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IMPROVING SPATIAL SKILLS THROUGH COMPUTER GAMES

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ABSTRACT

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This literary review spans a time period of twenty-five years and evaluates various studies related to the effects of computer game playing on spatial ability.

KEYWORDS: computer games, literary review, spatial ability

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1 INTRODUCTION

Computer games, amid other recreational forms of computer use have been largely ignored as a means of informal education (Subrahmanyam & Greenfield 1994, 13). Computer games touch people on a mass scale, usually during the formative years of childhood when cognitive development is taking place (Greenfield, deWinstanley, Kilpatrick and Kaye 1994) and considering the growing importance of games as modern tools, their "effect on cognitive skills is of interest from both theoretical and practical perspective" (Subrahmanyam & Greenfield 1994, 14). Overall, the symbolic universe of video games even though it includes primarily younger people, it also refers to everyone under 35 as the first generation of video gamers have not given up their hobby although they have matured (de Aguilera & Mendiz 2003, 2).

Spatial skills are one of the areas of cognitive skills that many computer games require and therefore must promote as players become more skilled (Greenfield 1984, 104); the spatial skills involved in video games appear to be similar to mental processes required in various spatial tests (Gagnon 1985, 165; Lowery & Knirk 1982-1983) and numerous studies (e.g. Dorval & Pepin 1986; McGee 1978; Scali et al. 2000) have found that spatial performance can be improved by practice.

Gender-based differences in spatial skills have also been systematically studied, the differences are consistent and men generally outperform women on spatial tasks (Linn & Petersen 1985; Voyer, Voyer & Bryden 1995; Roberts & Bell 2000, 1027; Greenfield & Brannon & Lohr 1994, 96). Okagaki & Frensch (1994, 34) suggest that improvement of spatial skills, which are crucial to success in many courses and lucrative careers (Brownlow et al. 2003, 371) plus has been linked to academic mastery of several sciences (Trindade et al. 2002), including male-dominated fields such as engineering, computer science and mathematics (Gagnon 1985, 274), could be important for females. As spatial skills are

credited to be valuable, the importance of advancing these skills is apparent (Gagnon 1985, 274). Especially in the computer industry, there is a conspicuous gender gap between the number of male and female employees (Natale 2002, 24).

The objective of this literary review is to evaluate existing studies examining the impact of computer / video game playing on spatial skills – these are discussed in Chapter 3, which is the main chapter of this paper. The central concepts are introduced in Chapter 2.

2 TERMINOLOGY

Game

Kramer (2002) explains that games are objects which consist of components and have certain criteria: rules, a goal, always changing course; chance; competition; common experience; equality; freedom; activity; diving into the world of the game; and no impact on reality.

According to The New International Webster's Dictionary & Thesaurus (1999) a game is "any contest undertaken for recreation or prizes, played according to rules, and depending on strength, skill, or luck to win".

Video Game

A video game is a game played using an electronic device with a visual display (Free Online English Dictionary, Thesaurus and Encyclopaedia 2004).

Spatial Ability

Halpern (1986, 48) summarizes that spatial ability is the ability to imagine what an irregular figure would look like if it were rotated in space, or the ability to discern the relationship between shapes and objects.

No consensus exists for categorization of measures of spatial ability (Linn & Petersen 1985, 1479; Caplan et al. 1985, 786) and there is confusion (Caplan 1985, 789) plus little agreement between authors as to how spatial ability should be classified (Voyer et al. 1995, 251).

Linn and Petersen (1985) present a categorization, which separates spatial ability into three different types of spatial skills:

1. Spatial perception - the ability to determine spatial relationships with respect to the orientation of one's own body in spite of distracting information.

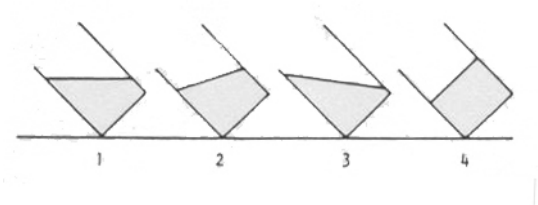

FIGURE 1. A spatial perception item. Respondents are asked to indicate which tilted bottle has a horizontal water line. (Linn and Petersen 1985, 1482)

2. Mental rotation – the ability to mentally rotate two or three dimensional figures quickly and accurately in imagination. In tests measuring mental rotation time is more critical than accuracy.

