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Examining the Connection Between Dynamic and Static Spatial Skills and Video Game Performance

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Abstract

Previous research has found a connection between spatial cognition and success in STEM areas and that spatial cognition skills can be trained using video games. The present study explores whether a relationship exists between non-trained spatial cognition skills and video game performance. Non-video game players first completed four spatial cognition tasks and then played two video games, Tetris and Unreal Tournament (UT). Results showed significant correlations between performance on UT and mental rotation, paper-folding, and the Race dynamic spatial task. In contrast, Tetris performance only correlated with paper-folding. These results indicate that performance on action video games such as UT may be related to more spatial skills than Tetris.

Keyword: spatial cognition, video games

Objective and Rationale

The goal of the present study is to examine the relationship between video game performance and performance on tests of static and dynamic spatial skills. The rationale is that (a) spatial skills may be instrumental for success in science, technology, engineering, and mathematics (STEM), and (b) video game playing may be related to the development of spatial skills.

Spatial Cognition and STEM Areas

In a longitudinal study Wai, Lubinski, and Benbow (2009) examined the connection between adolescents' spatial ability and later achievement in STEM fields (i.e., science, technology, engineering, and mathematics). Cognitive ability measures of mathematical, verbal, and spatial ability for 400,000 participants from the Project TALENT data bank of 9th-12th grades were compared to follow-up academic data from 11 years later. Three major conclusions were made from this study: (1) high spatial ability was found among almost all adolescents who went on to achieve educational and occupational credentials in STEM areas; (2) spatial ability was critical for students in the general population as well as those deemed intellectually talented; and (3) restricting talent searches to verbal and mathematical ability may miss many spatially gifted individuals. If we wish to encourage students to go into STEM fields the educational system may need to adapt to include spatial measures in talent assessment as well as to include interventions and training that encourage the development of spatial skills.

Studies in different areas of STEM have shown different spatial abilities are used on these tasks. For physics, Kozhevnikov, Hegarty, and Mayer (2002) found that there was a significant correlation between students' spatial abilities and accuracy on kinematic problems. Further research by Kozhevnikov, Motes, and Hegarty (2007) found several differences between high- and low-spatial students and the answer they gave to physics problems. High-spatial students could integrate several motion parameters while low-spatials only considered one. High-spatials used kinematic graphs as abstract representations of motion while low- spatial students interpreted graphs as being picture-like representations. For representations of the problems, high-spatial students could reorganize representations of spatial problems into other corresponding representations while low-spatials used multiple, uncoordinated representations of the same problems. Eye-tracking also showed that high-spatial students made eye movements that corresponded to elements of the problem while low-spatial students did not. The researchers suggested this is due to the high-spatial individuals visualizing the correct movement produced when the two movement components were integrated.

To help improve performance in engineering, Sorby and Baartmans (2000) developed a 10-week course to help teach spatial visualization skills to freshman engineering majors who were identified as having lower scores on the Purdue Spatial Visualization Test: Rotations (PSVT:R). Twenty-four students took the course while 72 acted as the control group. During the course students were taught topics such as rotations of objects, cross-sections of solids, and translation and scaling. Those who participated in the course showed significant gains on the PSVT:R beyond simple practice effects. Furthermore, after later analyzing the transcripts for the all of the 96 students, the researchers found that students who took the course scored higher on later graphics courses and had higher retention rates in the graphically oriented engineering program.

While higher spatial ability often facilitates STEM learning for novices, experts in the field often do no use spatial strategies when solving problems. For example, Stieff (2007) found that students used mental rotation strategies when determining if molecular diagrams were identical or enantiomers. In contrast, experts typically used an analytical strategy to complete the task. Uttal and Cohen (in press) propose that spatial ability actually acts as a gateway to getting into STEM fields. While experts develop contextualized spatial abilities and can also used prior semantic knowledge, novices must rely on de-contextualized spatial abilities. Therefore spatial training such as Sorby and Baartmans's (2000) can be used to help novices develop these skills and prevent dropout.

Video Games and Spatial Cognition

Spence and Feng (2010) propose that if students possess poor spatial skills, they will avoid learning in academic areas that require spatial cognition, such as STEM subjects. Similar to verbal or mathematic ability, we must try to improve spatial ability through training either through early education or through play. Research has shown that video games can be used to improve spatial cognition skills. Terlecki et al. (2008) found long lasting, transferable effects on spatial skills after participants were trained using Tetris. For the study, both control and experimental subjects were given a mental rotation task (MRT) once a week over a 12 week period. Participants in the experimental condition also played Tetris for one hour a week while the control participants played Solitaire. At the end of the 12 weeks, large improvements were found for both the repeat MRT exposure control group and the video game training group. Participants in the videogame training condition, however, showed significantly greater transfer effects on the Guilford-Zimmerman Spatial Visualization Task (Guilford & Zimmerman, 1947) and the Surface Development Test (SDT) (Ekstrom, French, & Harman, 1976).

