The Power of Play: The Effects of Portal 2 and Lumosity on Cognitive and Noncognitive Skills

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Abstract

In this study, we tested 77 undergraduates who were randomly assigned to play either a popular video game (Portal 2) or a popular brain training game (Lumosity) for 8 hours. Before and after gameplay, participants completed a set of online tests related to problem solving, spatial skill, and persistence. Results revealed that participants who were assigned to play Portal 2 showed a statistically significant advantage over Lumosity on each of the three composite measures—problem solving, spatial skill, and persistence. Portal 2 players also showed significant increases from pretest to posttest on specific small- and large-scale spatial tests while those in the Lumosity condition did not show any pretest to posttest differences on any measure. Results are discussed in terms of the positive impact video games can have on cognitive and noncognitive skills.

Keywords: assessment, persistence, problem solving, spatial skills, videogames

1. Introduction

Most children and young adults gravitate toward digital games. The Pew Internet and American Life Project surveyed 1,102 youth between the ages of 12 and 17 and found that 97%—both males (99%) and females (94%)—play some type of digital game (Lenhart et al., 2008). Escobar-Chaves and Anderson (2008) further note that the amount of time spent playing digital games continues to increase, and has since the introduction of home computers and gaming consoles in the mid-1980s. The increase in digital game play can be seen in a Kaiser Foundation study (Rideout, Foerh, & Roberts, 2010) that found that 60% of individuals aged 8 to 18 played digital games on a typical day in 2009, compared to 52% in 2004 and 38% in 1999. These young people aren't playing in isolation, either; Ito et al. (2010) found that playing digital games with friends and family is a large and normal part of the daily lives of youth.

Besides being a popular activity across gender, ethnic, and socioeconomic lines, playing digital games has been shown to be positively related to various competencies, attributes, and outcomes such as visual-spatial skills and attention (e.g., Green & Bavelier, 2007, 2012, Ventura, Shute, Wright, & Zhao, 2013), openness to experience (Chory & Goodboy, 2011; Ventura, Shute, & Kim, 2012; Witt, Massman, & Jackson, 2011), college grades (Skoric, Teo, & Neo, 2009; Ventura, Shute, & Kim, 2012), persistence (Ventura, Shute, & Zhao, 2012), creativity (Jackson et al., 2012), and civic engagement (Ferguson & Garza, 2011). Digital games can also motivate students to learn valuable academic content and skills (e.g., Coller & Scott, 2009; Shute, Ventura, & Kim, 2013; for a review, see Tobias & Fletcher, 2011; Wilson et al., 2009; Young et al., 2012). However, others have found a lack of transfer effects between action video game playing and basic cognitive functions and skills (e.g., Boot, Kramer, Simons, Fabiani, & Gratton, 2008) and have raised questions regarding the methodology of studies that observe transfer (Boot, Simons, Stothart, & Stutts, 2013; Kristjánsson, 2013). That is, Boot and colleagues (2013) argue that researchers need to compare any game/treatment condition with a similarly-active control group that has the same expectations of improvement as the experimental group. Only then can we attribute differential improvement to the strength of the treatment. Despite the need to match expectations between treatment and control groups, few psychological interventions do so.

This study seeks to extend the growing body of experimental research examining the relationships between video game play and cognitive and noncognitive skills. We investigate a popular video game called Portal 2, a 3D puzzle game that has received numerous awards for its innovative design. In this study we examine the impact of playing Portal 2 for eight hours on two cognitive competencies (problem solving and spatial skills) and on a noncognitive attribute (persistence). As a conservative control condition, we use a popular brain training game called Lumosity--widely advertised as supporting multiple core cognitive processes and skills such as problem solving, memory, attention, speed, and mental flexibility. This control game, with an explicit focus on improving the user's cognition, would generate expectations of improvement more than a simple game like Tetris, which is the game typically used to test game effects against. As such, our choice to use Lumosity as the control condition for the current study addresses and overcomes the main concern (i.e., differential expectations) raised by Boot, Simons, Stohart, and Stutts (2013).

We organize this section of the paper as follows. First, we describe Portal 2 and define our focal constructs (problem solving, spatial skill, and persistence) and their associated facets that may be improved by playing the game. Second, we describe Lumosity in relation to the company's stated goals on their website as well as some of the game activities included in their suite of brain games. We then present the hypotheses of our research study.

1.1. Portal 2

Portal 2 is the name of a popular linear first-person puzzle-platform video game developed and published by Valve Corporation. Players take a first-person role of Chell in the game and explore and interact with the environment. The goal of Portal 2 is to get to an exit door by using a series of tools. The primary game mechanic in Portal 2 is the portal gun, which can create two portals. These portals are connected in space, thus entering one portal will exit the player through the other portal. Any forces acting on the player while going through a portal will be applied upon exiting the portal. This allows players to use, for example, gravity and momentum to "fling" themselves far distances through the air. This simple game mechanic is the core basis of Portal 2. Figure 1 illustrates flinging in Portal 2.

