Developing Spatial Orientation and Spatial Memory with a Treasure Hunting Game

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(Submitted June 3, 2013; Revised September 27, 2013; Accepted November 26, 2013)

ABSTRACT

The abilities of both spatial orientation and spatial memory play very important roles in human navigation and spatial cognition. Since such abilities are difficult to strengthen through books or classroom instruction, there are no particular curricula or methods to assist in their development. Therefore, this study develops a spatial treasure-hunting game to enhance learners' spatial orientation and spatial memory. The game design is based on theoretical principles of spatial orientation and spatial memory. With such a design, the player can practice and learn these two spatial abilities by way of playing the game for a short period of time. This study adopts an experimental approach to test whether the game is effective in facilitating student development of spatial memory and spatial orientation. The findings show that this computer game is an efficient way of enhancing a learner’s spatial orientation and spatial memory over a very short period. Our research also points out that spatial orientation ability may differ between males and females, but after training through the game, the differences are reduced.

Keywords

Spatial orientation, Spatial memory, Computer game, Spatial ability

Introduction

The environment in which we live is filled with buildings, roads, and public facilities, and areas outdoors consist of a mix of various terrains, flowered landscapes, bushes, and woods. Given all of this contextual variation, for a human to navigate in such a complex environment without losing direction, a sense of personal orientation and human spatial ability to play critical roles (Hung, Hwang, Lee, & Su, 2012). Spatial ability is accepted as a significant attribute in humans that is necessary to evaluate the effectiveness of learning, training, working, and playing (Rafi, Anuar, Samad, Hayati, & Mahadzir, 2005). Spatial ability is also regarded as a sort of intelligence by many researchers and identified as a cognitive process that functions when dealing with problems related to the manipulation of spatial information (Yilmaz, 2009).

Looking at our primary focus, the application of spatial ability to the daily lives of human, there are two components of spatial ability that are highly related to finding place and searching for direction: spatial orientation and spatial memory. Spatial orientation helps us to address “where is it?” and “where am I?” (Allen, 2003). Spatial memory is used to recall all spatial information related to the process of location identification and place searching, which helps the learner orient her/his own position and the location of the searched-for object (Pentland, Anderson, Dye, & Wood, 2003). These two components of spatial competence play essential roles in location finding.

Although the two aspects of spatial ability are very important for humans in direction orientation and space location, there are no clearly defined methods of teaching available to assist students in enhancing these capabilities. Since such abilities are rather difficult to improve through books or classroom instruction, the general attitude toward this is to let them develop in their own natural way (Gittler & Gluck, 1998). Presently, there are no particular courses or methods to assist development.

A noteworthy issue, then, is how we can help students develop these spatial abilities as efficiently as possible. Due to the rapid developments in digital technology, we can adopt special features of multimedia to foster these two aspects of spatial ability by playing computer games. Computer games have proven to be very powerful tools in this regard since many games are available that involve abilities of this type (Sims & Mayer, 2002). Evidence from experimental studies has shown that spatial ability can be cultivated through proper training with digital aids (Kadam,
Sahasrabudhe, & Iyer, 2012; Subrahmanyan & Greenfield, 1994). For example, Yang and Chen (2010) designed a digital pentominoes game that tries to improve students’ spatial abilities, and the result showed that their abilities were enhanced. David (2012) revealed that people’s spatial abilities could be improved through practice with selected computer games. Do and Lee (2009) also demonstrated that a 3D computer game can be useful in improving people’s spatial abilities. Furthermore, Samsudin, Rafi, and Hanif (2011) showed that mental rotation and spatial visualization can be improved through technology-based training instruments. Finally, Wilms, Petersen, and Vangkilde (2013) claimed that intensive video action gaming can improve the encoding speed of visual information into visual memory.

Gender differences

Past research has claimed that there are marked differences between males and females in their spatial abilities. In tests on diverse types of spatial abilities, males perform better than females (Coluccia & Louse, 2004). However, other studies have shown that no significant differences are found between males and females in spatial visualization and spatial perception. Therefore, in tests of diverse types of spatial abilities different results might occur related to gender differences. On the capacity of spatial orientation, the majority of studies indicate that males perform better than females. Based on inductive statistics by Coluccia and Louse (2004), either in the real or simulated research environments, boys are substantially better than girls in the performance of spatial orientation. Recent studies have shown that males are also faster at locating targets in virtual environments (Lin et al., 2012).