Feng, Spence, and Pratt (2007) also found improvement on a mental rotation task after participants played a first-person shooter action game called Medal of Honor: Pacific Assault. First-person shooter games involve simulated combat in which the player competes against other players or computer controlled enemies. Improvement in mental rotation correlated with improvement on a useful-field-of-view task (UFOV). The authors suggest that the improvement in mental rotation was due to improving lower level attention skills.

Furthermore, Subrahmanyam and Greenfield (1994), in a study on improving both dynamic and static skills in school aged children, found that those with the best initial spatial skills were best at playing the video game. The researchers proposed that strong dynamic spatial skills helped the participants master a game while practice strengthened weak dynamic spatial skills. The fact that already existing strong dynamic spatial skills facilitate game mastery relates back to Uttal and Cohen's (in press) argument that spatial ability can act as a gateway to STEM areas. In these training studies students/participants are completing these training regimes either because they are being paid or as part of a class exercise. In the real world there is no external motivator to encourage individuals to continue playing video games if they find them too difficult, perhaps due to a lack of spatial ability, or because they find video games unappealing in general. Studies with expert video game players that display high spatial and visual attention skills are also dealing with individual that were self-selected game players (Feng et al., 2007). These individuals may have become regular game players because they possessed higher relative spatial skills to begin with. This could be causing a Matthews effect in which individuals with higher spatial skills enjoy playing action video games therefore they play more of them and further improve their spatial abilities. The question then becomes whether lacking preexisting spatial ability could affect video game performance and therefore affect the motivation to continue playing.

Present Study

The present study examines the relationship between performance on static spatial tasks (i.e., mental rotation and paper-folding) and dynamic spatial tasks (i.e., race task and interception task) on the one hand and novice performance on commercial video games (i.e., Unreal Tournament and Tetris) on the other. Prior research by Terlecki et al. (2008), Feng et al. (2007) and Subrahmanyam and Greenfield (1994), have found that playing video games can increase performance on tasks involving different cognitive skills. However, no study has explored how an individual's performance on any of these cognitive tasks may relate to their ability to play video games.

Participants. The participants were 69 college students from the University of California, Santa Barbara (44 women, 25 men). Ages ranged from 18 to 27 years old with a mean age of 19.29 years. All participants were classified as non-video game players, meaning that that did not regularly play commercial video games during their free time.

Materials and Procedure. The experiment took place over two sessions that were scheduled within two days of one another. In the first session, participants first filled out a survey assessing their video game usage to remove any regular video game players. Next, they completed battery of tests including two dynamic spatial tasks and two static spatial tasks. All tasks included in the battery were administered on computers using electronic versions. Static spatial ability was assessed using a version of the Shepard and Metzler (1970) mental rotation test (MRT) and the paper-folding test (Ekstrom et al.,, 1976). The first cognitive task that participants completed was paper-folding. During the task, on each item, a series of pictures is presented demonstrating how a piece of paper is being folded. The last picture on the left includes circles that signify where holes are punched all the way through the folded piece of paper. To the right of the vertical line are five figures with possible configurations for the holes in the paper once it has been completely unfolded. Participants indicated which of the five figures they believed had the correct configuration by pressing the corresponding key (i.e., 1-5). Participants had 3 minutes for each of the 2 sets of 10 trials.

The paper-folding task was followed by the mental rotation task, in which two 3D block figures were presented simultaneously. The participants were asked to indicate whether the two items were the same or different (i.e., mirror-reversed images). On same trials the block figure on the right hand side of the screen was a version of the left figure rotated in depth varying by 20° intervals. Participants completed a total of 120 trials for this task.

Dynamic spatial skills were assessed using variations of the Race2 and Interception tasks as described by Hunt et al. (1988). Specifics for the Race2 task were taken from D'Oliveira (2009). During the Race task, two oval objects (one black, one white) race. horizontally toward their own finish lines, as exemplified in Figure 1. Three relative speed differences between the objects were used to vary trial difficulty. Participants completed one block with a total of 108 trials. For the Interception task, the goal is to hit a moving target as it passes across the top of the screen with a 'missile' fired from a fixed location along the bottom of the screen. The target appeared in four different locations and traveled at four different speeds. Participants completed a total of 64 trials. The intent of the task was to measure how accurately the participants can judge the amount of time it will take for the 'missile' to intercept the target.

During the second session, participants played an hour of a first-person shooter action video game called Unreal Tournament 2004 (UT) as well as 45-50 minutes of the puzzle game Tetris. Which game was played first was counterbalanced between sets of participants.