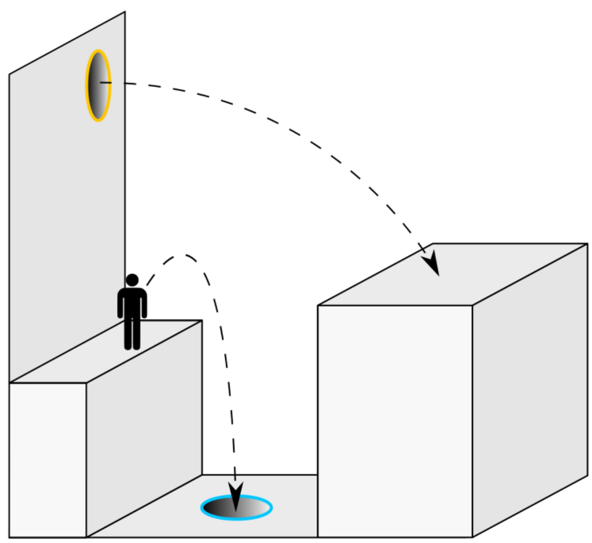

Figure 1. Flinging in Portal 2

Other tools that may be used to solve puzzles in Portal 2 include Thermal Discouragement Beams (lasers), Excursion Funnels (tractor beams), Hard Light Bridges, and Redirection Cubes (which have prismatic lenses that redirect laser beams). The player must also disable turrets (which shoot deadly lasers) or avoid their line of sight. All of these game elements can help in the player's quest to open locked doors, and generally help (or hinder) the character from reaching the exit. The initial tutorial levels in Portal 2 guide the player through the general movement controls and illustrate how to interact with the environment. Characters can withstand limited damage but will die after sustained injury. There is no penalty for falling onto a solid surface, but falling into bottomless pits or toxic pools kills the player character immediately.

There are several plausible ways for a person to acquire and hone certain skills as a function of gameplay in Portal 2. These are discussed in the context of our three focal constructs--problem solving, spatial skills, and persistence--in the theoretical review section.

1.2. Lumosity

Lumosity represents a computerized, commercial cognitive training program and claims to improve various core cognitive skills including memory, attention, processing speed, mental flexibility, spatial orientation, logical reasoning, and problem-solving skills. It was selected as the control condition in this study on the basis of assertions the Lumosity group makes relative to its games enhancing cognitive skills. For example, in a self-published paper on the Lumosity website entitled, "The science behind Lumosity" (Hardy, Farzin, & Scanlon, 2013 p. 5), the authors assert, "Taken together, the entire suite of exercises [in Lumosity] represents a comprehensive brain training system – an entire gym for the brain. There are exercises training speed of processing, memory, attention, mental flexibility, and problem solving."

The key component of the Lumosity cognitive training program is a suite of 52 games. Each game is a 2D puzzle-type game, designed to train on one of the aforementioned cognitive skills. Although the major game action involves only pointing and clicking, the games challenge players to perform speeded object or pattern recognition, attend to multiple objects simultaneously, associate and memorize visual and verbal information, and identify the hidden and changing rules in object sorting or sequencing. The challenge level of a game is usually decided by the presence and amount of distraction, the time limit, the salience or complexity of the pattern or rule to be recognized, and hence the amount of cognitive effort and skill required.

To play Lumosity, one logs into the Lumosity website and follows a personalized training program or *sequence* to play the games. The particular sequence is classified under each cognitive skill category (e.g., memory, attention, processing speed, mental flexibility). Each individualized training session consists of five games, and each game lasts around 5-6 minutes. The Lumosity website (http://www.lumosity.com/hcp/research) reports multiple empirical studies to support the efficacy of the Lumosity games on sustaining and/or promoting targeted cognitive skills. However, several recent studies have been conducted that challenge the assumption that cognitive training, using games like Lumosity, promotes generalization or learning transfer beyond the actual tasks performed during treatment (Ackerman, Kanfer, & Calderwood, 2010; Boot, Champion, Blakely, Wright, Souders, & Charness, 2013; Redick et al., 2013; Zickefoose, Hux, Brown, & Wulf, 2013).

Both game analysis and a review of the prior evaluation studies on Lumosity games indicate that this game suite is promising in promoting problem solving and spatial skills. Its multi-level and multi-game challenges require effortful gameplay and hence can also act as a vehicle for testing and reinforcing persistence. Therefore, in this study we have chosen Lumosity games as a rigorous comparison condition in examining the potential impact of Portal 2 on the development of problem solving, spatial skills, and persistence.

2. Theoretical Review of the Three Constructs

2.1. Problem Solving Skill

Researchers have long argued that a central point of education should be to teach people to become better problem solvers (Anderson, 1980) and the development of problem-solving skill has often been regarded as a primary goal of the education process (Ruscio & Amabile, 1999). Problem solving consists of four relatively independent skills: (1) rule application (solving problems by applying existing rules), (2) problem decomposition (determining the goals, sub-goals, and individual steps of the problem) (3) flexibility (i.e., using tools in novel ways), and (4) resource management (i.e., effective and efficient allocation of resources). For purposes of this study we focus on rule application and flexibility. Rule application refers to identifying and applying the rules in a problem in order to solve it. An example of rule application can be seen in the *Tower of Hanoi* puzzle problem (Chi & Glaser, 1985). The rules (or constraints) in this problem are (a) the solver can never place a larger disk on top of a smaller one, and (b) only one disk may be moved at a time. Rule application is an outward expression of the solvers' representation of the problem, which is crucial in problem solving (Gick, 1986; Jonassen, 2000; 2003).

Cognitive flexibility reflects one's ability to apply a rule and/or knowledge in a novel way within a particular context. Cognitive flexibility is often contrasted with "functional fixedness" (Bransford & Stein, 1984), which refers to individuals being blinded by their own thinking and beliefs. In such functionally-fixed situations, they are unable to break from their routine solution-seeking processes (Simon, 1969), or unable to notice obscure features of a problem. People with greater cognitive flexibility are more observant of features of an object or a problem situation, and may consider more alternatives in solving problems, than those with less cognitive flexibility (Bransford & Stein, 1984).