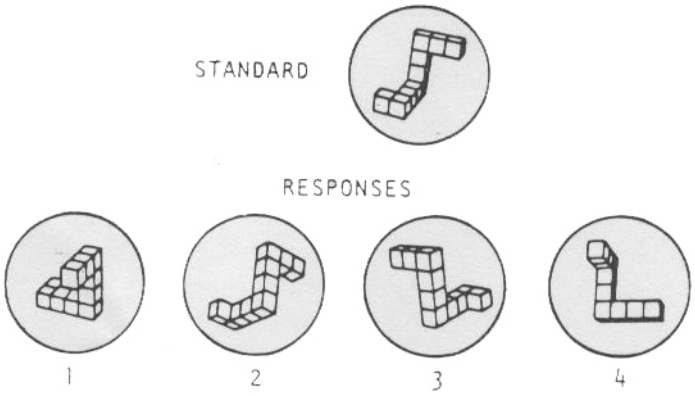

FIGURE 2. A mental rotation item. Respondents are asked to identify the two responses that show the standard in a different orientation. (Linn and Petersen 1985, 1483)

3. Spatial visualization is the ability to manipulate complex spatial information through several stages. It is commonly associated with complicated, spatial multi-step manipulations (e.g. mental paper folding). In spatial visualization tasks, mental rotation and spatial perception may, or may not be required in the solution strategy. Linn and Petersen (1985, 1485) summarize success of spatial visualization requiring “analysis of task demands and flexible adaptation of a repertoire of solution procedures”.

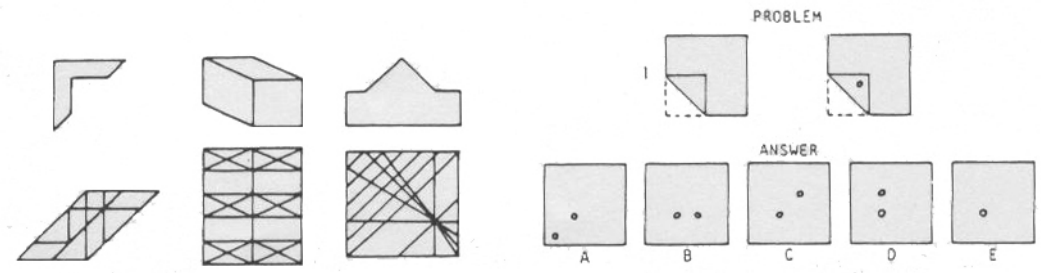

FIGURE 3. Spatial visualization items. Left, Embedded Figures: respondents are asked to find the simple shape shown on the top in the complex shape shown on the bottom. Right, Paper Folding: respondents are asked to indicate how the paper would look like when unfolded. (Linn and Petersen 1985, 1485)

Other categorizations are possible (Linn and Petersen 1985, 1485). The categorization above is at least “reasonably successful” (Voyer et al. 1995, 262).

3 EFFECTS OF GAME PRACTICE ON SPATIAL SKILLS

Chapter 3 presents and evaluates studies relevant to the subject area. This review spans a time period of twenty-five years and considers studies between 1978 and 2003.

3.1 Literature Review

As early as in 1978, Ball analyzed the potential of video games for improving the spatial skills of children, with special emphasis on 3D features and real world simulation. In addition to this he researched the role of video games in the intellectual development of children and adolescents in learning language and mathematics. Ball concluded that video games are beneficial in learning various intellectual skills and various authors followed his footsteps. (de Aguilera & Mendiz 2003, 5)

In the beginning of the 1980's, Lowery & Knirk (1982-1983; cited by Gagnon 1985; Greenfield, Brannon and Lohr 1994, 89) similarly to Ball, reasoned that video games, produced by the industry are suitable for enhancing spatial skills as spatial skills are built over a period of time and repeated interactions (cited by Subrahmanyam & Greenfield 1994, 15; see also Gagnon 1985, 265). They proposed that the fast-paced nature of videogames forces players to utilize spatial skills (cited by Gagnon 1985, 265) and suggested that in addition to spatial skills video game playing may also improve eye-hand coordination (cited by Subrahmanyam & Greenfield 1994, 14). For example, Space Invaders is described by Lowery and Knirk (cited by Gagnon 1985, 265) as a game, which requires "the ability to simultaneously coordinate horizontal and vertical axes and anticipate the intersection of imaginary lines".

