Impact of Binocular Vision on the Perception of Geometric Shapes in Spatial Ability Testing

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Introduction

With the advancement of stereo 3D hardware and mass distribution for entertainment and visualization, new opportunities in research techniques have begun to surface. Stereopsis is defined as a binocular depth cue produced by the processing of the separate perspectives of both eyes into a fused image (Schwartz, 2010). This effect can be reproduced by exposing each eye to a separate perspective to generate the illusion of depth. Binocular vision is only one of the many indicators the human visual system uses to infer depth and can only come into play when both eyes are functioning and are receiving separate perspectives.

The process of perceiving, analyzing and solving a spatial problem is an important and continuous process that is performed by engineers, educators and graphic technologists (Jensen, 1986). This process can be quantified and is measured by the capacity to perform spatial operations (Hart & Moore, 1973) by calculating the time and/or accuracy for an individual to solve a spatial problem (Study, 2001). These tests often used problems within three-dimensional (3D) space and many of these tests were developed to be completed on paper and were limited by the medium of the time. These tests used two-dimensional (2D) representations of three-dimensional objects in order to limit and have control over the available information presented to the test subject. Some examples include Vandenberg's Mental Rotation Test (MRT) (Vandenberg & Kuse, 1978), the Purdue Spatial Visualization Test (PSVT) (Guay, 1976), the Three Dimensional Cube (3DC) (Gittler & Glueck, 1998), and Mental Cutting test (MCT) (CEEB, 1939).

Many of these paper tests consisted of line drawings depicting 3D objects, yet due to the limited context available within the drawings, some representations may be ambiguous (Jianping, 2007). As a result, some researchers have re-designed existing spatial ability tests to decrease ambiguity within the illustrations while investigating the effects of these changes on the test (Jianping, 2008; Aitsiselmi & Holliman, 2009). Existing research has given mixed results on the effects of binocular vision on perception of 3D shapes (Pizlo, 2008; Aitsiselmi & Holliman, 2009; Leroy, Fuchs, Paljie & Moreau, 2009). In an attempt to investigate stereoscopy and its effects on the perception of geometric shapes, this research was designed to isolate stereopsis and determine if this depth cue contributes to the mental processing of a spatial problem.

Method

To measure the effect of stereoscopy on spatial ability tests 218 participants volunteered from an introductory engineering graphics course at Purdue University: West Lafayette Campus within the Computer Graphics Technology department. Participation in this study was strictly voluntary and did not collect any identification information. The collected data included a random identification number to associate the participant's initial and final score and did not distinguish gender, age, ethnicity, or any other parameter. In order to properly weigh the effect of stereoscopy on a participant's score, the Vandenberg's Mental Rotation Test was selected to gain a base line measure of an individual's spatial ability. This was followed by splitting the participants into two groups and administering a non-stereoscopic and a stereoscopic version of the Purdue Spatial Visualization Test: Visualization of Rotations (PSVT:ROT).

This study utilized the original version of Vandenberg's Mental Rotation Test as a pre-test due to its well documented usage and validity in measuring spatial cognition (Peters, Laeng, Latham, Jackson, Zaiyouna & Richardson, 1995). In order to maintain consistency between the two variants of the PSVT:ROT, a redrawn version was created for the purpose of this research. Given that a stereoscopic version of the test must be generated by illustrating two separate perspectives of the same object, 3D models based on the original PSVT:ROT were built in a CAD software package. As the original PSVT:ROT illustrated the models in orthographic view, it was necessary to reproduce both versions of the test in perspective views. Similar to the Jianping's (2008) research, shading was also added to the facets of the 3D models in order to give additional context to the orientation of each face.

In order to create an appropriately calibrated stereoscopic image, it is necessary to constrain specific parameters to maintain the illusion of this depth cue. This research used Autodesk 3DStudio Max to place the virtual objects into the scene, while placing cameras at the estimated distance and angle to match the participant's viewing angle and inter-pupillary distance (IPD). The stereo version of the PSVT:ROT was rendered to simulate the average human IPD at approximately 23" from the screen. As seen in Figure 1, the three cameras are directed at the object within view and are toed-in to adjust for proximity and parallax while correcting for the keystone effect. The center camera was used to generate the non-stereo version of the PSVT:ROT. An example question of the resulting render of the recreated PSVT:ROT can be seen in Figure 2.