Recently, scholars have begun to suggest that video games can promote the development of problem solving skills (e.g., Prensky, 2012) but empirical support for these claims is still sparse. One such study looked at the longitudinal relationship between video game use and self-reported problem-solving skill (Adachi & Willoughby, 2013). In their study, strategic video gameplay (i.e., role playing and strategy games) predicted self-reported problem solving skills among a sample of 1,492 adolescents (50.8% female), over the four high school years.

Some possible outcomes of playing Portal 2 may be the enhancement of rule application skills and the reduction in functional fixedness (i.e., the enhancement of cognitive flexibility, as measured by insight problems). For example, Portal 2 provides a unique gameplay environment that can promote cognitive flexibility through multiple contextualized insight problems that require players to creatively apply newly-learned rules or tools. This practice reinforces players to rethink solutions to problems and be flexible in terms of trying alternative strategies (e.g., creating and using a portal to transport objects in addition to oneself; using the blue gel to smother turrets rather than using it for bouncing). This is important since the way in which students learn problem-solving strategies may influence their subsequent ability to understand and flexibly apply this information in the world.

2.2. Spatial Skills

Of particular importance in understanding the role of video gameplay relative to spatial cognition is the distinctions among: (1) figural, (2) vista, and (3) environmental spatial skills (Montello, 1993; Montello & Golledge, 1999). Figural spatial skill is small in scale relative to the body and external to the individual. Accordingly, it can be apprehended from a single viewpoint. It includes both flat pictorial space and 3D space (e.g., small, manipulable objects). It is most commonly associated with tests such as mental rotation and paper folding tasks. Vista spatial skill requires one to imagine an object or oneself in different locations—small spaces without locomotion. Vista spatial skill is useful when trying to image how the arrangement of objects will look from various perspectives (Hegarty & Waller, 2004). Environmental spatial skill is large in scale relative to the body and is useful in navigating around large spaces such as buildings, neighborhoods, and cities, and typically requires locomotion (see Montello, 1993, for a discussion of other scales of space). It usually requires a person to mentally construct a cognitive map, or internal representation of the environment (Montello & Golledge, 1999). Environmental spatial skill depends on an individual's configurational knowledge of specific locations in space, and is acquired by learning specific routes. Configurational knowledge depends on the quality of an individual's cognitive map, or internal representation of an environment. In this map-like representation, all encountered landmarks and their relative positions are accurately represented.

A game like Portal 2 has the potential to improve spatial skills due to its unique 3D environment that requires players to navigate through problems in sophisticated ways. Over the past 20 years, a growing body of research has shown that playing action video games can improve performance on tests of spatial cognition and selective attention (e.g., Dorval & Pepin, 1986; Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003, Spence, Yu, Feng, & Marshman, 2009; Uttal et al., 2012). Recently, Ventura, Shute, Wright, and Zhao (2013) showed that self-reported ratings of video game use were significantly related to all three facets of spatial cognition, and most highly related to environmental spatial skill. Feng et al. (2007) found that playing an action video game improved performance on a mental rotation task (i.e., small-scale or figural spatial cognition). After only 10 hours of training with an action video game, subjects showed gains in both spatial attention and mental rotation, with women benefiting more than men. Control subjects who played a non-action game showed no improvement.

Recently, Uttal et al. (2012) conducted a meta-analysis of 206 studies investigating the effects of training on spatial cognition. Of these 206 studies, 24 used video games to improve spatial skills. The effect size for video game training was .54 (SE = .12). Findings like these have been explained due to the visual-spatial requirements of 3D action games which may enhance spatial skills (e.g., Feng et al., 2007; Green & Bavelier, 2003; 2007).

2.3. Persistence

Over the past two decades, conscientiousness has emerged as one of the most important personality traits in predicting academic performance (e.g., Poropat, 2009) as well as in various life outcomes (e.g., Roberts, Kuncel, Shiner, Caspi, & Goldberg, 2007). Persistence (i.e., industriousness in Roberts, Chernyshenko, Stark, & Goldberg, 2005; achievement in Perry, Hunter, Witt, Harris, 2010) is a facet of conscientiousness that reflects a dispositional need to complete difficult tasks (McClelland, 1961), and the desire to exhibit high standards of performance in the face of frustration (Dudley, Orvis, Lebiecki, & Cortina, 2006). Perry et al. (2010) suggest that persistence may drive the predictive validity of conscientiousness and is the facet that consistently predicts a variety of outcomes over other facets of conscientiousness (Dudley et al., 2006; Perry et al., 2010; Roberts et al., 2005).

One way video games may affect persistence is through the principle of challenge used in video games. Challenge entails adjusting the optimal level of difficulty for a player. Thus video games can be seen as vehicles for exposing players to increasingly more challenging problem-solving activities. This repeated exposure to challenge can affect persistence, which again requires a willingness to work hard despite repeated failure. Recently, video game use was found to be related to a performance-based measure of persistence that measures how much effort people exert when facing difficult tasks (Ventura, Shute, & Zhao, 2012). Portal 2, for example, provides a gameplay environment that can potentially improve persistence because the game involves many challenges that typically require players to persevere despite failure and frustration. It is our belief that pushing one’s limits is an excellent way to improve persistence, especially when accompanied by the great sense of satisfaction one gets upon successful completion of a very thorny problem.

2.4. Hypotheses

Based on the literature review of the three focal constructs and the aforementioned features of Portal 2 and Lumosity, we make the following hypotheses:

1. Portal 2 outcome scores for problem solving, spatial skills, and persistence will be comparable to (or greater than) the Lumosity outcomes on the same constructs and on specific measures.

2. Players in both the Portal 2 and Lumosity conditions will show improved pretest-to-posttest gains relative to both facets of problem solving skill: rule application and cognitive flexibility.

