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COGNITIVE EFFECTS OF VIDEO GAMES

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My eleven-year-old nephew Sean and I are playing a race-car video game. He races around the board, passing cars and moving his hands at lightening speed. I struggle along at the end of the pack. Sean, who is able to watch me play as he is winning the game against the computer (who is providing more competition than I am), begins to give me some verbal guidance about how to use my joystick. At one point, he even says, "Turn around, Aunt Sandy—you're going the wrong way!"

Sean is able to multitask and win a complex game, requiring skills of attention, memory, concentration, and planning while coaching and teaching me to play at the same time. How does he do it?

American children spend approximately six hours each day with media (Roberts et al., 1999). Although most of this time is currently spent viewing television, an increasing amount of time is invested in interactive technologies, including video games (Rideout et al., 1999). Video games are often children's first experiences with computer information technologies (Calvert, 1999). The popularity of gaming at home, often with other peers, now extends to online interactions with known and unknown competitors. Although the specific amount of time that children in other cultures spend with electronic games may be less than their American counterparts, the ways that children learn from media should be consistent across cultures.

Using an information-processing model that is sensitive to developmental differences in learning, I address the following questions: Who plays video games? How do children interact with, and think about, video games? What kinds of skills are needed to extract information from these games, and what kinds of skills does game playing cultivate? Why do boys gravitate to these games more than girls, and what is the potential impact of differential interest for children's development?

Who Plays Video Games?

For video games to impact children's development and cognitive skills, children must first play them. The kinds of video games available for children to play are as follows: (1) general entertainment, a story or game with no fighting or destruction; (2) educational, in which children learn about new ways to use information; (3) fantasy violence, in which the theme is to fight and avoid being killed; (4) human violence, in which the goal is to fight and avoid being killed as a human character; (5) nonviolent sports, sports games without fighting; and (6) violent sports, sports game with fighting (Funk & Buchman, 1995). Game play has now moved from consoles to online interactions with characters moving fluidly between offline and online spaces. In addition, virtual reality games provide three-dimensional versions of games for children to immerse themselves in (Calvert & Tan, 1994). These innovations, particularly the virtual reality game, may make gaming an increasingly realistic experience for children.

Boys are the overwhelming players of video games, typically spending twice as much time gaming as girls (Buchman & Funk, 1996). Gaming is a core part of boys' friendships and socialization experiences (Wartella, O'Keefe, & Scantlin, 2000). Boys primarily play fast-action games that include a considerable amount of violent content as well as sports games (Funk, Germann, & Buchman, 1997; Gailey, 1996; Wright et al., 2001). Girls, by contrast, prefer spatial games such as *Tetris*, fantasy genres, educational games, and games with traditional feminine themes such as *Barbie Fashion Designer* (Funk et al., 1997; Gailey, 1996; Subrahmanyam et al., 2001; Wright et al., 2001). Gaming is a much less important facet of girls' friendships and socialization than that of boys.

Video game play increases from ages two to seven (Huston et al., 1999), but then decreases as children grow older (Buchman & Funk, 1996). For instance, fourth-grade girls spent approximately five and a half hours per week of gaming compared to only about three hours per week for eighth-grade girls. Although the overall levels of game play was higher than that of girls, boys showed similar declines in play as age increased. Specifically, fourth-grade boys spent approximately nine and a half hours per week playing games, compared to only five hours per week by the eighth grade (Buchman & Funk, 1996).

Sean, my nephew, is at peak performance as a gamer. He has played games for several years by age eleven, and he knows the games well. He prefers action games, selecting a nonviolent sports game for us to play.

Does playing video games facilitate the development of children's cognitive skills, particularly visual and spatial skills? Or does playing video games impede the development of children's cognitive skills, particularly verbal linguistic skills?

Development and Information Processing Theory

Two major developmental theories are useful in understanding how and what children learn from playing video games. The first is information processing theory. The second is developmental theory grounded in the work of Piaget (1962) and Bruner, Olver, and Greenfield (1968). Both theoretical perspectives view children as active processors of information.

