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Media Symbol Systems and Cognitive Processes

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Tools have played a central role in human evolution. The stone tools of prehistoric man, the machine tools of the industrial revolution, and recent computerized and digital tools, have all driven changes in human behavior in the era in which they appeared. Tools, particularly mental ones, have played an important role in developmental theory – on the Vygotskian view, psychological tools (i.e., language, mathematics) provided by the culture lead to the emergence of higher mental functions. Elsewhere we have argued (Maynard, Subrahmanyam, & Greenfield, 2005) that the particular tools provided by the culture – be they the back strap loom or the computer – elicit and develop particular sets of cognitive skills.

Media, which are the focus of this book, are first and foremost tools provided by the culture, and our central concern is their influence on our thinking and learning. When considering media as tools, it is important to distinguish between the physical platform or hardware (i.e., the television set, computer, or videogame system), formal features (i.e., audiovisual production features that characterize a medium), and the content (i.e., the topic or focus of a television program or software program) within it (Calvert et al., 1982; Wright & Huston, 1983). The hardware aspects are akin to physical tools and are not the focus of this chapter. The formal features are independent of content and are akin to a language, which is a psychological tool and a symbol system. Just as the words of a language are symbols that a listener has to decode, the formal features of media consist of symbol systems that the user has to decode to understand the message. The content is the material or message conveyed by the formal features, for example, a particular story, as well as the words and actions of the characters in the story. We start by presenting the theoretical framework of our analysis and then examine the formal features of each medium to understand their influence on cognitive processes.

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Theoretical Framework

According to Olson and Bruner, "each form of experience, including the various symbolic systems tied to the media, produces a unique pattern of skills for dealing with or thinking about the world. It is the skills in these systems that we call intelligence" (Olson & Bruner, 1974, p. 149). We draw on this line of reasoning as we focus on the symbol systems of older media such as print, radio, and television, as well as the newer media forms such as videogames and Internet interfaces; we will show how the symbolic systems used in different media forms influence cognitive skills.

The theoretical premise of this chapter is that using a particular tool set develops the cognitive skills that are part of a group's implicit definition of intelligence (Greenfield, 1998). Different cultural or ecological niches provide different tools and these different tools not only utilize, but also develop particular sets of cognitive skills. Most importantly, from the perspective of this paper, is the idea that tools evolve and change over time. These changes in cultural tools are accompanied by changes in the cognitive skills and valued forms of intelligence within that ecological niche (Maynard, Subrahmanyam, & Greenfield, 2005). In this view, we should expect changes in cognitive processes and skills as media forms have evolved and changed – from print to radio, television, and, more recently, the Internet. This is the heart of our developmental idea – that different media forms develop different cognitive skills.

Here we examine cognition at two different levels – attention and representation. Almost a hundred years ago, William James defined attention as the focusing of the mind on some aspects of the sensory input over others (James, 1890), a concept known as selective attention. Representation concerns the internal mental encoding of objects and events (e.g., Piaget, 1951). Information about the world can be encoded in many different ways such as auditory, linguistic, visual/iconic, and motor/enactive representations. For example, a simple object such as a ball can be represented by a verbal description of what it is and what one can do with it, a visual/iconic representation of what it looks like, a motor/enactive representation of the action/s one can perform with it, or an auditory representation of what it sounds like when it bounces.

Bruner (1965) has distinguished three different kinds of representation which appear in a developmental order: enactive – representation through action; iconic – representation through images that resemble their referent; and symbolic – representation through symbols that bear no resemblance to their referent, are arbitrary, and are therefore established by social agreement or convention. Because Bruner was referring to the child's ways of representing the world, it can be difficult to apply the developmental ordering to media. However, the general ideas that different modes of representation can be used to symbolize the same content and that different kinds of representations can be at different developmental levels are important for understanding the role of representation in mediated experience and cognitive development. These ideas are central to our developmental theory, to which we now turn.

A new developmental theory of media understanding and use

We propose that the more real-world perceptual and cognitive cues a media representation makes available, the less mental transformation it will require and the earlier it will become accessible and usable to a child. This is really an extension of Piaget's emphasis on mental transformation as a hallmark of cognitive development. In line with this basic idea, prior research (e.g., Wright & Huston, 1983) suggests that the information delivered in different media forms may become accessible at different developmental periods depending on the particular representational systems they employ and the user's level of representational development. Taken together this means that there likely will be developmental trends in the internalization of the symbol form presented in a medium. In this view, television, which preserves the static and dynamic cues of the real world as well as its sounds, may be more appropriate for the very youngest children; picture books, which contain less realistic iconic representations in mainly static forms and, in their pure form, no sound, may be more appropriate for slightly older preschool and school-aged children; and books with only printed text – an arbitrary symbolic representational form bearing no physical relation to the real world – may be most appropriate for older children and adolescents. These developmental ideas can apply not just to chronological age ordering, but can also predict the degree of effort involved in using a particular medium. In particular, the more real-world cues and the less mental transformation involved in using and processing a mediated representation, the less effort to use and the more "natural" the use will seem.