3. Players in Portal 2 will improve all three facets of spatial skill: figural, vista, and environmental while players in Lumosity will only improve their figural and vista skills.

4. In-game performance measures in Portal 2 and Lumosity will predict posttest scores in problem solving and spatial skills, after controlling for pretest scores.

3. Method

3.1. Participants

We solicited subject participation via flyers placed around the campus of a major research university in the southeastern United States. Potential participants were screened using an online questionnaire on prior game experiences. A total of 218 students applied to participate, and 159 were approved to participate. Approval was not given if a person indicated (a) susceptibility to motion sickness, (b) had played through Portal 2 before, or (c) self-reported as a frequent video game player (i.e., playing every day). Among the approved population: 77 completed the study, 54 never signed up for scheduling, 1 signed up but never showed up, and 27 dropped out of the study due to various reasons (e.g., sickness or lack of time or interest). Among the 27 who dropped out, most of them did after the first session. Our sample of 77 subjects were 18- 22 years old (M = 19.7; SD = 1.3) and 43% male and 57% female. All subjects were randomly assigned to condition (42 to Portal 2, and 35 to Lumosity). We needed at least 34 participants per condition to estimate moderate effect sizes in our analyses, with a power of .90. After completing all parts of the study, subjects were given a $100 gift card.

3.2. Procedure

Each participant spent 10 hours in the study, which spanned four separate sessions in the on-campus laboratory of the university, across 1-2 weeks. Each of the first three sessions lasted 3 hours. Session 4 lasted one hour--solely for administering the posttest battery. At the beginning of the first session, subjects in both conditions were asked to read and sign the consent form. After signing the form, subjects were randomly assigned to one of the two conditions. All subjects were then administered an online set of pretests. Once they finished the pretests, they logged in to play their assigned game for the rest of the first session. They continued to play their assigned game for the entire second and third session (for a total of 8 hours of gameplay). During the last session, they completed the online set of posttests.

Subjects were seated in small groups of about 3-4 participants per session (up to occasionally 8 participants or just 1 for a session). They were provided with a pair of Sony headphones to wear during gameplay. Talking about their respective games was not permitted. One or two graduate students served as proctors in the study, per session. Proctors were instructed to only provide technical assistance to the students.

3.3. Instruments

Before and after 8 hours of gameplay, subjects completed an online pretest and posttest battery of tests measuring our focal constructs and their relevant facets. Each test battery required about 50-60 minutes to complete. The tests for problem solving, spatial skills, and persistence are described next. With the exception of persistence, all measures were matched and counterbalanced between pretest and posttest. That is, half of all subjects received form A as a pretest and form B as a posttest, and the other half received the opposite ordering. We conclude this section with a summary of the performance-based (in-game) measures per condition, as well as an enjoyment-of-condition measure.

3.3.1. Problem solving. We used several external measures of problem solving to examine learning in Portal 2 and Lumosity. All of our external instruments were administered online after we created (or recreated) the items. To measure rule application, we used Raven's progressive matrices, and for cognitive flexibility, we used a suite of insight problems and creative problem solving tasks (i.e., RAT--remote association task). Each is described in more detail below.

3.3.1.1. *Raven's Progressive Matrices* (RPM). RPM requires participants to infer the pattern of the missing piece from the other patterns given. Although the test is widely used as an intelligence test (e.g., Carroll, 1993; Snow, Kyllonen, & Marshelek, 1983), as Raven (2000) pointed out, the RPM focuses on two cognitive processes–eductive and reproductive skill. Eductive skill involves making sense out of chaos and generating high-level schema to handle complexity. Reproductive skill requires the recall and reproduction of information that has been explicated. Rule application in general is the behavior of following the basic rules of a problem in order to solve the problem. It is an outward expression of the solvers' perception of the problems' features, via both eductive and reproductive abilities. The full RPM test kit consists of 60 items, arrayed by difficulty. Reported reliability for this test is about .90. We selected 12 RPM items for our pretest and 12 items for our posttest. We matched the items in the two tests by difficulty level (as presented in the RPM test kit) choosing four easy, four medium, and four difficult items per form. The time limit per item is four minutes. The split-half reliability of the 12 items in our pretest is .65 (posttest reliability is .70). Using the Spearman-Brown prediction formula to adjust the reliability based on a 60-item test length, the adjusted reliability is .90.

3.3.1.2. *Insight test.* Insight problems require problem solvers to shift their perspective and look at obscure features of the available resources or to think of different ways to make use of an object. Dow and Mayer (2004) concluded that insight problems are domain specific and three major domains are mathematical, verbal, and spatial. Among them, verbal insight problems require the least prior knowledge (Chu & MacGregor, 2011). For example, consider the following question: Marsha and Marjorie were born on the same day of the same month of the same year to the same mother and the same father yet they are not twins. How is that possible? The answer is that they are triplets. The question requires the problem solver to think beyond the immediate context. We selected three verbal insight problems for the pretest and three for the posttest. The time limit per item is five minutes. The reliability of the 3 items in our pretest is .64.

Using the Spearman-Brown prediction formula to adjust the reliability based on a 15-item test length, the adjusted reliability is .90.