During the 1 hour action video game session, game play was separated into three 20 minutes intervals. During the first two 20 minute game intervals participants played at the lowest level of difficulty (novice). For the last 20 minute game interval, the difficulty level was raised to the second lowest difficult level (average). The difficulty level determine how effective the 16 enemy "bots" controlled by the game were at firing and tracking down the player. In order to be successful the players must be able to avoid enemy fire while aiming and returning fire. The game keeps track of how many times the player kills an enemy as well as how many times the player is killed.

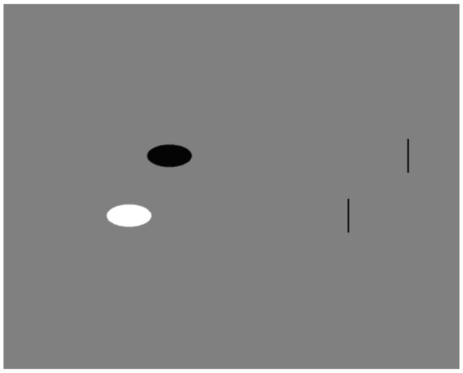

Figure 1: Sample trial from Race task adapted from D'Oliveira (2009)

Tetris is a puzzle game in which players use 7 different block shapes in order to create lines. Every time a complete line is created the line disappears and the player is awarded points. The more lines that the player completes at a time the higher the point value awarded. If incomplete lines fill the given area the game ends. Participants are given one block shape at a time and have to place it somewhere at the bottom of the play area. As the player's score increases, the falling rate of the blocks increase making the game harder. The 7 block shapes can be rotated in increments of 90 degrees. Five of the block shapes are asymmetrical allowing for 4 different possible configurations that can be used to complete lines.

After finishing playing each game, participants were asked questions relating to their game satisfaction including how much they enjoyed the game, how likely they would play the game again, and how difficult they found playing the game. To measure performance on UT, total number of kills across all three games was used. For Tetris, performance was assessed by recording the highest score achieved while playing the game.

Results

To first examine whether the order in which the participants played the game affected their performance independent sample t-tests were conducted. No significant differences were found between participants who played UT first or second for either UT performance, $t(63) = .224$, $p = .823$, or highest score on Tetris, $t(64) = .906$, $p = .368$. Looking at performance on just the first two games of Tetris, since all participants played at least 2 games, revealed that participants in the UT first group scored significantly higher than those that played Tetris

Table 1: Correlations between the game performance measures and performance on the four cognitive tasks.

Game performance	Mental rotation		Paper folding	Race	Intercept
	Total Errors	Mean RT	Score	RT Combined Easy Trials	Accuracy
Tetris (Top Score)	-.206	.002	.244*	-.196	.185
Unreal Tournament (Total Kills)	-0.267*	-0.334**	.271*	-.269*	.212

*Designates a significance level of .05
** Designates a significance of .01

first, *t*(64) = .2.087, *p* = .041, on their second game This suggests that playing UT first may actually increase performance on Tetris playing. To examine whether performance on one video game related to performance on the other a Pearson correlation was conducted and revealed no significant correlation between UT kills and highest Tetris score, *r*(64) = -.007, *p* = .957.

Static Spatial Tasks. Table 1 shows the correlation between measures for mental rotation and paper-folding and UT and Tetris performance. For paper-folding, performance was assessed by combining the score for the two segments. Participants were penalized (-.2) for attempted items that they got wrong. As shown in the first column of Table 1, there was a modest, positive correlation between UT total kills and paper-folding score, *r*(63) = .271, *p* = .032, as well as a modest, positive correlation between high Tetris score and paper-folding score, *r*(64) = .244, *p* = .050.

Next we examined whether response time (RT) performance on mental rotation correlated with performance on either UT or Tetris. As shown in the second column of Table 1, there was a moderate, negative correlation between UT total kills and mean response time across all mental rotation items , *r*(64) = - .334, *p* = .007. This indicates that participants who had higher scores on UT had faster response times for the mental rotation. There was no significant correlation between highest Tetris score and response time for mental rotation, *r*(66) = .002, *p* = .990. The same pattern was obtained for error rates on the mental rotation task: there was a significant negative correlation between total kills in UT and error rate for mental rotation, *r*(64) = -.267, *p* = .031, but no significant correlation between highest score in Tetris and error rate for mental rotation, *r*(66) = .002, *p* = .990.