Individual differences In addition to developmental trends, we also speculate that there will be individual differences in preferences for different media forms given the evidence that there are individual differences in processing style (e.g., Childers, Houston, & Heckler, 1985). Of relevance to us is Richardson's (1977) visualizer/verbalizer distinction, which captures individual preferences for processing words versus pictures and images. Accordingly we expect that individuals or groups of individuals who prefer to process certain symbol forms (e.g., verbal versus visual) will prefer media that incorporate those representations.

Representational competence The recognition that different modes of representation can be used to symbolize a common referent constitutes the skill of representational competence as defined by Sigel and Cocking (1977). Simply put, representational competence is involved when we grasp that stick figures and photographs are both two-dimensional representations of three-dimensional individuals. However, the idea that meaning is conserved across transformations of medium (Sigel, 1993) is only partially true. While reference may remain constant, meaning changes in the translation of content from one medium to another (Greenfield, 1993). A dramatic play broadcast over radio might draw attention to a character's words and the emotions conveyed in those words; in contrast, the same play broadcast over television might draw attention to the very same character's physical appearance and actions, leading to different meanings or interpretations (Greenfield & Beagles-Roos, 1988).

Sigel also introduces the notion of psychological distancing as one dimension of representational competence. He uses the term to refer to "a class of cognitive demands that serve to activate a separation of self cognitively from the here and now" (Sigel, 1993, p. 142). He continues, "Irrespective of the context in which it is used, the meaning of distancing is similar, namely, the interposing of physical and/or psychological space between the person and the event" (Sigel, 1993, p. 142). This notion of psychological distance between the self and the here-and-now event is very relevant to developing human beings operating in interactive virtual environments and is illustrated in the distance between users and their virtual representations such as nicknames and avatars. We will come back to this concept in relation to online multiplayer games.

Internalization of media forms Another theoretical piece is Salomon's (1979) idea that the symbol forms found in media, such as a computer, can become internalized mental representations for the user. A related theoretical idea comes from Bandura's (2001) social cognitive theory. According to Bandura, observational learning from mass communication is governed by cognitive representational processes; retention of modeled information occurs when the observer symbolically transforms modeled information into memory codes, and when recall involves the reconstruction of the coded information.

Greenfield (1993) coined the term cognitive socialization to refer to the internalization process by which cultural tools influence the development of processing skills; in this view media are important tools of cognitive socialization. It is important to remember that media differ in the symbol systems that they utilize and thus each medium has its own strengths and weaknesses in terms of the information that it presents (Greenfield, 1984). These differences result in subtle transformations of meaning. That is, when content is transferred from one medium to another, meaning is only partially conserved. For instance, television utilizes both auditory and visual symbol systems whereas print uses text and pictures. What do these different theoretical ideas predict about media symbol systems and their influence on cognitive skills? Salomon's work (1979) leads us to expect that the way a particular medium represents information will provide opportunities for different kinds of representational processes and skills.

Relation between Medium, Attentional Skills, and Representational Competence

In the next sections, we analyze the particular representational processes utilized by a medium and then provide evidence that the medium enables the construction of those kinds of representational skills. Note that we are talking about internalization of symbol systems rather than the learning of content. Where available, we present evidence that bolsters our claims about the developmental appropriateness of different media forms and individual differences.

We start with the oldest medium, print, then turn to radio, television/movies, and finally computers and the Internet. For our purposes, it is not necessary to distinguish different physical platforms (for example, we consider the DVD to be a particular platform for delivering movies); a movie utilizes the same representational codes and content whether it is delivered via a DVD or on a computer or seen in a movie theater. On the other hand, each medium is not totally separate either, but relates historically and representationally to other media. Thus, radio utilized the verbal aspect of print, but replaced the symbolic medium of print with that of spoken language. Television encompassed the verbal and sound environment of radio, but added moving images. Computers encompassed all of these prior media and added interactivity. In terms of Bruner's modes of representation, print and radio are similar in being mainly symbolic media. However, radio adds non-verbal sound elements such as music, sound effects, and intonation, while print can add pictures and diagrams.

Print

While print is older as a medium than electronic media, its lack of resemblance to the real-world stimuli – people, objects, and events – it is used to represent, makes it appear much later in development. Children typically learn to read around age 6, years after they can process the representations of television or even a simple videogame. But print itself also occurs in different formats. According to Kozma (1991), books employ the symbol systems of text and pictures; importantly the orthographic symbols that are used for text are stable – in English, text is placed horizontally from left to right and goes top to bottom. The stability of the symbols used in books is an important feature that distinguishes it from other technologies that also use these orthographic symbols; for instance the moving ticker tape on the television screen or on the Internet allows both text and pictures/images to be either static or dynamic. Kozma points out that the stability of books contrasts with other media such as lectures or audiotapes, which provide the same linguistic information but use different symbol systems in a transient, dynamic format.

Because books have been around human life for at least the past thousand years, they are taken for granted. Therefore, one does not see research examining the effect of its symbol systems on verbal representational skills in the same way that we have seen research on the effects of television and the computer. So we draw on research from other relevant areas to speculate about their influence on representational competence. Firstly, we know from research on early childhood education (Teale & Suzby, 1986) that the suite of skills referred to as emergent literacy skills comprise knowledge of the symbol systems and its conventions (e.g., that text goes from left to right, a book has a front and a back) among very young children. Research suggests that these emergent literacy skills are critical for the development of reading and require practice with the medium of books to develop (Scarborough & Dobrich, 1994).