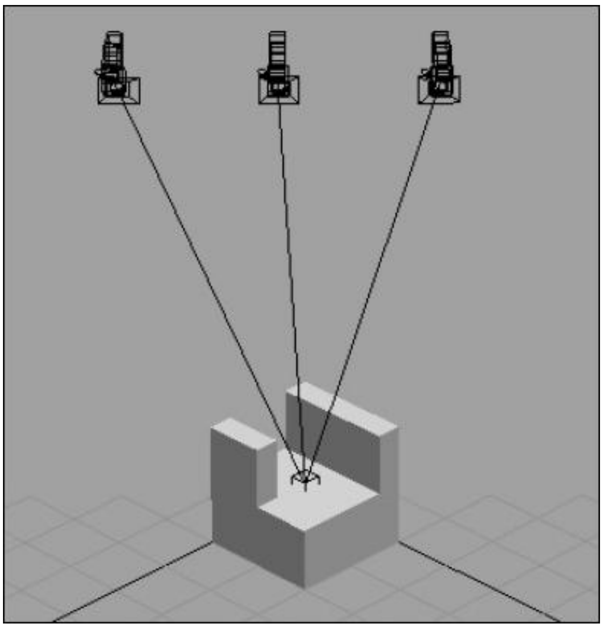

Figure 1. Screen capture of the setup in 3DStudio Max 2011

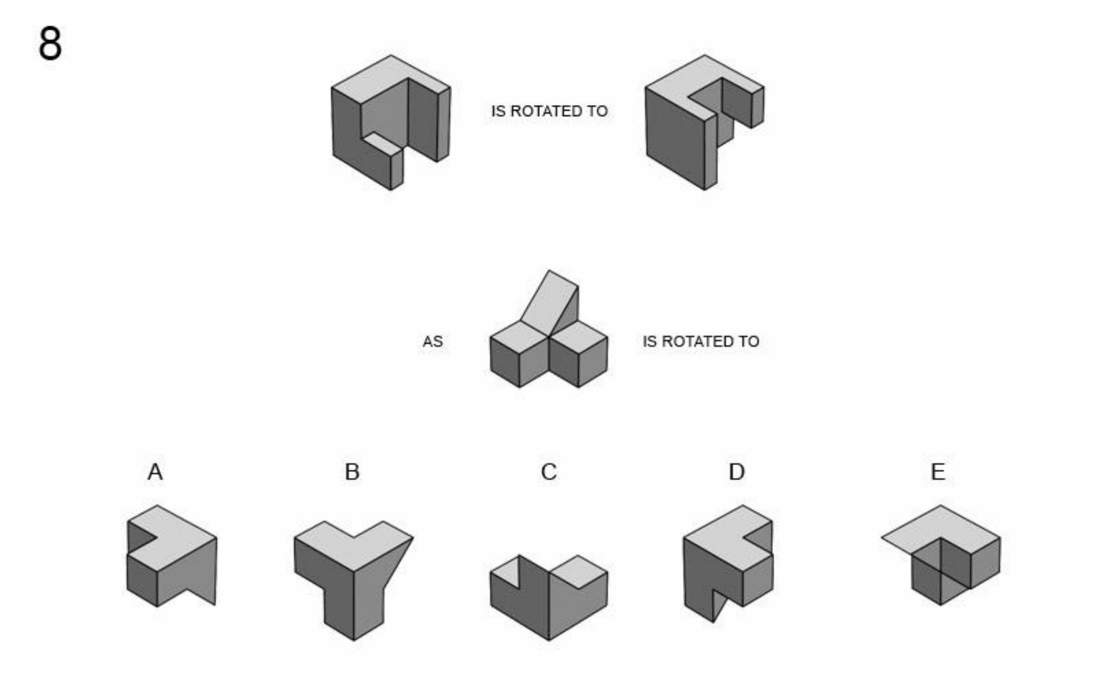

Figure 2. Non-stereo rendered version of the PSVT:ROT, problem 8

The testing methodology consisted of administering the timed Vandenberg's Mental Rotation Test online, consisting of 20 multiple choice questions as seen in figure 3. This was followed by randomly splitting the participants into two groups and assigning one group to complete the stereo version, while the other completed the non-stereo version of the PSVT:ROT. Both versions of the recreated PSVT:ROT replicated the original's problems and consist of the same 30 questions of varying difficulty with an imposed time limit. The only differences between the two recreated versions were the different perspectives required to simulate stereopsis. This version of the PSVT:ROT did not only change the illustration technique of the original, but also fixed some of the inconsistencies and errors found in the original PSVT:ROT as noted by Jianping (2007).

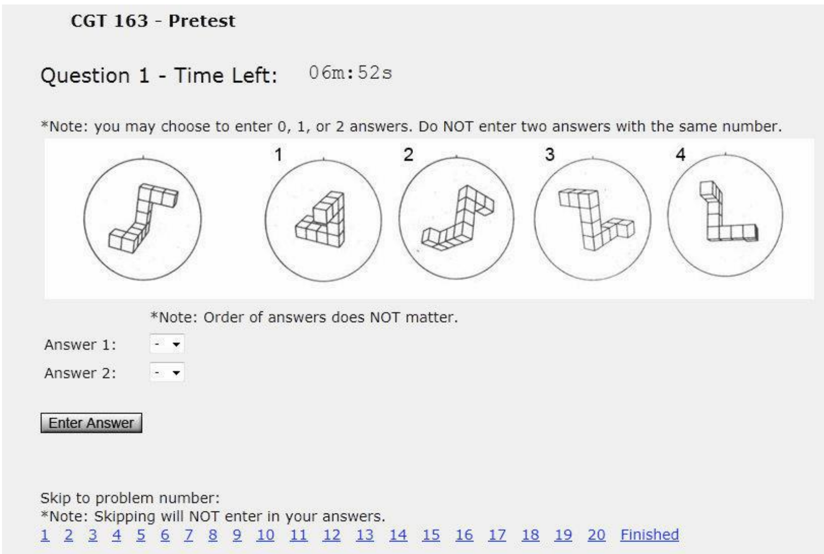

Figure 3. Screenshot of the online Vandenberg MRT

Results