3.3.1.3. *Remote Association Test (RAT).* Mednick (1962) developed the remote-association test (RAT) as a means of measuring creative thought without requiring knowledge specific to any field. He constructed two college-level versions of the test, each consisting of 30 items (Mednick, 1968). Each item consists of three words that can be associated with a solution word in a number of ways. For example, the three words SAME/TENNIS/HEAD may be associated with the solution MATCH by means of synonymy (same = match), formation of a compound word (matchhead), and semantic association (tennis match). Reaching a solution requires "creative thought" because the first, most related, information retrieved in solution attempts is often not correct, and solvers must think of more distantly related information in order to connect the three words. And while problem solvers' success on items from the original RAT has been shown to correlate with success on classic insight problems (Schooler & Melcher, 1995), the RAT requires language skills and hence differs from insight problems, even though both claim to measure problem solving. We have 5 RAT problems for the pretest and 5 for the posttest. The time limit per item is five minutes. The reliability of the 5 items in our pretest is .54. Using the Spearman-Brown prediction formula to adjust the reliability based on a 20-item test length, the adjusted reliability is .82.

3.3.2. Spatial cognition. We used several external measures of spatial cognition to assess subjects' figural, vista, and environmental spatial skills. To measure figural (or small-scale) spatial skill, we used the mental rotation task. We administered the Spatial Orientation Test (Hegarty & Waller, 2004) to assess vista spatial skill. And to assess environmental spatial skill, we developed and validated our own assessment called the Virtual Spatial Navigation Assessment.

3.3.2.1. *Mental Rotation Test* (MRT). The MRT we used was adapted from Vandenberg and Kuse (1978). In this test, participants view a three-dimensional target figure and four test figures. Their task is to determine which of the test figure options represent a correct rotation of the target figure. The MRT has two correct answers for each item. There are six SOT items per form, with no time limit set on items in this test. The total score is based on the total number of items where both correct objects are found. Higher scores indicate higher figural spatial skill. The reliability of the 6 items in our pretest is .65. Using the Spearman-Brown prediction formula to adjust the reliability based on a 30-item test length, the adjusted reliability is .90.

3.3.2.2. *Spatial Orientation Test* (SOT). The SOT requires the participant to estimate locations of objects from different perspectives in one picture (Hegarty & Waller, 2004). In each item the participant is told to imagine looking at one object from a particular location in the picture and then point to a second location. An example item is as follows: Imagine you are looking at the tree from the position of the cat, now point to the car. The participant must draw the direction in a circle relative to an arrow in the circle that is always pointing to the 12 o'clock position. Each response is scored as a difference between the participant's angle and the correct angle (scores range from 0-180 degrees). Larger differences between a participant's drawn angle and the correct angle indicate lower vista spatial skill. There are six SOT items per form, with a three-minute time limit for each item. The reliability of the 6 items in our pretest is .72. Using the Spearman-Brown prediction formula to adjust the reliability based on a 24-item test length, the adjusted reliability is .89.

3.3.2.3. *Virtual Spatial Navigation Assessment* (VSNA). The VSNA (Ventura, Shute, Wright, & Zhao, 2013) was created in Unity, a free video game development software tool. In the VSNA, a participant explores a virtual 3D environment using a first person avatar on a computer. Participants are instructed that the goal is to collect all the gems in an environment and return to the starting position. Participants first complete a short familiarization task that requires them to collect colorful gems in a small room. The VSNA consists of an indoor environment consisting of halls in a building (i.e., a maze), and an outdoor environment consisting of trees and hills. The gems are strategically located in both environments so that an optimal path can be used to collect all the gems. In each environment the participant must collect the gems twice. The first collection is the training phase and the second collection is the testing phase. The VSNA collects data on the time taken to complete the training and testing phases in an environment (i.e., time to collect all gems and return to the starting position) as well as the distance traveled in the training and testing phase of an environment. Warm-up time to gain familiarity with the interface is two minutes, and the training and testing for indoor task is 15 minutes as well as 15 minutes for the outdoor task. The main measure used in the current study consists of the time to collect all gems and return home, in warmup, indoor, and outdoor environments. Less time suggests greater navigational skill. The VSNA has been validated against other spatial measures (see Ventura, Shute, Wright, & Zhao, 2013). The test-retest reliability of the latency data from the 3 trials (warm-up, indoor, outdoor) is .65.

3.3.3. Persistence. To measure persistence, we used a performance-based measure (i.e., picture comparison task) and a self-report survey.

3.3.3.1. *Picture comparison* (PC). We developed and validated an online performance-based measure of persistence that measures how much effort people exert when facing really difficult tasks (see Ventura, Shute, & Zhao, 2012). The task involves comparing two pictures, where pairs of pictures appear one at a time over a series of trials. Individuals click on the features that differ between the two pictures, and then submit their response. For each picture pair, participants are told to identify four differences between the two pictures (where "differences" reflect missing features). If the answer is wrong, the screen displays "incorrect" and the individual can try again (for up to 180 seconds). At any time the individual can select the "skip" button to leave the current trial and go on to the next one. If the individual guesses correctly, the person is told that he or she is correct. A trial is classified as "solved" if the person accurately completes the trial. A trial is classified as unsolved if the person skips the trial or is timed out after 180 seconds. The critical information in the PC task that informs the assessment of persistence is time spent on unsolved trials (i.e., impossible tasks—i.e., where the participant is told to identify four differences, but only three differences exist). More time spent on the item suggests greater persistence. The PC test presents 5 impossible and 4 easy filler problems. This test was only administered in the posttest to avoid participants detecting the nature of the task (i.e., that some trials are impossible to solve). Latency data from the 5 impossible trials was used as our persistence measure. The reliability of the latency data from the 5 impossible trials is .64. Using the Spearman-Brown prediction formula to adjust the reliability based on a 15-item test length, the adjusted reliability is .84.