Chatters (1984; a thesis, cited by Subrahmanyam & Greenfield 1994) tested sixth-grade children and found a remarkable positive effect on the WISC (Wechsler Intelligence Scale for Children) Block Design subtest after 3 hours 45

minutes of practice on Space Invaders. Chatters did not observe gender differences.

Gagnon's (1985) study was also one of the first experimental studies utilizing video game training (Subrahmanyam & Greenfield 1994, 15). Gagnon examined the relationship between video game playing, spatial skills and eye-hand coordination. Scores of two games, a two-dimensional game Targ and a three-dimensional game Battlezone (FIGURE 4), were compared with scores of three spatial skills tests (Spatial Orientation Test and Spatial Visualization Test by Guilford-Zimmerman, plus Psychological Services' Employee Aptitude Survey: Visual Pursuit Test).

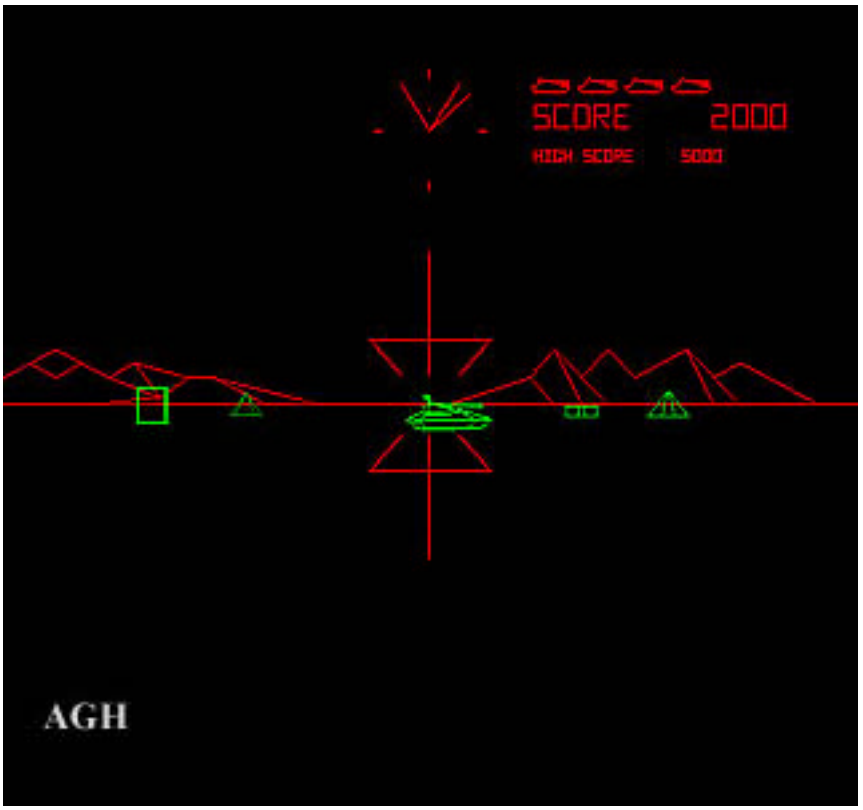

FIGURE 4: Battlezone, Atari Inc., 1980. "Battlezone was the first video game to feature truly interactive 3-D environment. It had 2-color vector display. The United States Armed Forces were so impressed by the game that they commissioned Atari to build specially modified and upgraded versions for use in tank training." (Kuittinen 1997)