Regarding gender differences in spatial memory, the research findings are mixed. According to Canovas, Garcia and Cimadevilla’s (2011) research findings, males outperform females in remembering the position of objects in a space. Piccardi et al. (2008) adopted the Corsi Block test to examine people's spatial memories, and the findings showed that boys perform better than girls. However, other researchers (Bull, Davidson, & Nordmann, 2010; Rahman, Bakare, & Serinsu, 2011) proposed that no gender differences exist in the ability of spatial memory. Voyer, Postma, Brake and McGinley (2007) even pointed out that females outperform males on most tests of object location memory.

Although males and females may differ in their spatial abilities, the differences can be reduced via certain learning strategies that fit males and females well (Coluccia, Louse, & Brandimonte, 2007). As Yang and Chen (2010) have shown, gender differences in spatial abilities can be reduced with the support of a digital game.

Game design for certain instructional purpose

Whether though brick and mortar retail markets or via the internet various types of computer games are available; however, the number of games specifically designed for certain cognitive abilities are limited (Sung, Chang, & Lee, 2008). Ideal games for such purposes should be interesting, fun, and attractive and, at the same time, meet the teaching goal prescribed by the designer.

Researchers have argued that the design of computer games has been driven by technological advances rather than theoretical principles (Hegarty, Quilici, Narayan, Holmquist, & Moreno, 1999). In other words, the first step in creating an effective game is to analyze the substance and definition of the prescribed cognitive ability and then explore a strategy that provides an ideal process to enhance that cognitive ability.

Research purpose

Because there are very few computer games based on cognitive theory and because of the specific need to design domain-related multimedia learning environments, this study sets out to demonstrate how to design a computer game based on theory and domain-specific concepts. Furthermore, there is limited research on the improvement of spatial orientation and spatial memory through the design of computer games. As such, this research aims at designing a computer game based on theories related to the development of spatial ability through which students can enhance their spatial orientation and spatial memory. The second purpose of this study is to evaluate the effects of the designed game on facilitating students’ development of spatial orientation and spatial memory within the limited duration of implementation.
The theoretical basis of the design

Landmark information for spatial orientation

One relevant facet of spatial competence is spatial orientation, which is the ability of people to orientate themselves in new environments. Spatial orientation indicates an essential cognitive function through which most humans find their direction and location (Wolbers & Hegarty, 2010).

Landmark information seems to play an important role in orientation. According to Presson’s (1982) research, when identifying the precise location of a target without knowing its position beforehand, 6-8 year old children depend mainly on distance, far or near, between a landmark and the target. If the landmark is directly connected to the target, we call the landmark a “proximal cue”. On the other hand, a landmark that provides only indirect or limited information about the distance to the goal is called a “distal cue.” In other words, when searching for a position that is out of sight, people tend to use an obvious landmark or a familiar place to orient and clarify what they want to identify. Whether the target is far or near, the landmark can be used as a reference.

Spatial memory

Another relevant factor concerning spatial competence is spatial memory, which is the cognitive process that enables people to remember locations and the relationship between locations and objects in the environment. In other words, the ability to recognize and understand spatial relationships (Kozhevnikov & Hegarty, 2001). The cognitive process of spatial memory enables people to remember relationships among events and objects involved in the environment. The formation of spatial memory depends on how such sensory information is collected and applied (Johnson & Villani, 2010).

People can easily remember a location mainly because at that place, compared to other places, they made certain significant decisions (Doherty, Gale, Pellegrino, & Golledge, 1989). As to the factor, Herman & Roth (1984) discovered that if certain situations or stories can be interwoven with the location for which they have searched, people can better remember such spatial locations.

The design of the game

The strategy of the game design

The game is designed and constructed using the strategy of a treasure hunt. The framework of the game design is based on a simple idea that aims to lead the main character to seek treasures in the designed scenes and marked locations (Fig. 1). In this treasure hunt, the leading character is moved around by the player with a treasure map as the spatial guidance to find hidden treasures. Since the game of treasure hunt features the seeking of location and target, it is functional in enhancing the ability of spatial orientation.

Traditionally, the game of treasure hunt keeps a small-scale radar map on the screen. The player looks at this map to determine the direction and location of the hidden treasures. Nevertheless, the traditional game design aims at entertaining; thus, simply by watching the radar map and seeking the target, the player does not receive much direct stimulation that enhances spatial ability.