3.3.3.2. *Persistence self-report survey*. We administered 8 online questions relative to persistence (see Ventura & Shute, 2013) that were adapted from the International Personality Item Pool (IPIP), perseverance/industriousness/persistence scale. Examples of the items (rated on a 5-point Likert scale, from 1 = strongly disagree to 5 = strongly agree) are: I tend to give up easily (reverse coded), I have patience when it comes to difficult problems, and I always try my hardest. These items were only administered in the pretest and served as a covariate for the picture comparison task. The reliability of the data from the 8 responses in the survey is .79. Using the Spearman-Brown prediction formula to adjust the reliability based on a 16-item test length, the adjusted reliability is .88.

3.4. Game-related metrics

For each of the two conditions in the study, we collected in-game measures concerning gameplay performance.

3.4.1. Portal 2 in-game measures. Performance in Portal 2 was computed as the average of three individual performance indicators collected from players' log files after 8 hours of Portal 2 gameplay: (a) total number of levels completed (more is better), (b) average portals shot (less is better), and (c) average time to complete levels (less is better). Each variable was standardized then averaged together after the first variable was negatively scaled. The Portal 2 performance variable overall was scaled negatively, so lower means better.

3.4.2. Lumosity in-game measures. Performance in Lumosity was defined by a player's "brain power index" (BPI) which is the total score over all Lumosity activities and constructs. That is, the BPI (as well as constituent scores for speed, memory, attention, flexibility, and problem solving) are calculated automatically by the Lumosity game engine and displayed on the screen. The Lumosity performance variable (BPI) was scaled positively, so higher means better.

3.4.3. Enjoyment item. After participants in each condition finished their 8 hours of gameplay and before the posttest battery of tests was administered, we presented an item to players concerning their enjoyment of the assigned game. This was a single self-reported response to the statement: "I enjoyed playing (*Portal 2* or *Lumosity*)." The 5-point Likert scale ranged from 1 (strongly disagree) to 5 (strongly agree).

4. Results

4.1. Differences between Conditions

Table 1 displays the descriptive statistics for all measures used in the study. To test hypothesis 1 (i.e., differences among our three constructs by game condition), we computed three ANCOVAs comparing each composite posttest score by condition, controlling for the associated pretest score.

Table 1. Descriptive Statistics for Portal 2 (*n* = 42) and Lumosity (*n* = 34)

	PORTAL 2		**LUMOSITY**	
	Mean	**SD**	**Mean**	**SD**
Raven's (pre)	8.39	2.29	8.24	2.31
Raven's (post)	8.51	2.33	7.65	2.60
Insight (pre)	1.30	0.97	1.40	1.09
Insight (post)	1.36	0.91	0.96	0.99
RAT (pre)	2.59	1.40	2.65	1.28
RAT (post)	2.83	1.34	2.56	1.33
Problem Solving (pre)	0.03	0.67	0.01	0.76
Problem Solving (post)	0.16	0.62	-0.18	0.67
MRT (pre)	1.57	0.27	1.41	0.37
MRT (post)	1.65	0.27	1.45	0.37
SOT (pre)	36.03	28.79	35.68	25.11
SOT (post)	32.00	26.06	30.60	26.02
VSNA test (pre)	127.02	112.48	142.73	95.62
VSNA test (post)	91.03	29.39	115.45	86.23
Spatial Ability (pre)	0.15	0.77	-0.17	0.84
Spatial Ability (post)	0.23	0.53	-0.27	1.00
Picture Comparison (post only)	136.01	42.63	118.03	45.50
Persistence self-report (pre only)	3.91	0.62	4.00	0.67
Persistence (post)	0.18	0.89	-0.20	0.93

Notes. For SOT and VSNA measures, lower scores reflect greater spatial skills as they represent angular disparity and time to complete task, respectively. Average scores were computed for problem solving skill and spatial ability by standardizing each relevant measure and putting the tests on the same scale (higher is better).

Composite scores were created by computing z-scores for each pretest and posttest measure, then averaging them into a composite score for problem solving and spatial skills.

For the persistence measure, we removed some items from the picture comparison task because most subjects appeared to have figured out the deception (i.e., certain items were impossible to solve rather than just being very difficult) after two exposures to these items. The Means and SDs for the five impossible trials for all subjects, in order and in seconds, were: 131 (47.6), 124 (50.5), 90.3 (53.2), 80.2 (46.5), and 75.0 (47.9). After the first two tasks, latencies drop abruptly. Thus we computed and used the mean of the first two impossible items in the picture comparison task as our persistence score (and standardized persistence measure). In Table 1, the composite scores appear in the shaded cells under their respective test scores, and can be interpreted as standardized measures. The distribution of the three dependent variables fulfilled the normality assumption of the test.

The ANCOVA models revealed the following. There was a significant main effect for the *problem solving* construct, $F(1, 71) = 5.49$; $p = .02$; Cohen's $d = .59$, with an advantage for Portal 2 over Lumosity. There was also a significant difference between conditions on the *spatial skills* construct, $F(1, 71) = 4.41$; $p = .04$; Cohen's $d = .64$; again in Portal 2's favor. Finally, differences between conditions in relation to *persistence* (time spent on impossible tasks holding the self-report persistence score constant) was significant, $F(1, 71) = 4.00$; $p = .05$, Cohen's $d = .42$, with Portal 2 participants showing more persistence after gameplay compared to Lumosity participants. These general findings thus justified additional ANCOVA models for the individual tests comprising problem solving and spatial skills.