Research also suggests that reading skill and vocabulary knowledge are related (Chall, Jacobs, & Baldwin, 1990) and that the size of a child's vocabulary can be predicted from the amount that he or she reads (Cunningham & Stanovich, 1991). Hence, there is feedback from the representational medium of print to that of speech. We also know that, when the amount of education is held constant, vocabulary has declined between 1974 and 1990 (Glenn, 1994). Similarly, there has been a corresponding decline in reading newspapers and other print sources as well as a decline in verbal Scholastic Achievement Test (SAT) scores (Greenfield, 1998). Hayes, Wolfer, and Wolfe (1996) argue that the 50+ point decline in mean SAT-verbal scores between 1963 and 1979 may be linked to the simplification of school textbooks published between 1919 and 1991. It could also be linked to the simplified vocabulary utilized on television, a medium that was developed and became popular within this period of time. It is too soon to tell how performance on the new SAT, particularly the writing section, may be linked to these reading patterns. Although there is consensus that reading of traditional print sources such as books has declined, the Internet has opened new avenues for reading and writing text; the relation of Internet use to writing skills is a fertile area for future research. We will discuss the Internet in relation to writing and representation in a later section.

Although books primarily use text, they also contain pictures and diagrams. According to Kozma (1991), the research suggests that recall is increased by the use of pictures with text particularly when the pictures are related to central themes, new ideas, or structural relationships that are addressed in the text. This increase in recall is especially true for poor readers. What is relevant to us is that pictures seem to aid learners as they construct mental models of the concept in question – Kozma suggests that this may be because pictorial symbol systems are more similar to objects and events compared to linguistic symbol systems. In other words, they are visual iconic forms of representation. The particular symbol system utilized by a medium helps users construct representations of that kind. We therefore expect that books with text alone will aid the construction of verbal/linguistic representations and books with text and pictures will aid the construction of verbal and pictorial representations.

Radio and television

Next we turn to the effects of radio and television on children's representational processes. Radio is an audio medium and television is a largely audiovisual medium. From our developmental theory, we would predict that the dearth of visual cues would make radio more difficult for young children to use to process action information, and this is what the research shows (Greenfield & Beagles-Roos, 1988). We would also predict that radio would be more effortful to process than television and therefore less popular as a vehicle for drama for adults; the history of television replacing radio for fictional entertainment, and even to a great extent for news, provides evidence on this point. In addition, the processing of televised action by infants as young as 14 months in Meltzoff's (1988) research also provides evidence that the large number of real-world cues provided by television makes its processing possible extremely early in development.

Wright and Huston (1983) classified the formal features of television to include action, pace, visual techniques such as camera zooms, cuts, and visual special effects, and auditory features such as music, dialogue, and sound effects. They group fast action and rapid pace, high levels of auditory features such as sound effects and loud music, and high levels of visual effects such as rapid cuts and visual special effects as perceptually salient features. These features, they argued, were more likely to attract attention and interest from young children. By contrast, features such as dialogue and narration, which provide a verbal linguistic mode to represent content, are non-salient.

In addition to audio and visual features, television also uses other symbol systems such as text, pictures, and diagrams, both stationary and in motion (Kozma, 1991). Although both radio and television are transient, coming and going in a dynamic and changing fashion on the screen (Kozma, 1991), they can be recorded on audio- and videotapes as well as CDs and DVDs. When used with such hardware, their symbol systems can be played, stopped, rewound, and fast forwarded, thereby coming under the control of the user.

Cognitive implications Greenfield and colleagues explored the effects of adding moving visual imagery to an audio narrative of a story on children's (grades 1–2 versus 3–4) imaginal representation (defined as children's representational construction of elements that were not in the original narrative) and memory representation (defined as children's representational construction of elements that were present in the narrative) (Greenfield & Beagles-Roos, 1988; Greenfield, Farrar, & Beagles-Roos, 1986). In both studies, the stimuli consisted of a video version and an audio version of children's stories using the same soundtrack. Children were exposed to one story in the audio version and the other in the video version. Imaginal representation was assessed by stopping the story a bit before its ending and asking the participants to continue the story orally. The results showed that children who heard the audio version created endings with greater representation of novel events, characters, and words whereas children who heard the video version constructed endings with greater repetition of material from the story they heard. The findings support the following hypothesis: because television provides richer information in an explicit external representation, it is less stimulating to the children's internal imaginal representation.

To test memory representation, children saw and heard the stories until the end and were then given a free recall task (retell the story to another adult, who had never heard or seen the story), a cued recall task, and inference questions. In this instance, television led to significantly better performance – better recall of information, greater focus on action representation, and greater use of audio-visual detail both in direct recall and as a source of inferences. In contrast, radio led to a greater focus on material presented only in the auditory channel, such as dialogue. When asked to retell the story using pictures (picture sequencing), television yielded better performance than a radio presentation, highlighting the fact that television stimulates visual representational processes. Similarly, school-aged children performed better on a picture sequencing task following an audio-visual compared to an audio-only presentation (Calvert, 2001). Visually presented information has also been found to lead to greater recall compared to the same information presented aurally for preschool-aged children (Hayes & Birnbaum, 1980). Overall, the research points to the superiority of visual/action representations over verbal/audio representations for a variety of cognitive processes, at least from preschool through middle childhood. However, transfer effects are strongest when the modality of presentation matches the modality of retrieval (Calvert, 2001; Greenfield, Farrar, & Beagles-Roos, 1986).