The testing began by administering the Vandenberg MRT to all 218 participants and yielded an average of 13.19 out of 20 possible points with a standard deviation of 4.37 points. The students were then split into two groups to take the stereo or non-stereo version of the PSVT:ROT. To ensure both groups had similar results on the pre-test before taking the post test, each group's average was recorded as 13.13 for stereo and 13.24 for non-stereo while the standard deviations were 3.98 for stereo and 4.72 for non-stereo. The histogram of both groups' pre-test scores can be seen in Figure 4 and are split to show which group followed by taking the PSVT:ROT in stereo or in non-stereo.

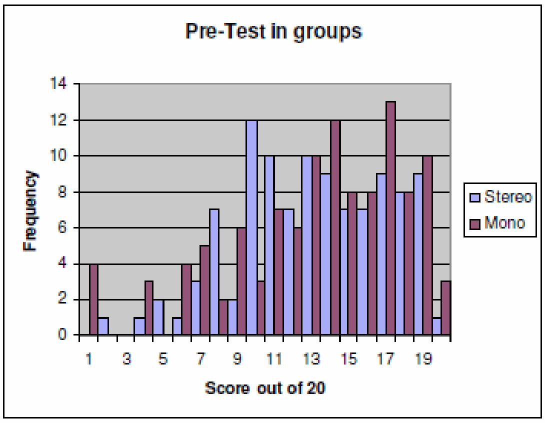

Figure 4. Vandenberg MRT histogram of scores

Once separated into stereo and non-stereo groups, a corresponding version of the PSVT:ROT was administered and a histogram of the scores can be seen on Figure 5. The results from both groups yielded an average of 23.75 out of 30 points for the stereo group and 23.44 for the non-stereo. The standard deviation for the stereo group was 4.58, while the non-stereo was 5.07. By using the pre-test as a covariate, an ANCOVA of the tests was calculated and demonstrated a high correlation between pre-test and post-tests with a $p < 0.001$. However, the comparison between the two post-tests with the pre-test as a covariant showed no correlation, with a value $p = 0.541$. An ANOVA calculation on the post-tests (without considering the pre-test) yielded a significance of $p = 0.649$