Therefore, the game design should include a function whereby the player can go through changes of location and direction and eventually find the target destination (i.e., the spatial orientation), and the player also has opportunities to practice instant memory of locations and directions of the objects or events involved (i.e., the spatial memory).
The learning of spatial memory

In the game’s design, before entering each level of the game, there will be a map providing an overall view of the scene with an arrow indicating, and speech sounds introducing, all possible treasure landmarks (Fig. 2). The player needs to quickly memorize the locations and the relative relationships and directions among all the landmarks. Upon entering the game, the view of the scene changes from an overall view to a selective partial one, which is similar to the limited viewpoint of people in a real environment. Then words and speech indicate the first treasure location, and the player uses the direction control key to move the character to seek the treasure (Fig. 3).

Given this, the player has to operate by spatial memory and quickly memorize the related landmarks and directions on the map. With advanced degrees of difficulty there are more landmark locations to be memorized.
The learning of spatial orientation

As mentioned above, spatial orientation ability means that one can identify his or her own location and direction within different and changing environments. Accordingly, the game design must contain two key elements to complete the learning of spatial orientation: Change of initial starting point and change of scenes (i.e., rotation of scenes).

In the above-mentioned order, the player memorizes the overall view of the map and enters at a random landmark as the starting point to seek the treasure. There are always six passes on the same level. The first three passes are the treasure seeker’s various initial positions (to change the starting point), and the next three passes are 90°, 180°, and 270° rotations of the scenes, as shown in Fig. 4. The player has to identify his/her location at this position, which is viewed as the base, and then go forward to a landmark and seek the treasure. The higher the level of difficulty, the more landmarks there will be.
Principles for the design of scenes

With regard to game design, in order to help the player memorize the various locations and seek the hidden treasures, there are three principles to consider: The referent landmarks, the decisive point, and the story context, which was previously discussed. These three principles assist the designer in developing a game situation that enhances the player’s spatial orientation and spatial memory.

By using these three principles as a foundation, the designer develops the treasure hunt game. Thus, this game design uses conspicuous landmarks to indicate every location of a hidden treasure, and the newly found treasure location serves as a new starting point; thus, the player goes on to seek the next landmark. At each level there is an introduction to the new theme as shown in the background of the plot.

Method

Participants

This study was conducted with 55 sixth grade students (aged 12-13 years, $M_{age}=12.4$) from an elementary school in Taiwan, who volunteered to participate. Due to differences in spatial abilities between males and females and the possibility of comparison between them, the numbers of males and females were controlled to provide a balanced sample: twenty-six male students and twenty-nine female students. The participants were randomly assigned to one of two groups: The treatment group had twenty-eight students, and the control group had twenty-seven students.

Instruments

Spatial orientation

In order to examine the participants’ spatial orientation ability, two instruments were used in this study. The first was the “Guilford-Zimmerman Spatial Orientation Test” (GZSOT) which is a traditional and the most commonly used instrument for testing spatial orientation ability (Guilford & Zimmerman, 1948). In this test, participants were shown the same landscape from two different view-points, both from the prow of the same boat so they could determine how much the position of the boat had changed in the second picture as compared with the original position in the first picture (Fig. 5). However, due to the complexity of the demonstration and application, this instrument often cannot effectively measure the ability. To improve on this weakness, Kyritsis & Gulliver (2009) created an electronic version of the GZSOT (internal reliability 0.88). Therefore, in order to avoid the possible weakness, this research adopted the newer electronic version (Fig. 5).

Figure 5. Traditional and electronic versions of Guilford-Zimmerman Spatial Orientation Test
Nevertheless, the first instrument has been criticized for one of its weak points; that is, any rotation of more than 90 degrees cannot be effectively measured (Kozhevnikov & Hegarty, 2001). In order to solve this problem, a second instrument was adopted; the “Perspective Taking Spatial Orientation Test” (PTSOT), which was developed by Hegarty & Waller (2004). This is a test of one’s ability to imagine different perspectives and orientations in space. This test can measure the perspective involving a rotation of over 90 degrees (internal reliability 0.83), as shown in Fig. 6.

![Figure 6. Perspective Taking Spatial Orientation Test](image)

**Spatial memory**

The Corsi Block-Tapping Task (CBTT), originally developed by Corsi (1972), was adopted to examine spatial memory. This test has frequently been used to assess short-term visuospatial memory performance in adults and children (Vandierendonck, Kemps, Fastame, & Szmalec, 2004). Fig. 7 shows the Corsi Blocks-Tapping Task.