In their review of television formal features, Wright and Huston (1983) concluded that the perceptually salient features of television productions (e.g., fast action and pace) are effective at attracting and holding attention irrespective of the program content. In fact, they report that when studies separated violent content from perceptually salient formal features, it was form, not content, that directed and sustained attention (Wright & Huston, 1983). Even so, the interface of form with content has implications for what children learn. For example, Calvert and colleagues (1982) found that perceptually salient features such as character vocalizations elicited attention and facilitated learning of central verbal content that was presented immediately after that feature. Features such as moderate action levels facilitated comprehension of verbal content by providing dual visual and verbal modes that children could use to represent content. These effects occurred for preschool-aged children, but also for children as old as 9 and 10.

Other aspects of television grammar that have been studied include zoom-in and zoom-outs, fragmented spaces, logical gaps, and close-ups. In particular, Salomon and Cohen (1977) showed children four versions of the same television program – the content was the same, but the versions varied in the use of formal features. Children who viewed the version that emphasized close-ups did better on knowledge concerning the relation between parts and whole. In contrast, children who viewed the version with logical gaps were better at comprehending the logical structure and continuity of the plot. According to Salomon (1976), any single medium, such as television, utilizes a wide variety of symbolic codes, and the particular combinations of the codes have very different effects on cognitive skills and processes, which in turn influence the way information is processed and learned.

Motor implications Another aspect of representational competence that may be influenced by television is that of motor or enactive representational skills, particularly among young pre-linguistic infants. Meltzoff (1988) has pointed out that television presents a two-dimensional representation of reality and asked whether young infants are capable of incorporating such two-dimensional representations into their own motoric behavior involving real objects in three-dimensional space. He studied 14- and 24-month-old infants' ability to imitate television models immediately after exposure and after a 24-hour delay. Infants in his study either saw the experimenter disassemble and reassemble a toy (imitation condition), saw the experimenter manipulate the toy without displaying the target action (adult manipulation control), or saw the experimenter but not the toy or the target action (baseline condition). Even the 14-month-olds remembered the actions of a televised model over a 24-hour delay and produced those actions in their motor behavior when given access to that three-dimensional object. This study suggests that motor actions represented as moving iconic imagery on television can be internalized by very young pre-verbal infants. In other words, infants have representational competence to equate an iconic image with a motoric act. They can translate from an iconic medium of representation to a real-world action.

The research reviewed above is also relevant to questions about developmental patterns in the accessibility of different symbol systems. Meltzoff's (1988) study showed that children as young as 14 months were able to represent enactive or motoric representations on television; recall that enactive representations are the first kinds of representations to emerge in Bruner's (1965) developmental progression of representational kind. The finding is that representations organized around visual/action-based information generally lead to better cognitive processing. This finding is consistent with the hypothesis that television may be more effective among young children as it incorporates representations that are available early in development.

Videogames and computer games

The best-known and earliest videogames and computer games are even more complex than television when it comes to presenting two-dimensional representations of three-dimensional space, but more recently very simple games have been developed for young children. Using a mouse involves creating an action representation on the part of the user, so it makes developmental sense, in terms of Bruner's representational theory, that children who are quite young should be able to master the basics of this technology. The 2003 Kaiser Report, Zero to Six, found that 64 percent of children between 4 and 6 years of age know how to use a computer mouse to point and click. In doing so, they are integrating their own enactive representations using the mouse with the icons and iconic representations they find on the screen (Rideout, Vandewater, & Wartella, 2003).

But screen representations in games are typically very complex and require much more than simple point-and-click skills with a mouse. Most action video/computer games, which are spatial, iconic, and dynamic, have multiple, often simultaneous things happening at different locations and require a variety of attentional, spatial, and iconic representational skills compared to earlier media forms such as print, radio, and television.

Given such complexity, one would expect action games to utilize and develop a different profile of cognitive processes compared to earlier media forms such as print (e.g., Greenfield, 1984). There is now a solid body of work that has shown that computer game playing does have an impact on the specific cognitive skills that are utilized in the game, such as attention and representation (iconic and spatial). In the next sections we review this research to demonstrate how the symbol systems used in a medium are internalized, thus affecting users' cognition and learning.

Computer games and attentional skills One basic skill involved in playing most computer games and videogames is that of divided visual attention, which is the ability to keep track of multiple events occurring simultaneously at different locations of the screen. Greenfield, deWinstanley, and colleagues (1994) explored the effect of videogame expertise and experience on strategies for dividing visual attention among college students who were expert and novice game players. Skill in dividing attention was assessed by measuring participants' response time to two events of varying probabilities at two locations on a computer screen. For participants in the unequal probability condition, the target appeared more often at one location than another. For participants in the equal probability condition, the target appeared with equal probability at both locations.