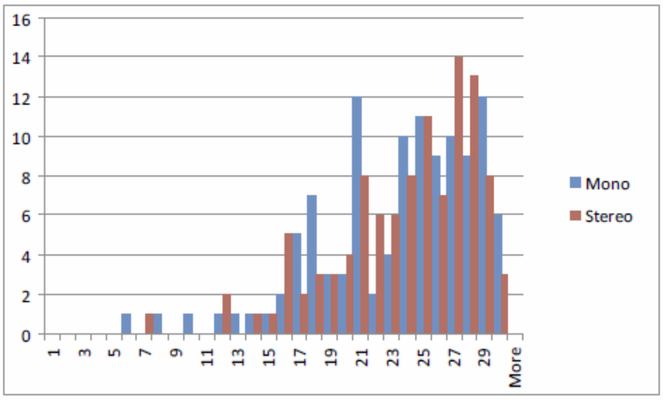

Figure 5. Stereo and non-stereo histogram of PSVT:ROT scores

The comparison of stereo and non-stereo versions of the test clearly illustrates there is no significant difference between them. However, when considering the lower end of the spectrum of spatial ability, and taking into account the participants who scored less than 10 out of 20 points in the pre-test, the ANOVA comparison in between both groups resulted with a correlation with significance of $p = 0.013$, indicating an increase in post-test score when taken in stereo. When an ANCOVA analysis is used to weigh the post-test scores, the correlation between pre-test and post-test become less significant at $p=0.052$, and the correlation between post-tests yielded no correlation with a $p = 0.058$ when based on a 95% confidence interval. The effect size of the participant pool resulted in a Cohen's d value of -0.0621 and an effect size of -0.0310, while when observing the participants with low spatial ability based on the pre-test, resulted in a $d = 0.6819$ and $r = 0.3227$.

Conclusions and Discussion

As demonstrated in the results, no significant difference was found between the stereoscopic and non-stereoscopic versions of the PSVT:ROT. This indicates that binocular vision does not aid students in the introductory engineering graphics course in performing spatial tasks. However, when observing participants who struggled with the pre-test, the results showed a minor difference in the post-test scores. This difference could imply that stereoscopic vision does not generally aid individuals with high spatial ability, but could possibly aid individuals with low spatial ability. Both versions of the PSVT:ROT consisted of the same exact problems with the same rotations and were only different in how the question was displayed.

A possible future research avenue would be to further extend upon this research by targeting individuals with low spatial ability and to re-test the sample with stereo and non-stereo versions of the PSVT:ROT and/or other validated spatial ability tests. If a significant difference is found, not only would it indicate that stereoscopic vision affects the test scores of individuals with low spatial ability, it could also allude to a critical issue with defining what a spatial ability test is actually testing. As many researches define spatial ability containing several spatial factors with varying definitions and confusing nomenclature (Carroll, 1993), it is important to investigate how the perception of the questions within the test affect the process of performing the spatial task. It is also crucial to determine if perceiving and understanding the spatial stimuli within a spatial ability test is a separate spatial task on its own.

The findings in this research could indicate that the PSVT:ROT test requires the participants to first recognize and comprehend each 3D model before mentally rotating it. If this statement held true, it could mean that individuals who struggle with the PSVT:ROT may possibly be negatively affected by not being able to perceive the illustrated 3D model and should warrant further research. If a future research finds a significant difference in spatial ability test scores by slightly changing how the problem is illustrated, it may expose this spatial perception step in the spatial task solving process that is a distinct yet necessary step in the processing of the spatial problem.

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