Information processing theory, which grew out of the developmental theories of Piaget and Bruner, is actually a group of theories that are based on how information flows through a "human" computer. These information-processing activities include perception, attention, representation and memory, and output. This chapter will integrate both theories into one framework, with the developmentalists primarily contributing to the section on representation and memory.

Perception

Perception involves the initial intake of information. In media research, one useful approach to the study of information intake is Berlyne's (1960) theory of perceptual salience. In Berlyne's approach, certain qualities of the environment are likely to trigger attention and interest because they have survival value for the organism. These perceptually salient qualities include movement, contrast, change, incongruity, complexity, and surprise.

In the predominantly visual medium of television, Huston and Wright (1983) examined perceptually salient qualities in relation to production techniques. These production techniques include *action*, how much movement there is in the production; *pacing*, how quickly scenes and characters change; *visual and auditory special effects*, the violation of real-life events through surprising and incongruous visual events and sounds; *foreground music*, loud music that appears in the absence of dialogue; and *character vocalizations*, nonhuman incongruous sounds made by characters. Nonsalient production features involve *dialogue*, in which characters talk to one another meaningfully, but often without features that easily attract attention.

These same perceptually salient features are also the hallmark of video game presentations. That is, perceptually salient features such as rapid action, loud music, rapid pacing, and visual and audio effects characterize video games with nonsalient features such as dialogue being used sparingly.

Using principles embodied in video games, Malone (1981) theorized that challenge, fantasy, and curiosity were key elements for a theory of intrinsically motivating instruction. Variable levels of challenge included goals that were personally meaningful as well as uncertain outcomes, the latter embodying the salient quality of surprise. Fantasy included those that were created by the player as well as by the game maker. Curiosity included sensory curiosity such as audio and visual effects, a direct link to both Berlyne's theory of perceptual salience and the production features that embody those qualities. Malone (1981) found that boys preferred action, whereas girls preferred musical rewards.

Visual Attention

Video games use perceptually salient features to move children to the next phase of information processing: visual attention. Perceptually salient forms are important, in part, because they attract attention to certain content (Calvert, 1999). Initially, this attraction can be involuntary, based in large measure on the survival value that attention to certain features brings to the developing child. This is called the *salience function* of features. Over time, however, children learn that certain features signal and mark important content for further processing. This is called the *marker function* of features (Calvert et al., 1982).

In video game play, sound effects often signal and mark the presence of important content. For instance, a sound informs knowledgeable players that they are about to enter a new level of the game or that a certain event is about to happen. It is through prior experience in playing the game that players gleam nuances of meaning from such experiences. Through temporal contiguity with these sound effects, children are primed for the next sequence of game play.

Video games also require sustained attention to the task in order to succeed, as well as the ability to look at the proper areas of the screen. Few empirical studies have examined the role of visual attention in video games, apparently presuming that the player will automatically attend in order to win. One exception is in a body of work by Patricia Greenfield.

Allocation of attention to the correct areas of a task may be affected by video game play. Greenfield, deWinstanley, Kilpatrick, and Kaye (1994) examined divided attention, as indexed by response time, for college students who had to locate a target on a computer screen. Experienced video game players were similar to novices when the target appeared in a high probability location on the computer screen; however, the experienced players responded faster than the novices when the target was in a low probability location on the screen. In a second experiment, the authors demonstrated that five hours of practice with a video game called *Robotron* improved response time for the low probability location. These findings suggest that attention is actually guided by memories, that is, schemas, developed by previous game play.

As attention becomes more automatic at a task, scarce attentional resources are freed up that allow the player to perform multiple tasks at the same time, or multitasking. So one reason that my nephew Sean is able to play video games well and coach me simultaneously is because he knows what to do at the game; his attention is automatically directed to parts of the game needed to win.