Small & Small (1982; cited by Gagnon 1985, 165) had described Battlezone as a game which involves "elaborate spatial skills such as the ability to visualize

rotation in three-dimensional space"; this detail presumably affected the game selection for the experiments. The subjects were undergraduate and graduate students who played the games for a total of 5 hours (2.5 hours each). Sex differences were found as follows: males scored higher on spatial orientation, visualization and the baseline measures on the game, Targ; females outperformed males on eye-hand coordination. Age correlated negatively on both, the spatial skills test scores and the videogames' scores. The amount of past videogame experience correlated positively with subjects' scores on spatial tests. In addition to Gagnon, also Nordvik and Amponsah (1998), point out that according to their questionnaire, "Computer games" (along with activities such as "Knitting" and "Jig-saw puzzle") correlate positively with spatial skills. Furthermore Gagnon discovered that the scores on two videogames correlated with different spatial test scores. Practice on videogames did not yield significant overall differences between the experimental and the control group, but it is noteworthy that the novices and especially the females in the experimental condition improved remarkably more on Spatial Visualization than the females in the control group; women were also able to equalize their scores on "Targ" and Spatial Visualization with males when provided with videogame training.

Miller and Kapel (1985) carried out an experiment, which had a positive effect on subjects' (7th and 8th graders) spatial skills (students were tested using Wheatley Spatial Test). A set of puzzle-type computer games were played by the experimental group. Puzzle-games were chosen as they do not require large amounts of specific knowledge and also due to the high interest-level. The games included ROBOT BLAST, a version of 'Nim'; 3-D MAZE; PHAROAH'S NEEDLE, a version of 'Tower's of Hanoi'; HAMLET, a version of 'Othello'; and FACTORY. Also, other than spatial abilities, logical and sequential thinking were tested - there was a negative or no effect on those. The authors' suggest that the result can possibly be explained by the fact that a greater portion of the

class time in the computer lab was spent on FACTORY, the visual rotation element of which was most difficult for all subjects. The results were also evaluated through anecdotal information; the high ability group mastered problem solving strategies at a greater rate and the teachers reported that the high ability students were able to transfer strategies to content areas, even though the high ability students had often difficulties in the beginning of the experiment and became easily frustrated.

In 1986, Dorval and Pepin tested whether playing Zaxxon (FIGURES 5 and 6) would enhance subjects' spatial visualization test scores (Forms A and B of the Space Relations Test of the Canadian Differential Aptitude Test, DAT, were used as measures of spatial visualization). The game, Zaxxon was selected as it presents face validity for spatial visualization and it is well known to possess excellent qualities in terms of design and manipulation. Their first hypothesis, that the test scores can be improved, was supported by the results. Their second hypothesis was that women can improve more than men. Dorval and Pepin tested 70 undergraduate students, found no initial sex differences and their second hypothesis was not supported by the results as they concluded that males and females gained equally and significantly from playing Zaxxon. The subjects participated in eight sessions of five plays and the time interval between sessions was 1-2 weeks.

FIGURES 5 & 6 (The Video Game Museum 2004): Zaxxon by Sega / Gremlin 1982.

120 American fourth- and fifth-grade students, who had prior experience with computers participated in a study by Forsyth and Lancy (1987). The researchers

wished to establish whether playing an adventure game called “Winnie the Pooh in the Hundred Acre Wood” could teach place location information to students and whether they would enjoy the experience (they all liked it). The game was chosen as it is a simple, generic search-type adventure game and “simulates a simple, purposive exploration of a finite space” (Forsyth & Lancy 1987, 383). Place location is a part of the ‘cognitive mapping’ or spatial representation process which is universal among humans and present throughout virtually the entire life-span (Forsyth & Lancy 1987, 378). They assumed that using the computer as a means would be less successful with females – the assumption was suggested by available evidence. This assumption was proven false. Students learned to correctly identify places encountered in the game, subjects playing with a map were more successful and there were no significant gender differences, which is what the researchers consider as “perhaps their most positive finding” (Forsyth & Lancy 1987, 389) and they also underline that their study is one of the few studies which involves games to report no gender differences.

Children’s, whom were fifth, seventh and ninth graders, mental rotation skills were improved by playing two games, The Factory, and Stellar 7 in a study by McClurg and Chaille (1987; cited by Greenfield, Brannon and Lohr 1994, 88). The skills improved – the study consisted of 12 sessions (cited by Sims & Mayer 2002, 99), 45 minutes twice a week for 6 weeks and the games require mental rotation and spatial visualization skills (cited in Okagaki and Frensch 1994, 36; see also Greenfield, Brannon and Lohr 1994, 89). Mental rotation skills were tested using a paper-and-pencil test featuring three-dimensional shapes. Boys’ initial skills were better and the sexes benefited equally – whether the difference in skill-level remained throughout the experiment is unclear (see Subrahmanyam & Greenfield 1994, 16).

