CHILD DEVELOPMENT PERSPECTIVES

Memory Constraints on Infant Learning From Picture Books, Television, and Touchscreens

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ABSTRACT—***The past 15 years have seen an explosion of educational books, television, and touchscreen applications developed specifically for infants. Although infants interact with these symbolic artifacts on a daily basis, they have difficulty going beyond the symbolic source and transferring learning to real-world situations. Infants imitate fewer actions and recognize fewer words following demonstrations depicted in picture books and on televisions and touchscreens than they do following face-to-face interactions, a phenomenon termed the* transfer deficit. *Age-related constraints on memory flexibility contribute to this deficit. Learning can be enhanced when such constraints are considered. Specifically, repeating content and adding visual and auditory cues reduce the transfer deficit. Given the widespread availability of educational media for infants, understanding memory constraints on learning from media has practical implications for the creation and effective use of infant-directed media in early education.***

KEYWORDS—*infant; media; imitation*

Infants learn about the world from directly observing events and from symbolic artifacts such as picture books, television, and touchscreens. Infants are exposed to these two-dimensional (2D) materials 1–2 hr a day—with more exposure for low-income and minority infants (Rideout, 2011)—and the potential to misuse digital devices during infancy has become a public health concern (American Academy of Pediatrics [AAP], 2011). In this review, I examine—from the perspective of a memory researcher—how infants use memory to learn from books, television, and touchscreens. Specifically, I argue that infants' imitation of media is limited by age-related changes in memory flexibility and that learning can be enhanced when these constraints to memory are considered.

AGE-RELATED CONSTRAINTS TO INFANTS' MEMORY FLEXIBILITY AND THE TRANSFER DEFICIT

Every day, infants are challenged with learning about their world from a variety of sources and applying what they learn across different contexts, called *transfer of learning* (Barnett & Ceci, 2002). Transfer of learning requires memory flexibility. To remember an event, specific details need to be encoded into the representation of that event in memory, known as memory specificity. However, to generalize beyond the specific details of a memory, these details need to be retrieved and mapped onto a new setting and applied appropriately, known as memory flexibility. Memory specificity and memory flexibility need to be balanced; too much specificity leads to inflexibility of memory, whereas too much flexibility leads to overgeneralization and memory retrieval errors. In studies of memory generalization between perceptually dissimilar objects and contexts, infants' memory is initially very specific, but infants gradually tolerate differences between conditions at encoding and retrieval, and exploit novel cues to retrieve a target memory (Hayne, 2006).

Flexibility is crucial to the adaptability of learning and memory because it allows past experience to be applied to a range of situations that are unlikely to be perceptually equivalent to the initial learning episode. This is the crux of learning from 2D materials. For example, a child may encounter the word *giraffe* in a book, then transfer that learning to use the word *giraffe* to refer to a real giraffe when visiting the zoo. The three-dimensional (3D) context is never perceptually equivalent to the

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2D context, so some of the memory attributes represented in the original encoding will not match attributes perceived at the time of retrieval (Tulving, 1983). This mismatch causes problems early in development, when even a minor disparity can disrupt performance (Hayne, 2006; Munakata & O'Reilly, 2003). The protracted developmental course of memory flexibility has been attributed to rapid development of the medial temporal lobe (MTL; e.g., Richmond & Nelson, 2007). Theoretically, within the MTL, memory attributes (such as cue, action, and context) encoded in the parahippocampal cortex might be fused into one representation, limiting generalization. Later development of the dentate gyrus allows attributes to be encoded and bound to one another in a relational hierarchy, enhancing flexible retrieval (e.g., Richmond & Nelson, 2007).

A number of factors may cause a mismatch between encoding from media and subsequent retrieval during infancy. First, 2D images are perceptually impoverished; discrepancies between perceptual cues provided by the 2D media and cues in the 3D world lead to a mismatch in retrieval cues between 2D representations and real 3D objects. Relative to real objects, 2D images are smaller and lack features, such as depth cues typical of real objects (e.g., Barr & Hayne, 1999). Second, a contextual or source mismatch exists in which discrepancies between the contextual cues lead to a mismatch in retrieval cues provided by the 2D context (e.g., book, television, or touchscreen) and the real-world test context. For example, the infant may encode irrelevant physical properties of the 2D context (e.g., the television frame) along with task-relevant attributes, fusing the two into one representation and limiting retrieval at test. Third, symbols (e.g., picture books) have dual representations; they are simultaneously objects as well as representations of something else. Broadly defined, a symbol is "any entity that someone intends to stand for something other than itself" (DeLoache, 1995, p. 109). The infant may not be able to hold both representations in mind simultaneously, limiting the utility of the symbol (Troseth, 2010). These explanations are not mutually exclusive, but may depend on age. The transfer deficit early in infancy is more likely to stem from perceptual impoverishment or contextual mismatch; later in toddlerhood, it is more likely to come from a lack of symbolic understanding.

IMITATION AS AN INDEX OF TRANSFER OF LEARNING

To examine how preverbal infants transfer learning from media, researchers have used deferred imitation (Barr, 2010). First, an infant observes an adult assemble a novel toy (encoding phase) and then the infant is allowed to reproduce the target actions (retrieval phase). During a book demonstration, an experimenter reads a book depicting static images of the target actions; during a televised demonstration, an on-screen experimenter models target actions on the television screen; and during a touchscreen demonstration, an experimenter models the target actions on a touchscreen device (see Figure 1). Infants have no contact with the target objects prior to the retrieval test and are scored on the number of target actions they can reproduce. Deferred imitation is defined as significantly more frequent reproduction of target actions than by infants in a control group who have not seen the actions demonstrated (Barr & Hayne, 2000).