Representation and Memory

McLuhan (1965) argued that television was unique in its form, not its content. That is, the same information could be presented in a book, on the radio, or on television, but how it was presented, and potentially represented, varied with the medium.

Video games are also presented in the unique audiovisual forms that first appeared with film and television. However, there are new ways of getting the content in video games that were not part of early media experiences. More specifically, children must now interact with content, not just observe it. This shift to interactive experiences provides very direct ways for children to control and to receive responsive feedback from media.

Through experience, children construct schemas, learned expectations that guide perceptions, memories, and inferences about content. These schemas can vary in the form in which they represent content and their repeated use over time can cultivate the development of visual and spatial skills. As they grow older, children develop metamemory skills that enable them to know about their knowing. At this abstract level, children become quite skilled at creating and articulating strategies, such as how to win video games.

Developmental theorists have been instrumental in putting forth a framework for understanding how children think differently at different points in development (Bruner, Olver, & Greenfield, 1968; Piaget, 1962). In Bruner et al.'s (1968) system, which was based in Piaget's earlier work, children represent information in: (1) enactive (with the body), (2) iconic (visual), and (3) symbolic (verbal) modes of thought. These levels of representation progress from enactive to iconic to symbolic, moving from very concrete to increasingly abstract ways of thinking about information.

Enactive representation, the first level of retaining information, involves representing information with the body. Young children, for instance, initially turn their head from side to side to avoid eating undesirable foods. That back and forth motion becomes an enactive representation for the concept "no." Enactive representations remain a part of thought, particularly in representing what it feels like to hit a baseball or throw a Frisbee. The body knows how to do these activities through the muscles.

In video game play, I've observed a child who physically jumped when he wanted his *Mario Brother's* character to jump over an obstacle. His body knew what he wanted his character to do (Calvert, 1999). Similarly, in playing a virtual reality game such as *Dactyl Nightmare*, adolescents may have developed enactive representations of events, such as pulling the trigger of a gun. That is, they knew how it felt to pull the trigger of a gun and that feeling was retained and represented in their body (Calvert & Tan, 1994). Similarly, Sean's muscles knew what it felt like to operate his joystick when he played video games with me.

Iconic representation, the second level of representation, involves the use of concrete symbols such as visual pictures, to remember events. It is in this tier of representation that video game research has focused.

Video game play frequently activates cognitive skills by calling upon the player to construct mental representations of space in order to win the game. Repeatedly playing video games may cultivate visual spatial skills.

Studies of children and adults who are expert video game players demonstrate that they mentally construct maps as they interact with the game, even if they have never viewed a map of the game drawn for them (Greenfield, 1994). In pilot studies, Greenfield found that boys and college students could either draw or reported the use of mental maps of a video game called *Castle Wolfenstein*.

These mental maps are constructed through the activities of game players. More specifically, computer games frequently require the user to move from one screen to another through branching techniques. As the player practices and becomes proficient at the task, he or she is developing an iconic, schematic mental construction of the space. For instance, in *Castle Wolfenstein*, the player moves through several rooms and has to exit through particular doors from each room to reach the ultimate destination: freedom! Although it is clear that expert players of such games are more proficient at these visual-spatial skills, it is unclear if they were initially more proficient at creating mental maps or if they developed the skill through playing the game.

Playing computer games can cultivate (i.e., develop) visual-spatial skills. Greenfield, Brannon, and Lohr (1994) first performed a naturalistic study in which they went to a video parlor and waited for college students to complete *The Empire Strikes Back*, a game requiring the player to navigate through three-dimensional space from a two-dimensional representation. The experimenters then asked the players to perform a mental paper-folding task, a test of visual-spatial skills. Those students who were extremely proficient on the computer game were more proficient on the mental paper-folding task than were less successful computer game players. The results suggest that visual-spatial skills are associated with expertise in the spatial skills area.