Expert players had faster response times than novices at both the high and low probability positions of the icon in the unequal probability condition, whereas there was no difference between the groups in the equiprobable condition. Based on attention research (Posner, Snyder, & Davidson, 1980), which shows that people generally allocate more attention to high probability targets compared to equiprobable targets, Greenfield, deWinstanley, and colleagues (1994) suggest that expert players did better when the probability of the targets was unequal because they were better able to deploy attentional resources strategically. This use of attentional strategies to monitor multiple screen locations can be thought of as a precursor to the multitasking required by simultaneously monitoring multiple computer windows, an increasingly common experience on the Internet.

In a second experiment, Greenfield, deWinstanley, and colleagues (1994) found a causal relationship between playing an action game and improving strategies for monitoring events at multiple locations. College students were randomly assigned to either play the action game *Robotron* (experimental group) or to not play any game (control group). *Robotron* consisted of multiple entities acting simultaneously. Participants in the experimental group received 5 hours of practice playing *Robotron* between the pretest and the posttest. On the pretest, more and less experienced players differed only at the higher probability target, where the more experienced players again had significantly faster response times; there was no difference at the low probability target. However after 5 hours of playing *Robotron*, members of the experimental group responded significantly faster to the target at the low probability position on the screen; in contrast, members of the control group did not show this improvement. Participants in the control condition showed selective improvement with the equiprobable targets, presumably because of practice on the test. The equiprobable targets require less strategic skill, and there was no difference between expert and novice players for such targets in the first study.

Subsequent research by Green and Bavelier (2003), using both a correlational and a training study, has confirmed that videogame playing does improve attentional skill and importantly this effect was found to transfer to very different attentional tasks. In the correlational study, participants who had consistently played videogames in the six months prior to the study had better attentional capacity, compared to participants who had little videogame usage in the six months prior to the study. In the training study comparing the action game *Medal of Honor* and the puzzle game *Tetris*, Green and Bavelier found that the action game led to greater improvements on all the attentional tests compared to *Tetris*. In contrast to *Tetris*, which is a dynamic puzzle game in which only one event takes place at a time, *Medal of Honor* is a battle game in which multiple entities are simultaneously engaged in various actions.

Together the studies suggest that videogame experts are better than novices at monitoring two or more locations on a game screen and that practice improves strategies for monitoring low probability targets. They show that videogame training can have immediate short-term effects on the development of divided attention strategies and that expert game players also had better-developed attention skills than novices. Finally, they suggest that transfer effects can also occur.

Computer games and spatial representational skills Spatial representational skills are comprised of several sub-skills (Pellegrino & Kail, 1982), including the ability to judge speeds and distances, the ability to mentally rotate objects, the ability to visualize spatially, and the ability to deal with two-dimensional images of a hypothetical two- or three-dimensional space. Researchers have suggested that these skills are utilized in all kinds of computer applications, from word processing and programming to action videogames (Greenfield, 1983, 1984, 1990). Research demonstrates that repeated practice with games enhances selected spatial skills.

In a training study of 10- to 11-year-old children, Subrahmanyam and Greenfield (1994) compared the effects of two computer games, *Marble Madness* and *Conjecture*, on spatial skills such as anticipating targets and extrapolating spatial paths. *Marble Madness* involved guiding a marble along a three-dimensional grid using a joystick – the player had to keep the marble on the path and prevent it from falling off or being attacked by intruders. *Conjecture* was a word game with no action. As predicted, playing *Marble Madness* improved children's spatial skills including the ability to anticipate targets and visualize paths. Interestingly the effects were obtained after just 2.25 hours of training and were limited to participants who started out with weaker spatial skills, typically girls. Even so, participants with better initial spatial skills – typically the boys – also showed better results: their videogame performance improved at the end of the training period. Thus, it would appear that skill in understanding dynamic spatial representations in a videogame is both required for videogame playing and developed with repeated game play.

A different kind of spatial skill is required in the mental paper-folding tasks in which one has to visualize three-dimensional movement from a two-dimensional display. This skill was utilized in an arcade game from the 1980s called *The Empire Strikes Back*. Researchers (Greenfield, Brannon, & Lohr, 1994) found that better players of this game also performed better on a classical mental paper-folding task. In a follow-up study, no effect was obtained from playing this game in an experimental setting; however structural equation modeling revealed that accumulated skill in playing *The Empire Strikes Back* played a causal role in spatial representational skill development, as measured by the mental paper-folding task (Greenfield, 1993).

Okagai and Frensch (1994) examined the effect of practice with the videogame *Tetris*, which requires the rapid rotation and placement of differently shaped rectangular falling blocks, on spatial representation skills of older adolescents. Mental rotation and visualization skills were assessed by using paper-and-pencil tests in the first experiment and a computerized test in the second experiment. In experiment one, transfer effects on the paper-and-pencil tests were found only for males. In experiment two, game practice led to quicker mental rotation and visualization times for both males and females. Subsequently, De Lisi and Wolford (2002) demonstrated that playing *Tetris* improved the mental rotation skills even among third graders and the effects were especially pronounced for girls. In sum, the research indicates that videogame play enhances visual spatial skills. Effects are often most pronounced for those who initially have weaker visual spatial skills. Transfer effects are also most likely to occur in a same or similar medium and on tasks that utilize the same skills as the game.