Subrahmanyam and Greenfield (1994) showed that playing a spatially oriented game, Marble Madness, improved children’s spatial ability test scores more

than playing a non-spatial computer game, Conjecture. Their sample included 61 subjects (28 boys, 33 girls) and the spatial skills were measured using a computer-based test battery by Pellegrino et al. (1987). Subrahmanyam and Greenfield (1994, 19) explain that Marble Madness was selected because it involves the use of "the spatial skills of guiding objects, judging speeds and distances of moving objects, and intercepting objects". Conjecture is a non-spatial word game, similar to the TV show "Wheel of Fortune". Spatial performance during pretest assessment was significantly better in boys than girls. The subjects in the experimental groups played either game for a total of 2 hr and 15 min, divided into three 45-minute sessions. Video game practice on Marble Madness was more effective on children who had poor initial spatial skills. Playing Conjecture did not improve performance. The authors suggest that video games may be utilized in equalizing individual and gender-associated differences in spatial performance. Subrahmanyam and Greenfield (1994, 26) also state that: "the results confirm the thesis that video games are cultural artifacts that provide informal education for spatial skills".

In a study by Greenfield, Brannon and Lohr (1994), the authors tested whether playing a 3-dimensional action arcade game, Empire Strikes Back had an effect on the spatial skill of mental paper folding (the test itself was constructed by Brannon and Lohr). This study is unique in using the ecology of a video game arcade: experiments by other researchers have taken place in a laboratory or classroom setting. The subjects were undergraduate students and two experiments were carried out. The first experiment established a correlation between the game and the test. In the second experiment it was concluded that short-term practice on Empire Strikes Back did have no effect on mental paper folding, but long-term practice did. Greenfield, Brannon and Lohr figured out that gender does not influence the spatial skill in question directly, but through its influence on video game expertise.

Okagaki and Frensch (1994) carried out a study the conclusion of which supports earlier findings by Subrahmanyam & Greenfield (1994; Okagaki & Frensch 1994, 53; see also Sims & Mayer 2002, 100). Okagaki and Frensch found a difference in between the sexes when it came to playing Tetris and testing spatial ability; larger pretest-to-posttest gains were shown on male undergraduates (on 2 out of 4 tests taken from the kit by French, Ekstrom and Price 1963), but none on females. The subjects were older adolescents and had no prior experience in Tetris. They played it for 6 hours. Okagaki and Frensch (1994, 33) consider their findings as reliable and consistent in relation to gender differences in complex mental rotation tasks. Like earlier research, they also conclude to have obtained mixed results (Okagaki & Frensch 1994, 54). They suggest that if the development of spatial skills within the video game context is an example of situated cognition (Brown et al. 1989), those who wish to "capitalize on the motivational aspect of video games for spatial skills training will need to find or develop games that are similar to the actual contexts in which the spatial skills will eventually be used".

Sims and Mayer (2002) executed two experiments regarding Tetris and mental rotation. They used computerized mental rotation tests similar to Shepard / Metzler (1971) and paper-and-pencil tests (Card Rotations, Formboard and Paper Folding tests) by Ekstrom, French and Harman (1976) to measure spatial skills. In the first experiment they compared spatial skills of students who were skilled in playing Tetris with students who had never played Tetris. In the second experiment Sims and Mayer compared two groups of non-Tetris players: the experimental group received 12 hours of Tetris playing practice and the control group received none. They concluded that the results obtained in Experiment 1 support a domain-specific theory of problem-solving transfer in which spatial cognitive skills learned in one domain do not generally transfer to other domains and the results of their experiments show that Tetris expertise is related only to performance on spatial ability tasks involving mental rotation of

Tetris shapes, or shapes very similar to Tetris shapes. Sims and Mayer also showed that skilled Tetris-players executed mental rotation procedures more quickly than other players, even though the procedures were the same. They found no evidence that 12 hours of Tetris-playing in the second experiment had any impact on the subjects' spatial skills.