Table 2 displays the marginal means for the posttest scores that were significantly different between the conditions ($p < .05$)—the Insight test (one of the problem solving measures), and two of the spatial tests (MRT and VSNA). The measures were controlled for player enjoyment in all models (when significant) to rule out any effect enjoyment might have in learning gains. That is, based on participants' responses to the statement about enjoying their assigned game, for Portal 2 participants, enjoyment $M = 4.32$; $SD = 0.93$, while for the Lumosity participants, $M = 3.50$; $SD = 1.05$. The difference between the two groups' enjoyment is significant, with a strong advantage for the Portal 2 group: $F(1, 73) = 12.69$; $p < .001$. Cohen's $d = .83$, which is a large effect size.

Table 2. Posttest marginal means (controlling for pretest) and effect sizes

Dependent Variable	**Portal 2**	**Lumosity**	**Cohen's d**
Insight	1.38	0.98	.45
MRT	1.61	1.50	.42
VSNA	87.31	119.94	.60

For the problem solving tests, the ANCOVA results show that the Portal 2 Insight posttest (M = 1.38, SD = .89) was higher than the Lumosity posttest (M = 0.98, SD = .90) at the one-tailed level $F(1, 73) = 3.66$; $p < .05$. The Raven's and RAT posttest means were not significantly different between the two conditions.

The ANCOVA results for the spatial tests show that Portal 2 MRT posttest scores (M = 1.61, SD = .27) were greater than the Lumosity MRT scores (M = 1.50, SD =.27) under a one-tailed test, $F(1, 73) = 2.83$; $p < .05$. Additionally, the Portal 2 VSNA posttest time (M = 87.31, SD = 8.46) was significantly faster than the Lumosity VSNA posttest time (M = 119.94, SD = 54.57, $F(1, 73) = 6.18$; $p = .03$. Enjoyment was a significant covariate in the VSNA ANCOVA model. The SOT posttest mean was not significantly different between the two conditions.

4.2. Pretest-posttest gains per Condition

Hypotheses 2 and 3 test pretest to posttest gains on specific problem solving and spatial test scores *within* each condition. We computed paired t-tests for each measure in each condition. For hypothesis 2 (problem solving gains), we found no significant gains for the Portal 2 condition, from pretest to posttest, for any specific problem solving measure. We also did not find any significant pretest-to-posttest gains for the Lumosity condition across any of the problem solving measures. Results provide partial support for hypothesis 3 (spatial gains). Participants in the Portal 2 condition showed pretest to posttest improvement on the MRT, $t(1, 39) = -1.80$, $p < .05$; Cohen's $d = .30$ under a one-tailed test. Additionally, Portal 2 players' VSNA scores significantly differed from pretest to posttest, $t(1, 40) = 2.42$, $p < .05$; Cohen's $d = .44$. There was no significant improvement for Portal 2 players on the SOT test. For participants in the Lumosity condition, there were no significant pretest-to-posttest improvements on any of the three spatial tests.

4.3. Game performance and learning gains

To test hypothesis 4 regarding in-game performance per game and the effect on posttest scores, we computed partial correlations for each performance measure. As discussed earlier, the Portal 2 performance measure consisted of: (a) total number of levels completed, (b) average number of portals shot, and (c) average time to complete levels. The Lumosity performance measure was the BPI index, calculated by the Lumosity software as the sum of the following constituent scores: speed, memory, attention, flexibility, and problem solving.

As seen in Table 3, Portal 2 performance significantly correlates to Insight problems, MRT, and VSNA after controlling for the respective pretest scores. Performance in Lumosity correlates with Raven's posttest score after controlling for pretest score. These findings suggest that performance in Portal 2 and Lumosity predicts outcomes on various measures beyond that predicted by their respective pretest scores.

Table 3. Posttest partial correlations to Portal 2 and Lumosity performance controlling for respective pretest scores

	Portal 2 Performance	Lumosity BPI
Raven's	.02	.37*
Insight	-.38*	.26
RAT	-.18	.10
MRT	-.33*	-.05
SOT	.27	-.11
VSNA	.34*	-.10

* *p* < .05. For the SOT and VSNA scores, lower values are better than higher values.

5. Discussion

The results of this study suggest that playing Portal 2 can have a noticeable impact on certain important cognitive skills relative to a control group that explicitly claims to improve cognitive skills (Portal 2 makes no such claims). That is, Lumosity is a commercial, online suite of games designed by a group of neuroscientists to enhance a number of cognitive skills including problem solving, flexibility, and mental rotation. Using Lumosity as the control condition was a conservative decision, and hence the findings showing a Portal 2 advantage are consequently more powerful than using either a no-treatment control or a casual game. Unlike a casual game such as Tetris (that is often used in gaming studies, but has been shown *not* to be a reasonable control; see Boot, Simons, Stothart, & Stutts, 2013) our Lumosity control group, due to pervasive advertisement, was likely perceived by participants assigned to it as a plausible intervention, and they likely expected to improve as a result. In other words, possible placebo effects are better controlled in our experiment compared to many existing gaming studies. In addition, care was taken to use validated tests that could be used to show transfer of learning as a result of playing the assigned game for 8 hours.

Regarding hypothesis 1, we found significant differences between conditions for all three of our primary constructs: problem solving, spatial skill, and persistence—all showing an advantage for Portal 2 over Lumosity. When examining differences at the individual test level, we saw significant differences, with a Portal 2 advantage, for the Insight test (reflecting the flexibility facet of problem solving), MRT (small-scale spatial skill), and VSNA (large-scale spatial skill).