Computer games and iconic representational skills Most videogames and computer games use iconic or analog representation – that is they require the user to "read" and interpret visual and iconic images such as pictures and diagrams. Although games today also utilize verbal and auditory representations (and activate neural regions involved in both visual and auditory processing; Murray 2001), more important information is typically conveyed via iconic images. Research suggests that exposure to iconicity in videogames does transfer to iconic representational skills.

In a cross-cultural study, Greenfield, Camaioni, Ercolani, Weiss, Lauber, and Perucchini (1994) found that playing a computer game shifted representational styles from verbal to iconic. College students played the game, *Concentration*, either on a computer or on a board. The player has to open either virtual or real doors to identify the location of pairs of numerals. In the computer version, icons were used – a virtual door and cursor in the shape of a hand – to perform the task. The board version had no icons, but involved direct action on an object: the participant used his or her hand to lift a solid door in order to reveal a numeral.

Iconic representational skills were assessed using a pretest and posttest that included several dynamic video displays from *Rocky's Boots*, an educational computer simulation designed to teach the logic of computer circuitry. Participants were given no information as to the content or operation of the displays and were asked questions about the displays (e.g., what does a particular game element represent?). Those who had played the game on the computer provided more iconic drawings in their answers, whereas those who had played the game on a board provided more verbal descriptions. Playing a computer game that utilized icons, then, influenced participants to use icons in their representations.

Not only did the experimental manipulation lead to more iconic representations, prior videogame exposure seemed to be related to participants' understanding of iconic representations as well. Experienced players, Americans, and males showed better understanding of the dynamic iconic simulations of computer circuitry in *Rocky's Boots*, compared to inexperienced videogame players, Italians (computer technology was less diffuse in Italy at that time in history), or females. The results suggest that exposure to videogames is related to both the comprehension and production of iconic representation.

Representational implications of new game technologies The technology is moving so fast that research cannot keep pace with it. Consider the representational issues brought up by new games – for example, the genre of sports games, including games such as EA Sports' football and basketball games. The images are very realistic and appear to be almost three-dimensional. How will these games influence representational skill development? Another genre is the music videogames such as the *Dance Dance Revolution* series. A dance pad with four arrow panels (left, right, up, and down) is connected to the computer and the player has to press the panels with his/her feet in response to the arrows that appear on the screen in front of him/her. The visual information provided via the arrows on the screen is synchronized to the beat of a song that is played simultaneously. Success on the game requires intermodal integration – the player has to see the arrows that have to be pressed and then press the correct ones with his/her feet. Additional research is needed to understand how these newer games influence the cognitive skills of youth.

Internet

In terms of the symbol systems that it uses, the Internet is unlike every other medium preceding it and actually seems to incorporate all the symbolic features of its predecessors. For instance, like books, the Internet contains text; like the radio, the Internet contains audio; like television, the Internet contains audiovisual representations; and like computer games and videogames, the Internet contains interactive audio and video.

Potential cognitive effects There has been surprisingly little systematic research on the effects of the Internet's symbol systems on the development of cognitive skills. We think that Internet use is most likely to have an impact on verbal and spatial representational skills.

While the information applications of the Internet largely require comprehension of text, the communication applications (e.g., email, instant messaging) require both the comprehension and production of text. However, as Greenfield and Subrahmanyam (2003) point out, online text has features of both oral and written representation – for instance chat conversations consist of incomplete, grammatically simple, and often incorrect sentences (Herring, 1996). Novel abbreviations, such as the ubiquitous "a/s/l" (asking others to give their age, sex, and location) are also rife in Internet communication (Greenfield & Subrahmanyam, 2003; Calvert et al., 2003). One wonders at the cumulative impact of such online reading and writing on verbal representational skills. On the one hand, online reading affords previously unavailable opportunities to read and write text; on the other hand, will online forms of written discourse transfer to more formal writing contexts such as tests and papers? Our experience grading papers suggests that students have considerable difficulty with the idea that oral forms of language are not appropriate in written contexts; these observations suggest that transfer effects would involve the use of informal writing modes in formal written contexts.

The other area of transfer is likely to be spatial representation skills, particularly with regard to two-dimensional representations of three-dimensional space. We consider a couple of different ways that the symbol systems used on the Internet may be internalized. First, unlike books, in which pages are arranged in a linear fashion, the Internet allows much more complex forms of linking across several websites and pages within websites. For example, Suzuki and Beale (2006) report that the personal web home pages of adolescent cancer patients contained hyperlinks to a variety of other sites. Navigating around a website requires users to create mental maps of the site organization. Thus, we would predict that users with more Internet surfing experience may have better spatial visualization skills.

A second example is the use of online map routing sites as well as global positioning systems (GPS). The current generation of navigation sites (e.g., www.maps.google.com) provide maps with detailed information about streets and landmarks; they are user-friendly, can be zoomed to the level of detail required, and allow one to use the mouse to navigate around the map in any direction. Even less cognitive processing is required with the GPS units that are available now – all one has to do is enter in the destination address, and follow the directions that are provided aurally by the system. What are the likely effects of such tools on users' spatial representation skills?