![Figure 7. Corsi Block-Tapping Task](image)

The second instrument for examining spatial memory was a “Game-Based Spatial Memory Test” (GBSMT). This test examines how well participants improve their ability to memorize and identify their position and direction. This test was designed based on the scenes of the game and includes eight scenes and twenty questions. Each scene has
six target objects. The object of the test is to memorize the locations in the scene within a limited period of time and then indicate the position and direction of the object requested by the question, as shown in Fig. 8.

![Figure 8. Game-Based Spatial Memory Test](image)

**Procedure**

This research adopts a pre-test and post-test design to measure the game’s effect on the students. In addition to the game’s effect on the experimental team, the game’s effect on the control team was measured. This was designed to reduce any possible inaccuracy that may have been caused by the pre-test and the post-test.

In each performance, four or five participants formed a team. Each participant operated a computer independently and maintained a certain distance from the other subjects to avoid any possible disturbance. A description of the entire process follows.

All participants were pre-tested with the GZSOT test (10min), the PTSOT (5min), the CBTT test (5min), and the GBSMT test (5min). After a five-minutes break, the game began. Once they entered the game, all participants started from the first pass and moved on to solve each pass until all were solved (about 45-55 minutes). The participants were required to wear headsets and were not allowed to have conversations with others during their participation. After the experiment was completed, they had a 10-minutes break and then the post-tests using the same instruments were conducted.

**Data analyses**

All the data collected from the pre-tests and post-tests of the GZSOT, PTSOT, CBTT, and GBSMT were coded for quantitative analyses. The GZSOT is comprised of fifty questions and for each correct answer the participant earns one point, but for a wrong answer 0.25 point is deducted, in case the participant is randomly guessing answers. The PTSOT has twelve questions and for each correct answer the participant earns one point. The CBTT is based on the participant’s ability, which is indicated by how far the participant can go in solving the passes; then the final result will be exposed, which includes the participant’s grade and total points. The GBSMT consists of twenty questions and each correct answer earns five points, with one hundred points being the maximum possible. The pre-test and post-test scores of the four exams were analyzed with descriptive statistics, including mean and standard deviation.

In order to check whether the differences between pre-test and post-test scores were significant, and to exclude certain moderating variables this research adopted the method of analysis of covariance (ANCOVA). Paired t-tests and an independent sample t-test were conducted for data analyses.
Results

Spatial orientation test

In order to examine differences in spatial orientation between the treatment and control groups, analyses were undertaken between the pre-test and post-test scores for GZSOT and PTSOT. The means and standard deviations of the participants’ pre-test and post-test scores for the PTSOT are shown in Table 1.

Analysis of covariance can exclude the interference effect from items of covariance. However, before the application of ANCOVA, we proceeded with the test of “Group regression coefficients homogeneity,” which was non-significant (data of a*x): $F = 0.188$, $p = 0.666$. This shows that the slope of the regression line in the two groups remains the same. Thus, the relationship between the covariates (pre-test scores) and the dependent variables (post-test scores) does not vary with each different handling standard of the independent variables, and this is in accordance with the homogeneity hypothesis of the group regression coefficients of covariance. Thus, the analysis of covariance can be further conducted.

The result of the ANCOVA was significant ($F = 55.41$, $p = 0.00$), which indicated there were significant differences between the treatment group and the control group in their post-test scores under PTSOT. The adjusted post-test average scores are shown in Table 1, with treatment group significantly greater than the control group. That is, after receiving the spatial game exercises, the participants in the treatment groups made significant progress in their post-test scores under the Perspective Taking Spatial Orientation Test (PTSOT).

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (SD)</th>
<th>Adjusted Mean</th>
<th>ANCOVA</th>
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<tbody>
<tr>
<td>Pre-test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>28</td>
<td>7.25 (9.28)</td>
<td></td>
<td>55.415</td>
</tr>
<tr>
<td>Control</td>
<td>27</td>
<td>7.88 (1.31)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post-test</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Treatment</td>
<td>28</td>
<td>9.79 (1.32)</td>
<td>9.99 (a)</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>27</td>
<td>8.22 (1.05)</td>
<td>8.01 (a)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 shows the means and standard deviations of the student’s performance on the GZSOT in the pre-test and post-test. First, we proceeded with the test of “homogeneity of the in-group regression coefficients,” and the result was non-significant ($F = 0.283$, $p = 0.597$). Thus, the analysis of covariance can be applied.