In an experimental follow-up of this naturalistic study, Greenfield, Brannon, and Lohr (1994) exposed college students to the video game *The Empire Strikes Back* for an hour or two. Although short-term exposure did not improve students' performance on the paper-folding task, long-term exposure did predict performance. That is, the more frequently students had participated in computer games, the better they performed at the paper-folding task. This study suggests that long-term exposure to computer games is central to understanding their impact on the development of children's visual-spatial skills.

In another study of spatial performance (Okagaki & Frensch, 1994), older adolescents played the game *Tetris* for six hours. *Tetris* calls upon and cultivates rapid rotation of objects and placement of blocks. Compared to a control group, video game players were faster at mental rotation and spatial visualization. Men performed more quickly than women did on complex mental rotation tasks, but not on simple visual rotation tasks.

Boys such as Sean, who spend many hours each week playing video games, construct visually based schemas that allow them to anticipate the game layout and moves that they must make. His game playing has become so automatic that he can simultaneously instruct me as he carries out complex mental and motor activities involved in successful game performance.

Symbolic modes of thought, the most abstract way of representing information, involves using words or other abstract symbols that are arbitrary and do not have a direct link to the information that is being represented. There are numerous complaints that visual media, including video game play, are replacing verbal ways of thinking about information, leading to an illiterate society. To date, there is no firm evidence that an erosion of verbal skills has taken place due to experiences with visual media. Instead, it appears that video game play cultivates the development of visual spatial skills, an underutilized skill in American culture.

Sean has abstract metamemory skills that allow him to think about strategy, to plan his game so that he will be successful. He has developed the abstract as well as the concrete skills that are needed for successful gaming.

Output

The evidence suggests that the way that information comes into the information processing system is often similar to how it is encoded and represented. Therefore, how that information is remembered may also be modality specific. Visually presented information may be remembered in a visual form and verbally presented information may be remembered best in a verbal form (Calvert, 1999).

Preliminary evidence suggests that playing video games may cultivate iconic modes of information processing and subsequent output. In a cross-cultural study by Greenfield and colleagues (1994), college students from the United States and Italy interacted with one of six video games. Prior qualities, such as being a male, being an experienced video game player, and being American, positively affected pretest scores on scientific-technical discovery skills. After short-term exposure to video games for two and a half hours, all participants playing discovery games improved their decoding of graphs depicting scientific-technical information more than the control groups.

Participants also used iconic diagrams rather than written words to represent their memories during retrieval tasks. These visual diagrams paralleled the presentation of the task they had experienced, suggesting that information is best remembered in the form in which it was initially experienced. The findings suggest that computers can cultivate the use of iconic modes of expression.

Sean's output is smooth, fluid video game play as he maneuvers every turn and overcomes every obstacle. Through practice, he has become an expert at a visually based activity.

The Cultivation of Visual and Spatial Skills

Although visual skill development typically generalizes best to similar rather than more distant cognitive skills, there is some evidence that visual processing skills have improved during the twentieth century (Subramanyam et al., 2001). Consider the case of IQ scores.

IQ tests comprise school-like items because they were originally designed to predict success and failure in the French school system. During the twentieth century, children's performance on the visual subcomponents of IQ tests increased, a finding known as the Flynn effect (1994). Greenfield (1998) argued that these improvements in visual scores parallel and are probably caused, in part, by children's use of visual media, including video game play, because computer games develop many of the same nonverbal skills that are tested on the Stanford Binet and Weschler IQ tests (Greenfield, 1998). For example, the spatial visualization skill developed by playing *Tetris* is similar to the Object Assembly subtest of the Weschler IQ Test (Subramanyam et al., 2001). Because of these informal learning experiences, visual IQ performance may have actually increased over time. The implication is that visual interactive games are becoming informal learning tools that cultivate iconic ways of thinking about information. These visual skills, in turn, may be useful in occupations such as computer programming that require visual spatial thinking and visual forms of representation for successful performance.