Perhaps the most distinctive feature of computer and Internet symbol systems is the phenomenon of multiple windows, each one representing a different activity. This system of representation leads to multitasking (Gross, 2004), which is the phenomenon of using multiple computer applications (e.g., Internet and word processing applications) or multiple windows of the same application (e.g., multiple instant message windows) at the same time; this is different from media-multitasking which is the practice of using different media at the same time, such as the telephone, computer, and television.

Knowledge is just starting to accumulate about the cognitive and neural effects of processing multiple representations and tasks, all present at once. Foerde, Knowlton, and Poldrack (2006) have found that dual-task conditions (i.e., multitasking) decreased the acquisition of meta-knowledge about a weather-prediction task (learning what cues were associated with what weather outcomes). Relative to a single-task condition, multitasking shifted the neural processing of the task from the medial temporal lobe, which supports flexibly accessible knowledge and meta-knowledge, to the striatum, which supports habit learning. Although the neural processing differed, the basic task performance (being able to use cues to predict the weather) did not differ under single- or dual-task conditions.

Calvert and Wells (2007) examined the cognitive cost of multitasking. Although college students who were heavy multitaskers took twice as long to write a critique, there was no difference between heavy and light multitaskers with regard to the quality of the critiques. While the tasks are different in each study, both of these studies suggest that multitasking produces a decrement in higher-level or executive processing skills, and the study by Foerde and colleagues (2006) suggests a neural basis for this decrement.

Another kind of Internet forum is the "massively multiplayer role-playing game," that combines the visual qualities of stand-alone games with the virtuality not only of the game but of many other players. What are the effects of how the self and others are represented on the screen, both as physical beings and as agents of action? Ethnographic research suggests that, in one of these games, *The Sims Online*, the absence of a first-person player viewpoint in favor of an all-seeing "godlike" perspective was one factor in the dissociation of the all-seeing self from the embodied avatar (Steen et al., 2006). In other words, players do not see the scene from their avatar's visual perspective; instead they see the whole scene from above, including a view of their own avatar. Clearly it is difficult to identify with an entity that you are viewing from the outside. Another barrier to avatar identification in this game was the mode of avatar control, which had very specific representational characteristics. In direct avatar control, which is typical in stand-alone action videogames, one's actions with the joystick represent avatar or cursor movement. In *The Sims Online*, however, the representational link between hand action and avatar action is much more distant. In particular, Sims avatars are controlled robotically through giving them instructions to move in various directions; that is, they had to be programmed to move. In other words, there is psychological distance, to use Sigel's term, between player and avatar. Cognitively, this distance is undoubtedly challenging, but socially it is a disaster. The study of *The Sims Online* revealed that the time and operational lag caused by the use of robotic control disrupted social interaction (Steen et al., 2006).

On the one hand, we can see direct avatar or cursor control as a representational situation in which there is an iconic relationship between hand movement and cursor or avatar movement. On the other hand, we can see robotic control as a representational situation in which there is a symbolic relationship between player action and cursor or avatar movement. In Bruner's (1965) scheme, symbolic representation constitutes a higher level of cognitive development than iconic representation. However, in a multiplayer game, robotic control seems to contribute so much distance that virtual social interaction moves so far away from direct social interaction that it is no longer interesting or motivating (Steen et al., 2006). Players had to program instructions to their robots as to how to act; they could not simply act or react using a joystick or cursor that would move in parallel to the action desired by the player for his or her avatar. Social interaction in the game – that is, interaction among players from different locations – was represented as interaction among avatars controlled by the different players; this mode of controlling one's avatar through programmed instructions rather than "direct" action removed all spontaneity from the interaction among avatars. In this way, robotic control removed all spontaneity from the social interaction the game could provide, and players quit playing.

Advances in hardware

Recent advances in hardware have set the stage for new lines of research questions. There is now an incredible variety and complexity of television screens that are available – high-definition television, wide-screen television, projection television – that have sophisticated digital and surround sound systems. Will the dominance of visual information continue in the newer generations of enhanced televisions? Or will the visual track receive competition from the better audio systems of today?

The merging of hardware platforms is another technological advance – television shows are available on videos and DVDs, and these make possible very different viewing experiences. Similarly books are now available on CD and iPods. IPods are really mini-computers that allow one to play audio and audiovisual information. Music can now be played on cell phones and movies on handheld game systems such as the Sony PSP. Earlier distinctions between media are getting very blurry and raise interesting questions for research. For instance, consider books and their use of verbal representational skills. Will the effects of conventional book reading on vocabulary continue to hold if books are heard on tape, CD, or iPod? Does one have to "see" the text in order for reading to impact verbal representational skills? These are but a sampling of the cognitive questions raised by the symbol systems of newer digital media.

Implications of the Research for a New Developmental Theory of Media

Having examined a variety of research studies on the symbols systems of media and their relation to cognitive processes, it is important to consider the larger implications of this body of work. Greenfield (1998) has argued that the change from print to visual media has contributed to the Flynn effect – the well-documented gains in visual and spatial IQ compared to verbal IQ. The research discussed in the previous sections fits well with her proposal. Consider some of the key findings: (1) the decline in reading over the past couple of decades has been accompanied by a decline in vocabulary as well as a decline in SAT English scores; (2) television exposure, an audiovisual experience, facilitates learning of visual/action information over verbal/audio information; and (3) playing with visual symbols facilitates the development of iconic and spatial representational skills. All of these findings are indications of the theoretical points of Olson & Bruner (1974), Salomon (1979), and Greenfield (1984): the representational systems of media become internalized and become intellectual tools, developing the valued skills of a particular culture, be they visual or verbal in form.