The subsequent ANCOVA was significant ($F = 44.61$, $p = 0.00$), indicating that there are significant differences between the treatment group and the control group in their GZSOT post-test scores.

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (SD)</th>
<th>Adjusted Mean</th>
<th>ANCOVA</th>
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<tr>
<td>Pre-test</td>
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<tr>
<td>Treatment</td>
<td>28</td>
<td>18.21 (7.98)</td>
<td></td>
<td>44.61</td>
</tr>
<tr>
<td>Control</td>
<td>27</td>
<td>18.00 (7.40)</td>
<td></td>
<td></td>
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<tr>
<td>Post-test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>28</td>
<td>22.37 (8.51)</td>
<td>22.27 (a)</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>27</td>
<td>18.35 (7.18)</td>
<td>18.45 (a)</td>
<td></td>
</tr>
</tbody>
</table>

Spatial memory test

We used the Corsi Block-Tapping Task (CBTT) to examine the participant’s spatial memory. The scores from the CBTT are shown in Table 3. We conducted an ANCOVA with a single factor to test pre-test and post-test differences between the treatment and the control groups.

The test of “homogeneity of the in-group regression coefficients” was not significant ($F = 0.139$, $p = 0.711$). This is lower than the significant level and the null hypothesis is accepted. This means that the analysis of covariance can be applied. The result of the subsequent ANCOVA was significant ($F = 6.578$, $p = 0.013$), indicating that there are significant differences between the treatment group and the control group in their CBTT scores.

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Table 3. Scores of pre- and post-tests in the Corsi Block-Tapping Task (CBTT)

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (SD)</th>
<th>Adjusted Mean</th>
<th>ANCOVA</th>
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<tr>
<td>Pre-test</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>28</td>
<td>56.46 (19.21)</td>
<td>74.67 (a)</td>
<td>22.66</td>
</tr>
<tr>
<td>Control</td>
<td>27</td>
<td>53.52 (16.13)</td>
<td>60.50 (a)</td>
<td></td>
</tr>
<tr>
<td>Post-test</td>
<td>28</td>
<td>76.00 (22.24)</td>
<td>74.67 (a)</td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>28</td>
<td>59.11 (16.64)</td>
<td>60.50 (a)</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>27</td>
<td></td>
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</table>

The scores for the Game-Based Special Memory Test (GBSMT) are shown in Table 4. The results showed that the difference between the treatment and the control groups in the test was significant ($F = 5.20$, $p = 0.027$). The adjusted average values of the post-test are shown in Table 4, and it can be seen that the treatment group is significantly greater than the control group in the adjusted average value of the post-test game test.

Table 4. Scores of pre- and post-tests in the Game-Based Spatial Memory Test (GBSMT)

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean (SD)</th>
<th>Adjusted Mean</th>
<th>ANCOVA</th>
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<tr>
<td>Pre-test</td>
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<td></td>
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<tr>
<td>Treatment</td>
<td>28</td>
<td>77.5 (14.37)</td>
<td>87.33 (a)</td>
<td>5.208</td>
</tr>
<tr>
<td>Control</td>
<td>27</td>
<td>78.15 (14.49)</td>
<td>82.95 (a)</td>
<td></td>
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<tr>
<td>Post-test</td>
<td>28</td>
<td>87.14 (10.49)</td>
<td>87.33 (a)</td>
<td></td>
</tr>
<tr>
<td>Treatment</td>
<td>28</td>
<td>83.15 (11.70)</td>
<td>82.95 (a)</td>
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<tr>
<td>Control</td>
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<td></td>
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</table>

Gender differences

In order to examine gender differences in spatial memory and spatial orientation abilities, analyses were undertaken between boys and girls in the pre-tests and post-tests. Table 5 shows the results of the analyses of the PTSOT, which indicates there is a significant difference between boys and girls in the pre-test ($t = 4.829$, $p < 0.05$). Boys obviously performed better than girls on this test. Although there is a significant difference between boys and girls in the post-test of PTSOT ($t = 2.07$, $p = 0.048$); however, after the exercises in the spatial game, the difference between the boys' and girls' performance on the PTSOT is reduced.