Will Sean's IQ scores show increases in visual-spatial subscores because of his video game play? Will other children who play video games show increases in these subcomponents of IQ tests?

Gender Differences in Cognitive Skills

If, as the literature suggests, certain kinds of video game play increase visual and spatial skills, then getting girls to play games that cultivate this kind of skill may be important in their cognitive development. If researchers can get girls to play video games, do their spatial skills improve?

Subrahmanyam and Greenfield (1994) attempted to reduce gender differences in visual-spatial skills by exposing ten- and eleven-year-old children to a maze-based video game called *Marble Madness* for two and one-fourth hours. Children were initially pretested on spatial skills. A control group played a word game on the computer, while the experimental group played *Marble Madness*. Finally, children were posttested on two of the three original pretests. Boys were initially better on the visual-spatial tasks. After exposure to the computer games, however, girls who had received treatment in visual-spatial tasks had caught up to the boys in visual-spatial skills. Although girls performed as well as boys in the more general spatial task after video game exposure, boys continued to outperform girls at the video game. So even if I practice and improve my visual-spatial skills, Sean will probably continue to outperform me at video game play.

Kafai (1995) took a different tack in addressing the gender differences in video game play. Instead of having children play another person's game, she had children create their own games. Boys created games that were very much like the action and violent games that they played every day. Themes of good triumphs over evil were prevalent in their games, where players often fought off evil bad guys to achieve their goals. By contrast, girls' games had more variability in themes and in outcomes and rarely had evil characters. For instance, girls tried to avoid a spider or ski down a slope without taking a spill. Many of these "girl" games were nonviolent in focus and had treasures as a reward. All children constructed physical spaces as a setting for their game. Girls' games typically took place in real-life settings such as ski slopes and airports, whereas boys' games took place in imaginary places such as haunted houses, space stations, and "Funland." The characters of boys' games tended to be boys, whereas girls left the gender of the character flexible. Finally, the feedback of boys' games was violent; players were often killed and lost the game when they made mistakes. In contrast, the feedback of girls' games was rarely violent; players could continue the game if they made mistakes. So maybe there is hope for my video game play—I just need to create my own video game and I will have the advantage!

Conclusion

Computer games are often children's first entry into the world of interactive media. Boys like Sean are most interested in playing video games, and they reap the cognitive benefits of video game play, particularly the cultivation of visual-iconic and spatial representation skills. Such playful experiences can cultivate the skills that are necessary for successful navigation along the information highway as well as prepare children for later occupational skills in areas such as engineering and computer programming. Where our school system ends, our informal gaming environments begin, providing lessons in the visual skills needed to excel in many technical careers.

References

Berlyne, D. (1960). *Conflict, curiosity, and arousal.* New York: McGraw Hill.

Bruner, J., Olver, R., & Greenfield, P. M. (1968). *Studies in cognitive growth.* New York: Wiley.

Buchman, D., & Funk, J. (1996). Video and computer games in the '90s: Children's time commitment and game preference. *Children Today, 24,* 12–15.

Calvert, S. L. (1999). *Children's journeys through the information age.* Boston: McGraw Hill.

Calvert, S. L., Huston, A. C., Watkins, B. A., & Wright, J. C. (1982). The relation between selective attention to television forms and children's comprehension of content. *Child Development, 53,* 601–610.

Calvert, S. L., & Tan, S. (1994). Impact of virtual reality on young adults' physiological arousal and aggressive thoughts: Interaction versus observation. *Journal of Applied Developmental Psychology, 15,* 125–139.

Flynn, J. R. (1994). IQ gains over time. In R. Steinberg (Ed.), *Encyclopedia of human intelligence.* New York: Macmillan.

Funk, J., & Buchman, D. (1995). Video game controversies. *Pediatric Annals, 24,* 91–94.

Funk, J., Germann, J., & Buchmann, D. (1997). Rating electronic games in the United States. *Trends in Communication,* 2, 111–126.