Green & Bavelier (2003) carried out a set of five experiments, with subjects aged 18-23 years, exploring whether visual skills can be altered by video-game playing. Four experiments establish changes in different aspects of visual attention in habitual video-gamers as compared with non-video-game players. Video-gamers, who had played action video games, such as Grand Theft Auto III (Figures 7 & 8), Half-Life, Counter-Strike, Crazy Taxi, Team Fortress Classic, 007, Spider-Man, Halo, Marvel vs Capcom, Roguespeare and Super Mario Cart on at least 4 days per week for a minimum of 1 hour per day for the previous 6 months, had significantly increased attentional and visual skills.

FIGURES 7 and 8 (The Video Game Museum 2004): Grand Theft Auto III.

In the fifth experiment a group of non-video-game players went through training, in which the participants played Medal of Honor: Allied Assault (Electronic Arts) for an hour per day for 10 consecutive days. The control group played Tetris. The subjects who had been playing Medal of Honor showed greater improvement in visual attention, spatial distribution and its temporal resolution than the control group. Green and Bavelier (2003, 536) explain that

Tetris has a challenging visuo-motor component, but demands focus on one object, whereas action games require that attention is distributed and/or switched around the field. Green & Bavelier (2003, 536) conclude that "although video-game playing may seem to be rather mindless, it is capable of radically altering visual attentional processing".

3.2 Summary

This chapter introduced manifold studies focusing on the effects of computer gaming on spatial abilities. The researched spatial factors, the type of subjects used in the experiments, the games played, and most importantly the primary conclusions were presented. The research reviewed cover roughly the time period modern computer/video games have existed and been commercially available. The scientific themes have remained the same; after all, research into video games is still relatively rare (de Aguilera & Mendiz 2003, 3-5). It can be noted that some details in the actual experimental designs have changed in time, e.g. the paper-and-pencil tests utilized to measure subjects' spatial skills have often been replaced by computerized test batteries.

4 DISCUSSION

Different types of games provide their own operational requirements and may in spite of similarities, require different cognitive and other skills. Computer games and the effects of which in studies, are however, often generalized. Gagnon (1985, 271) points out different videogames appearing to use or be related to different types of spatial cognitive skills; many of the studies discussed here fail to underline this issue: a limited number of computer / video games are utilized in experiments and a general conclusion is drawn. It should be noted that, for instance a game, such as Tetris may require and improve skills very different from a 3D action game from either the 1st, or the 3rd person perspective. Computer games have evolved rapidly and the games in the 1980's (e.g. Pac-Man or Donkey Kong) were compact in comparison with the 1990's 3D games (e.g. Tomb Raider or Doom). Three-dimensionality according to today's standards is a component that can be found scarcely in the games studies discussed here examine; merely in research by Greenfield, Brannon & Lohr (1994) and Green & Bavelier (2003).

All studies reviewed in this paper reported improved spatial performance (of varying levels) through gaming. Unlike other studies, Sims & Mayer (2002) and Greenfield, Brannon & Lohr (1994) did not discover short-term practice having any effect on spatial skills – only long-term practice was successful; this seems logical and is also an interesting finding as a 12-hour practice had zero effect, when a 6-hour practice on the same game (Tetris) in an experiment by Okagaki and Frensch (1994) led to different result. Some gender differences were observed in the studies discussed: Gagnon's (1985) experiments' lacked overall effects (anyhow a positive correlation between the amount of past videogame experience and spatial test scores were shown), but the females improved significantly on spatial visualization, McClurg & Chaille (1987) and Subrahmanyam & Greenfield (1994) mention males outperforming females on the initial spatial test scores; Okagaki and Frensch (1994) witnessed larger pre-

to posttest gains on males than females, and Dorval & Pepin (1986), Forsyth & Lancy (1987) and McClurg & Chaille (1987) state both sexes gaining equally from game-practice.

It is evident that computer/video games have established a solid position as a form of entertainment and, apart from recreational purposes, the possible educational significance of computer games yet seems somewhat vague, however appears to have potential and requires more attention. Studies with larger samples and a greater number of games, or a meta-analysis is required in order to draw a further conclusion. The question is: Can spatial training be transferred to real-life situations?

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