Table 5. Performance of boys and girls in the pretests and posttests on the PTSOT

<table>
<thead>
<tr>
<th>Test</th>
<th>Sex</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>M</td>
<td>13</td>
<td>7.9231</td>
<td>.75955</td>
<td>4.829</td>
<td>0.00</td>
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<tr>
<td></td>
<td>F</td>
<td>15</td>
<td>6.6667</td>
<td>.61721</td>
<td></td>
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<tr>
<td>Post-test</td>
<td>M</td>
<td>13</td>
<td>10.3077</td>
<td>.85485</td>
<td>2.070</td>
<td>.048</td>
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<tr>
<td></td>
<td>F</td>
<td>15</td>
<td>9.3333</td>
<td>1.49603</td>
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</table>

The results of another spatial orientation test, the GZSOT, are shown in Table 6. These results indicate a significant difference between boys and girls in the pre-test and post-test performance in that boys perform better than girls ($t = 2.07$, $p < 0.05$).

Table 6. Performance of boys and girls in the pretests and posttests on the GZSOT

<table>
<thead>
<tr>
<th>Test</th>
<th>Sex</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>p</th>
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<tr>
<td>Pre-test</td>
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<td>23.2115</td>
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<td>.001</td>
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<td></td>
<td>F</td>
<td>15</td>
<td>13.8833</td>
<td>3.30160</td>
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<tr>
<td>Post-test</td>
<td>M</td>
<td>13</td>
<td>27.0962</td>
<td>9.14612</td>
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<td>.004</td>
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<td></td>
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<td>15</td>
<td>18.2667</td>
<td>5.41284</td>
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</table>

The test of spatial memory in the Corsi Block-Tapping Task (CBTT) provided the results shown in Table 7, which indicate there was no significant difference between boys’ and girls’ performance on the CBTT, in either the pre-test or in the post-test.
Table 7. Performance of boys and girls in the pretests and posttests on the CBTT

<table>
<thead>
<tr>
<th>Test</th>
<th>Sex</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-test</td>
<td>M</td>
<td>13</td>
<td>59.6154</td>
<td>23.0164</td>
<td>.803</td>
<td>.429</td>
</tr>
<tr>
<td>Post-test</td>
<td>F</td>
<td>15</td>
<td>53.7333</td>
<td>15.49869</td>
<td>.640</td>
<td>.528</td>
</tr>
</tbody>
</table>

In line with the results of the CBTT, the results for the GBSMT shown in Table 8 illustrate there was no significant difference between boys’ and girls’ performance on the game test either in the pre-test or post-test, although boys’ mean scores are slightly higher than girls’.

Table 8. Performance of boys and girls in the pretests and posttests on the GBSMT

<table>
<thead>
<tr>
<th>Test</th>
<th>Sex</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pretest</td>
<td>M</td>
<td>13</td>
<td>81.1538</td>
<td>11.02154</td>
<td>1.267</td>
<td>.217</td>
</tr>
<tr>
<td>Posttest</td>
<td>F</td>
<td>15</td>
<td>74.3333</td>
<td>16.46063</td>
<td>1.769</td>
<td>.089</td>
</tr>
</tbody>
</table>

Discussion

Many studies have shown that multimedia computer games can improve the performance of a variety of human capabilities and intelligence (Pannese & Carlesi, 2007; Sung et al., 2008; Wilms et al., 2013). In terms of ability for spatial intelligence, many researchers have also pointed out that some of the relevant games can instantly enhance human spatial ability (David, 2012; Samsudin et al., 2011).

The authors of this study designed a treasure hunting game to train and improve students' spatial ability, focusing particularly on spatial orientation and spatial memory. The findings show that the designed game has effectively improved the participants’ abilities in spatial orientation and spatial memory.

In two kinds of spatial orientation tests, either the small-angle test or the large-angle test, both PTSOT and GZSOT indicate that participants’ abilities in spatial orientation improved significantly after their exposure to such a designed game. This result is consistent with previous researchers’ findings that spatial capabilities can be effectively improved through the use of computer games (Yang & Chen, 2010; You, Chung, & Chen, 2008). A possible explanation for this positive result lies in the fact that the game is designed according to the theoretic principles of spatial ability, which can directly stimulate both spatial abilities. For instance, in the game, the character is constantly changing her/his starting position, and the view of the setting is constantly rotating to different angles. With the changes in location and environment, the player must constantly locate her/his position and find the relevant landmarks in order to identify the target treasures.