Gailey, C. (1996). Mediated messages: Gender, class, and cosmos in home video games. In I. Sigel, P. Greenfield, & R. Cocking (Eds.), *Interacting with video: Vol. 11. Advances in applied developmental psychology.* Norwood, NJ: Ablex.

Greenfield, P. M. (1994). Representational competence in shared symbol systems: Electronic media from radio to video games. In R. R. Cocking & K. A. Renninger (Eds.), *The development and meaning of psychological distance.* Hillsdale, NJ: Erlbaum.

Greenfield, P. M. (1994). Video games as cultural artifacts. *Journal of Applied Developmental Psychology, 15,* 3–12.

Greenfield, P. M. (1998). The cultural evolution of IQ. In U. Neisser (Ed.), *The rising curve: The long-term gains of IQ and related measures.* Washington, DC: The American Psychological Association.

Greenfield, P. M., Brannon, C., & Lohr, D. (1994). Two-dimensional representational movement through three-dimensional space: The role of video game expertise. *Journal of Applied Developmental Psychology, 15,* 87–104.

Greenfield, P. M., deWinstanley, P., Kilpatrick, H., & Kaye, D. (1994). Action video games and informal education: Effects on strategies for dividing visual attention. *Journal of Applied Developmental Psychology, 15,* 105–124.

Greenfield, P. M., Camaioni, L., Ercolani, P., Weiss, L., Lauber, B. A., & Perucchini, P. (1994). Cognitive socialization by computer games in two cultures: Inductive discovery versus mastery of an iconic code? *Journal of Applied Developmental Psychology, 15,* 59–86.

Huston, A. C., & Wright, J. C. (1983). Children's processing of television: The informative functions of formal features. In J. Bryant & D. R. Anderson (Eds.), *Children's understanding of television: Research on attention and comprehension.* New York: Academic Press.

Huston, A. C., Wright, J. C., Marquis, J., & Green, S. (1999). How young children spend their time: Television and other activities. *Developmental Psychology, 35,* 912–925.

Kafai, Y. (1995). *Minds in play.* Hillsdale, NJ: Erlbaum.

Malone, T. (1981). Toward a theory of instrinsically motivating instruction. *Cognitive Science, 4,* 333–369.

McLuhan, M. (1965). *Understanding media: The extensions of man.* New York: McGraw Hill.

Okagaki, L., & Frensch, P. A. (1994). Effects of video game playing on measures of spatial performance: Gender effects in late adolescence. *Journal of Applied Developmental Psychology, 15,* 33–58.

Piaget, J. (1962). *Play, dreams, and imitation in childhood.* London: Routledge & Kegan Paul.

Rideout, V., Foehr, U., Roberts, D., & Brodie, M. (1999). *Kids and the media @ the new millennium. Executive summary.* Menlo Park, CA: Kaiser Family Foundation. http://www.kff.org.

Roberts, D. F., Foehr, U. G., Rideout, V. J., & Brodie, M. (1999). *Kids and media @ the new millennium.* Menlo Park, CA: Kaiser Family Foundation.

Subrahmanyam, K., & Greenfield, P. M. (1994). Effect of video game practice on spatial skills in boys and girls. *Journal of Applied Developmental Psychology, 15,* 13–32.

Subramanyam, K., Greenfield, P. M., Kraut, R., & Gross, E. (2001). The impact of computer use on children's and adolescents' development. *Journal of Applied Developmental Psychology,* 22, 7–30.

Wartella, E., O'Keefe, B., & Scantlin, R. (2000). *Children and interactive media: A compendium of current research and directions for future research.* A report to the Markle Foundation.

Wright, J. C., Huston, A. C., Vandewater, E. A., Bickman, D., Scantlin, R., Kotler, J., Caplovitz, A., Lee, J., Hofferth, S., & Finkelstein, J. (2001). American children's use of electronic media in 1997: A national survey. *Journal of Applied Developmental Psychology, 22,* 31–47.