Dynamic Spatial Tasks. For the race task we examined both accuracy (indicating the correct object would win the race) and response time (how quickly participants determined which object would reach the goal first). Reponses times were only used for correct trials. In general there was a high accuracy across all participants, especially at the higher relative speed increases (easier trials). For Tetris, there was no significant correlation between Tetris score and race accuracy, *r*(67) = .144, *p* = .245, or race response times, *r*(67) = -.177, *p* = .152. For UT, there was no significant correlation between total kills and race accuracy, *r*(67) = .148, *p* = .239. When looking at response times, analysis revealed a weak, negative correlation between total kills and average response times for the higher speed difference ratios, *r*(65) = -.269, *p* = .030, but not the smallest speed increase, *r*(65) = -.178, *p* = .157, or overall average response times, *r*(65) = -.242, *p* = .052. This indicates that at the easier levels, when the relative speed between the two objects was greater, participants that had higher scores on UT made faster responses on the race task.

Finally, for the intercept/missile task, performance was measured by looking at the participant's accuracy at hitting the target over the 64 trials. No significant correlation was found between missile accuracy and game performance for either total kills in UT, *r*(64) = .212, *p* = .091, or highest score in Tetris, *r*(64) = .185, *p* = .135.

Discussion

The results from the present study suggest that individuals who already posses certain spatial skills, such as indicated by faster response times for dynamic spatial skills, mental rotation, and paper-folding, are more likely to do better at playing an action video game such as Unreal Tournament, whereas the connection between spatial skills and early Tetris appears to be less pronounced.

Unlike prior research by Terlecki et al. (2008) this study found no connection between Tetris playing and mental rotation. This is similar to results found by Sims and Mayer (2002) in which there were no significant differences between high-skill and low-skill Tetris players on any spatial tasks except for those that involved Tetris shapes or Tetris like shapes. In a separate study they also found that after 12 hours of training Tetris, participants did not significantly differ on mental rotation tests from those who had not practiced except for using different strategies when rotating Tetris shapes. Research by Kirsh and Maglio (1994) suggests that Tetris may not be the best environment to increase mental rotation performance. Tetris players often offload the mental rotation effort by using the game mechanics to rotate the figures instead of mentally doing the rotation. According to their model, the player should first compute the best place to put the Tetris piece before planning any rotation or movement to place it. The data shows that participants actually begin rotating the shape very early, before a possible placement could be decided upon. Rotating a shape in the external world is classified as an epistemic action, which are actions that are designed to change the input to the information-processing system and a way that an individual can alter the external environment to provide information needed to complete the task. In Tetris, if the game can complete the rotations faster than it takes the individual to do the rotations mentally, then it make sense from a limit cognitive resources standpoint for the individual to rely on the eternal rotation that only requires a simple motor action to complete (Kirsh & Maglio, 1994). Therefore, if participants are not actually practicing mental rotation during Tetris, it may not be the best game to use to increase spatial cognition.

Our findings did show that Tetris performance correlated significantly with paper-folding. One possible reason for this is that while Tetris does not require skills in mental rotation, it does require other visualization skills. Good Tetris players may be better able to visualize all possible configurations of the Tetris pieces therefore being able make quicker decisions about where to place pieces.

Both Tetris and action video games have been used to successfully train spatial cognition skills such as mental rotation (Terlecki et. al. 2008, Feng et al., 2007). The results from this study lead to two questions that should be addressed in future research. First, would playing one type of game lead to higher, more transferable, or longer lasting spatial skills compared to playing another? Four measures from our static and dynamic spatial skills were related to performance in game playing for Unreal Tournament while only one was related to Tetris. Feng et al. (2007) theorize that improvements in spatial tasks depend on the skills required during the game. The action video game improves lower-level spatial attention capacities, which in turn improves MRT performance. Their control condition did use a 2D puzzle game but because the game did not sufficiently exercise spatial attention capacities there was no benefit from playing. This suggests that the best way to improve mental rotation is to improve spatial skills in a way that is more generalizable. This could involve improving lower level cognition skills such as attention. Spence and Feng (2010) also proposed that along with improving spatial selective attention, one other key difference between puzzle games like Tetris and many action video games is the perspective. The majority of puzzle games are played from a more allocentric perspective making the visuomotor coordination in Tetris is less natural compared to the more egocentric perspectives used in most first person shooter action games. Playing an action video game may therefore be more likely to increase spatial ability. A comparison of two comparable training regimes using either Tetris or an action game like Unreal Tournament should be done to determine whether there is any benefit to using one game over the other.

Another possible question is if both games can increase spatial ability, as prior research has shown, could the required level of preexisting spatial ability to play affect whether it is a viable choice for training? As proposed by Spence and Feng (2010), a student with poor spatial skills may avoid tasks that require them. As mentioned previously, this suggests the potential for a Matthew effect with spatial cognition and video games. Those that already possess high spatial skills do better at playing action video games and are more likely to continue to playing. By continuing to play these individuals increase their spatial ability. Therefore, a game such as Tetris which appeared to require less preexisting spatial skill to be successful may encourage students to play more than one like Unreal Tournament.

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