From the results of both spatial memory tests we found that this computer game has a positive effect on the development of spatial memory. Both spatial memory tests showed that, after about one hour practicing the game, participants greatly improved their spatial memory. The main reason for this is the involvement of spatial memory in the game. In this game’s design, every detail of the process requires the game player to use her/his spatial memory, from the simple pass of three landmarks to the complex pass of twelve landmarks, the player has to memorize within a very short period of time the spatial locations of these landmarks. Thus, this research demonstrates that a theory-based computer game can be very helpful in improving students’ spatial memory after a short period of practice, as compared with the students in the control group.

By playing the game, students practice many kinds of spatial skills, such as orientating location and direction on the map, determining the correct landmark, and memorizing related locations. This result echoes previous researchers’ findings that spatial ability can be improved through appropriate training with computer-based games (Yang & Chen, 2010).
This study also examined gender differences in spatial orientation and spatial memory. First, in the performance of spatial orientation ability, the pre-test results show that the abilities of boys are greater than those of girls. This result echoes the findings of previous studies in which males were found to perform better than females in spatial ability (Monahan, Harke, & Shelly, 2008; Yang & Chen, 2010).

After the boys and girls play the game, the boys’ post-test results were still better than the girls’; however, the difference was greatly reduced. That is to say, through the training with the game, the gap between males and females on spatial ability can be narrowed. This result is consistent with the findings of Terlecki, Newcombe and Little (2008) and Yang, Chen (2010) who suggest that, although boys comparatively have better spatial intelligence, there is almost no gap in performance between girls and boys after training with the game. The fact that there is a significant difference between boys and girls in spatial ability is likely the result of traditional social attitudes and socio-cultural factors. As observed by Voyer, Nolan, and Voyer (2000), most male-typical activities involve high spatial content, while female-typical activities do not. Therefore, less experience with spatial activities naturally affects the development of spatial ability (Saucier, McCreary, & Saxberg, 2002). Traditionally, due to fewer opportunities for girls to practice, their spatial abilities are weaker, but whenever they have the appropriate opportunity to practice, the gap between males and females will decrease.

As to spatial memory, the boys’ pretest and posttest scores are, on average, higher than girls’ but this feature is not significant. In other words, there is no significant difference in the spatial memory between males and females. The findings of this study are consistent with the work of Maki, Yoshida and Yamaguchi (2010), who concluded that there were no significant gender differences in the performance of spatial memory. The main possible explanation for this lies in the fact that spatial memory is more like a memory capacity and, in related studies, no differences between males and females were found. Also, some studies have shown that the spatial ability construct is made of many facets, such as spatial perception, spatial visualization, mental rotation, and so on (Linn & Petersen, 1985). Nevertheless, some of those facets have demonstrated differences between males and females, but others do not. For example, the findings of Yang and Chen (2010) show that there is no difference between the male and the female performance in spatial perception and spatial visualization.

Conclusions

Previous studies have effectively increased spatial ability through the use of digital games (David, 2012; Do & Lee, 2009; Sims & Mayer, 2002). Yang and Chen’s (2010) studies further proved that the digital pentominoes game can enhance three kinds of spatial abilities: spatial perception, spatial visualization, and mental rotation. However, for spatial orientation and memory, the two direction-identification abilities, only limited studies have used digital games to improve them and even more rarely using treasure hunting games. Therefore, based on the theoretical foundation of spatial orientation and memory, this study developed a digital treasure hunting game; thus, the effects of two essential spatial factors and gender differences were examined within the game.

Our findings demonstrate that a digital spatial game is an efficient way of enhancing learners’ abilities in spatial orientation and memory within a short span of time. These findings echo related prior works in that digital games can be very effective in improving students’ spatial ability as discussed above. This study provides further evidence that, although males generally outperform females in spatial orientation, the training provided in this game can effectively reduce the differences. This result is consistent with the findings of Terlecki, Newcombe and Little (2008). In addition, the study has shown that incorporating theory into the design of digital games is functional in enhancing the learner’s acquisition of cognitive concepts, which echoes work by Sung, Chang and Lee (2008).

However, a limitation of this study is the lack of exploring the long-term influence of the game, such as the reduction of gender differences over time. Further studies can focus on discovering the long-term effects of the digital games.

This study provides more evidence to demonstrate that digital games can be designed to not only offer entertainment functions, but also contribute to educational functions. Echoing the concept of "edutainment" proposed by Druin and Solomon (1996), the focus of the issue here is the proportional use of computer games.
References