Developmental issues

The developmental framework that we have expanded to media, based on Bruner's theory of modes of representation, seems to predict approximate lower bounds of age when a particular medium can be understood and will contribute to learning. Developmentally, we expect very young children to be facile in understanding and therefore to be able to be influenced by and learn from television, which involves action stimuli, iconic representations, and so many real-world cues. Meltzoff and colleagues' finding that 14-month-olds imitate televised actions confirms this idea (see also Barr, this volume, Chapter 7). The Kaiser report indicates that this kind of imitative learning from a televised representation often transfers to the real world (Rideout, Vandewater, & Wartella, 2003). Seventy percent of parents had seen their 6-month- to three-year-old children imitate positive behavior and 27 percent had seen their children imitate negative behaviors from television. These percentages rise dramatically between ages 4 and 6.

With the recent development of computer graphics that equal the realism and three-dimensionality of television graphics, we also expect the age of videogame and computer use to decline. Indeed, the Kaiser Report (Rideout, Vandewater, & Wartella, 2003) indicates that the age for using computers and videogames is declining rapidly. Parents report that 14 percent of their 6- month to 3-year-olds and 50 percent of their 4- to 6-year-old children have played a videogame. For computers, the findings are even more dramatic: 31 percent of 6-month- to 3-year-olds and 70 percent of 4- to 6-year-olds have used a computer.

Because of its arbitrary symbolic nature, we would not expect the age of learning to read to decline, and it has not. The minimal age for reading is clearly constrained by cognitive development. However, parents do make use of the iconic nature of most children's books, which are profusely illustrated and sometimes even have sounds and actions built in (e.g., pop-up books, electronic books). Seventy-six percent of parents report reading to their 6-month- to 3-year-olds on a typical day, and 83 percent report reading to their 4- to 6-year-olds (Rideout, Vandewater, & Wartella, 2003). Even so, the picture/action/sound books of today can be as much socialization for visual media and mixed media as for print-only media. As the Internet is such a medley of media, age and developmental considerations are more complex. A historical movement towards increasingly young access has begun. No children who were 6 in 2003 had visited a children's website before age 2. However, in the cohort that was 2 years old in 2003, 10 percent had already visited websites for children.

Nevertheless, the use of the Internet for social communication presents cognitive challenges not present in visiting a website. Recall our theoretical proposal that the more real-world perceptual and cognitive cues a media representation makes available, the less mental transformation it will require and the earlier it will become accessible to a child. Social networks linked by the Internet provide virtually no real-world perceptual cues that other members of an Internet network are present, whether it is a question of email, chat, or a social networking program such as MySpace. Yet understanding that the Internet links you to other people in a network is basic to using the Internet as a means of maintaining or establishing social relationships. In line with Piaget's stage definitions, one might place email in concrete operations because the user is manipulating representations of real objects, that is, representations of (and by) known others. However, in the case of an Internet application like chat, where the social network consists of people one does not know in the real world, our developmental theory would predict that an understanding of the social network would appear later, in Piaget's stage of formal operations, which involves the mental manipulation of purely symbolic representations in the absence of real-world referents.

A systematic test of this hypothesis remains for future research. However, existing facts concerning both use and comprehension are encouraging. Let us begin with comprehension. Assessing children from age 5 to age 12, plus a group of adults, Yan (2005) found that understanding of the Internet as a network was virtually absent through age 10. Indeed, even the majority of 11- and 12-year-olds did not have an understanding of the Internet as a network, while the majority of adults did have such understanding. Although Yan did not survey adolescents, these facts concerning cognitive understanding are in line with the facts about use: communication uses of the Internet do not reach their zenith of popularity before adolescence, a time period when the abstract thinking of formal operations can also be well developed. Our theory would of course also predict that email would be used at an earlier age than are applications that connect the user to a network of never-seen strangers.

Conclusion

The historical development of representational systems in media corresponds to trends in information processing skills. Print stimuli were linear; television and videogames could have multiple events happening simultaneously in one screen – the greater socialization of parallel processing had begun (Greenfield, deWinstanley, et al., 1994). The effects of visual media on cognition became greater as the graphics became more highly developed and as games became increasingly popular (Green & Bavelier, 2003). Then simultaneous processing took a new leap as multiple locations on a screen were transformed into multiple tasks in each location – the dawn of computer and Internet multitasking. We are just starting to know some of the costs and benefits of this new mode of action and cognition.

As children are increasingly growing up in a virtual world that reaches its epitome in the Internet, they are spending less and less time in face-to-face interaction, in physical activity, and in interactions with solid objects. Put another way, distancing is one of the outcomes of the increasing "screen" time that developing individuals are experiencing over historical time. To use Sigel's terminology, media serve to activate a separation of the self both cognitively and socially from the here and now.

Societies provide experience to develop what they consider to be the most important skills. Technology skills have become important survival skills in our environment, and the lowering of the age of introduction reflects this belief. As online representations become an increasingly larger part of life, that is, as life becomes increasingly virtual, what will be the developmental costs and benefits?

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