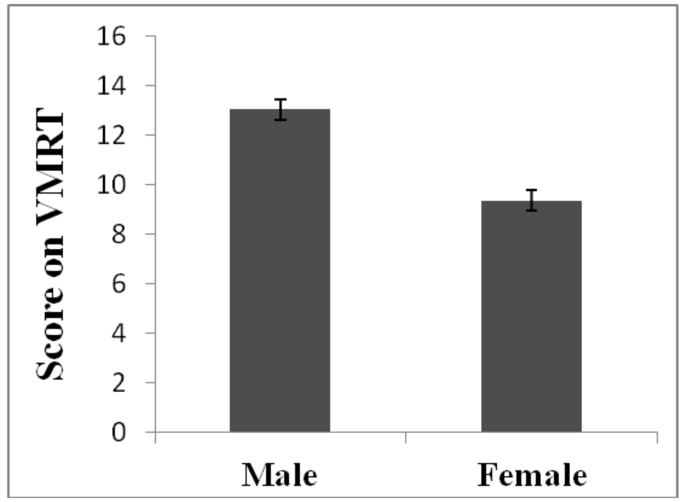

Figure 2. The average number of problems correctly solved (± SE) on the VMRT. Participants answered 24 problems in total.

GENERAL DISCUSSION

The goal for this research was to explore the gender effect for mental rotation ability in a VE using a comparison-based test while using newer VR technology. To do this, we created the VMRT which was completed using Oculus Rift DK1. In line with previous research using paper and pencil tests of mental rotation, we found that, on average, males scored approximately one standard deviation above females when completing the VMRT. Additionally, we found a small, positive relationship between scores on the PQ and the VMRT.

Our finding is not consistent with previous work by Rizzo and colleagues (2001) and Parsons and colleagues (2004) who were unable to find a gender effect when individuals completed a mental rotation test inside of a VE. However, there are many possible reasons for the differences in results.

First, we replicated a full, validated test of mental rotation (i.e., MRT-A). Additionally, we scored our test for accuracy whereas Rizzo and colleagues (2001) and Parsons and colleagues (2004) measured the time to rotate a working stimulus to match a base stimuli. Second, we used a newer technology (i.e., Oculus Rift DK1) that may have had a higher quality or fidelity facilitating performance on the test. Third, the generation of participants in our study may be more familiar with technology (e.g., smart phones, tablets, etc.) as a whole now that technologies are ubiquitous.

Future research should be directed at determining whether scores on the VMRT are predictive of performance on tasks inside of VE, namely tasks tapping spatial ability. For example, studies have shown new surgeons benefit from simulated VE training (e.g., Seymour, 2008; Seymour et al., 2002). Visuospatial skills are necessary to successfully interact and complete such tasks; thus, it would be interesting to determine whether scores on the VMRT predict performance on a simulated surgery task.

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