Regarding hypothesis 2, there is no evidence that playing either Portal 2 or Lumosity improves specific problem solving skills as reflected in external pretest-posttest gains per test. Thus contrary to media claims--that Lumosity improves specific problem solving skills--Table 1 shows that while there were increases in scores from pretest to posttest for those in the Portal 2 group, all three of the problem solving test scores slightly decreased for the Lumosity group, from pretest to posttest. Possible reasons for this finding include (a) participants not having enough time to fully benefit from the problem solving activities in their respective game condition, (b) the lack of alignment involving specific problem solving tests and the respective game activities, and (c) the use of shortened external tests given time constraints. Regarding the latter point, for each matched pretest/posttest, there were 12 items for Raven's, 3 items for Insight, and 5 items for RAT.

For hypothesis 3, we found partial support that playing Portal 2 improved subjects' performance on small- and large-scale spatial tasks. Thus the repeated requirement in Portal 2 to apply and practice their spatial skills to solve problems appears to have transferred to increased performance on two measures of spatial skill – namely the MRT and the VSNA. This result supports other work investigating video game use and spatial skill (e.g., Feng et al. 2007; Uttal et al., 2012; Ventura, Shute, Wright, & Zhao, 2013). There were no improvements for the Lumosity group on any of the three spatial tests.

The findings of between-group differences on the MRT and VSNA measures, combined with the significant Portal 2 pretest-posttest gains in MRT and VSNA, give strong evidence that playing Portal 2 causes improvements in small- and large-scale spatial skills. Moreover, the fact that we used a conservative control group gives even greater credence to the finding that playing Portal 2 can improve spatial skills over other activities that claim to improve spatial cognition. While video gameplay has been shown before to improve MRT performance (e.g., Uttal et al., 2012), no one to our knowledge has provided experimental evidence that video game play can improve performance in large-scale spatial skill. Our findings suggest that video game use can improve one's ability to encode, store, retrieve, and apply environmental spatial information which could potentially transfer to actual real world navigation. These findings might be informative for professions that require large-scale spatial skill (e.g., taxi and delivery drivers, military personnel, and pilots). Future work could focus on how 3D video gameplay can improve performance in jobs requiring large-scale spatial cognition.

A case can be made that the VSNA is similar to a video game thus calling into the question whether the VSNA is a proper transfer task for Portal 2. However, Ventura et al. (2013) found that participants gave low ratings to a question concerning the similarity of VSNA to a video game. The VSNA requires little motor control beyond skills learned by normal computer use (i.e., single button press with one hand and mouse control with the other hand).

In this regard, the VSNA can be seen as a transfer task of environmental spatial skill independent from other video gameplay heuristics (e.g., effective use of controllers).

Additionally, we found that Portal 2 pretest–posttest gains relative to the Insight test were greater than Lumosity gains on this test. This finding can be understood by looking at the means of the two groups. As can be seen in Table 1, the Lumosity pre-post differences for the Insight test are slightly negative, while Portal 2 pre-post differences are slightly positive. In addition, there are ample opportunities for a player in Portal 2 to use insight in his or her solution. Many of the levels in the game require a player to apply a tool in a novel manner. Insight in solving Lumosity games was less of a key requirement, as far as we could discern.

The persistence measure (picture comparison task), obtained after gameplay, was greater for the participants in the Portal 2 condition than for those in the Lumosity condition. This supports other research that has been conducted on the relationship between video game use and persistence (Ventura, Shute, & Zhao, 2012). These results are also consistent with prior experimental research on the presentation of difficult tasks improving effort in subsequent tasks. That is, when individuals are required to exert high effort in one task, they will continue to exert high effort in a subsequent task (see Eisenberger, 1992 for a review). Our results complement this finding by showing that repeated challenges and failures as a result of engaging video gameplay can cause players to try harder on a subsequent task (picture comparison) over and above activity in a control task (e.g., playing Lumosity).

Finally, regarding hypothesis 4, we found that performance in Portal 2 predicts gains in Insight, MRT, and VSNA scores even after controlling for the respective pretest knowledge. Additionally, we found that performance in Lumosity predicts Raven's posttest scores after controlling for pretest scores. This suggests that increased performance in games (for entertainment or cognitive training) can yield improvement of cognitive skills. Future research should focus on performance indicators within games to see how they can mediate the effect of training manipulations on cognitive skills.

In conclusion, the results of this study complement a growing body of research on the effects of video gameplay on cognitive skills. This study contributes to the field by introducing a rigorous design for testing the relationship between video game use and cognitive and noncognitive skills. Specifically, we implemented a conservative control group--Lumosity--that we expected to improve problem solving and spatial skills. Additionally, we found that Portal 2 gameplay improves persistence scores (a noncognitive attribute) compared to Lumosity gameplay.

In terms of limitations of the study, the sample in this study is relatively small and may lack sufficient statistical power; hence caution should be taken when generalizing the findings. The power analyses of our three ANCOVAs conducted on the composite measures of problem solving, spatial skill, and persistence are .64, .54, and .50 respectively. In addition, our tests used in the study showed relatively low reliabilities. All other factors held constant, reliability will be higher for longer tests than for shorter tests and so these values must be interpreted in light of the particular test length involved. We computed the Spearman-Brown prediction formula to test reliabilities based on longer test lengths and the adjusted reliabilities ranged from .82-.90. Future research can replicate this current research project by using a larger sample, a different population (e.g., high-school students who differ from the college students in prior competencies), more items per test, and/or a daily, informal game-play setting.

Acknowledgements

We acknowledge the support for the John D. and Catherine T. MacArthur foundation, Connie Yowell in particular (Grant number 11-99517-000-USP). We additionally want to thank our excellent graduate student research team for their support in soliciting and testing subjects (Lubin Wang, Weinan Zhao, Tim Wright, Ben Emihovich, and Casey Campbell), as well as valuable feedback from Walter Boot, Russell Almond, and Yanyun Yang.

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