In studies of deferred imitation of media, infants in experimental groups produced significantly more target actions than infants in the control group, indicating that infants can learn from picture books, television, and touchscreens (Barr, 2010), with imitation from television starting as young as 6 months (Barr, Muentener, & Garcia, 2007). Although learning occurs, it is cognitively challenging. Infants consistently exhibit a transfer deficit (Barr, 2010),[1] imitating fewer actions following a demonstration using 2D materials than following a live demonstration. For example, although 18-month-olds imitated more than infants in a control group after observing a televised (Barr & Hayne, 1999) and a book demonstration (Simcock & DeLoache, 2008), they imitated half as many target actions as infants who saw a live demonstration. Furthermore, they remembered these actions for half the time that they remembered those modeled during a live demonstration (Brito, Barr, McIntyre, & Simcock, 2012). Imitation from books and television differs: After some forgetting has occurred, televised reminders effectively prime infants' memory, but photographs and book reminders do not (Barr, Brito, & Simcock, in press; Hudson & Sheffield, 1999).

Imitation from touchscreens has been studied to distinguish between perceptual impoverishment and contextual mismatch theories of the transfer deficit (Zack, Barr, Gerhardstein, Dickerson, & Meltzoff, 2009). In touchscreen studies, in which infants are tested using a 2D touchscreen to examine direct learning from touchscreens (2D demonstration to 2D test), as well as transfer of learning in both directions (3D–2D, 2D–3D), transfer across dimensions was impaired in *both* directions (Zack et al., 2009). Infants were shown how to push a button on a touchscreen (2D demonstration; see Figure 1) or on a toy (3D demonstration), and then were tested using either the touchscreen (2D test, Figure 1) or the toy (3D test). Both transfer groups (3D–2D, 2D–3D) performed above baseline, but they reproduced half as many target actions as the nontransfer (3D–3D, 2D–2D) groups. The fact that the 2D–2D group did not differ from the 3D–3D group rules out a simple explanation of perceptual impoverishment for less effective learning from 2D than from 3D demonstrations: Infants can imitate on the touchscreen despite the perceptually degraded input. Similarly, the 3D–2D finding demonstrates that even when infants have encoded perceptually rich information, they still exhibited a transfer deficit when tested in the 2D context. It is the inability to transfer between the 2D–3D contexts that results in the transfer deficit. Practically speaking, although

[1]Initially, studies examined only learning from television and the term *video deficit* was coined. More recently, as studies have expanded to picture books and touchscreens, the same pattern of results has emerged, so I use the more general term *transfer deficit*.

Figure 1. Imitation study procedures for three studies: television study (Barr, Muentener, & Garcia, 2007), rattle study (Simcock & DeLoache, 2008), and touchscreen 2 study (Zack, Gerhardstein, Meltzoff, & Barr, 2009). Top panel: Examples of stimuli used in television, book, and touchscreen imitation studies. Middle panel: Demonstration of target actions via television, book, and touchscreen. Bottom panel: Test phase. Infant imitating target actions on puppet, rattle, and 2D touchscreen version of the button box toy.

infants readily learn to operate a touchscreen device, they have a limited ability to transfer that learning beyond the 2D context.

Infants show a similar transfer deficit across media types. Analogous transfer deficits have been reported using object search paradigms (Troseth, 2010) and word learning paradigms (Allen & Scofield, 2010; Ganea, Pickard, & DeLoache, 2008; Krcmar, 2010; Vandewater, Park, Lee, & Barr, 2010). For example, until approximately 18 months of age, infants fail to match a word learned from a video or picture book to a real-world object. Slightly different developmental trajectories in the transfer deficit depend on the complexity of the task, but these studies illustrate that transfer deficits are not limited to learning action sequences but rather to transferring information across contexts. Several other factors contribute to the transfer deficit during infancy, including age-related changes in attentional processing (see Richards, 2010), language processing (see Linebarger & Vaala, 2010), and processing of social contingency and social meaningfulness (see Krcmar, 2010; Troseth, 2010). Nonetheless, memory constraints contribute to the transfer deficit.

Taken together, these findings are consistent with the theory that the transfer deficit partially reflects limitations in flexibility of memory during infancy. Transferring information learned from 2D media to corresponding 3D objects is challenging during infancy because few retrieval cues at the time of the test match the original encoding conditions. Explanations involving perceptual impoverishment, contextual mismatch, and dual representation all lead to the prediction that increasing the match between the encoding and retrieval conditions and increasing the number of relevant retrieval cues would enhance learning. The next series of studies illustrates that providing additional relevant visual and auditory retrieval cues reduces the transfer deficit and improves infants' imitation from media.

HOW CAN LEARNING FROM MEDIA BE IMPROVED?

Although it is difficult for infants to transfer information from 2D to 3D and vice versa, the same variables that likely increase the transfer of knowledge across other domains (Hayne, 2006; Munakata & O'Reilly, 2003) likely increase the transfer of learning from media. Repetition and adding visual and auditory cues tend to enhance transfer of learning (Barnett & Ceci, 2002; Hayne, 2006), presumably due to an increase in the availability of retrieval cues. These factors have also been examined in transfer of learning from media.

Repetition

Parents report that infants frequently request to view the same television program or book over and over (Barr, Zack, Muentener, & Garcia, 2008), and the transfer deficit declines after repeated exposure to target actions in videos and books (Barr, Muentener, & Garcia, 2007; Barr, Muentener, Garcia, Fujimoto, & Chavez, 2007; Simcock & DeLoache, 2008). Repetition likely enhances transfer by inducing encoding variability so that during the first demonstration, infants may attend to one aspect of the stimulus, but during subsequent repetitions, they often attend to other aspects of the stimulus. Encoding variability results in the formation of a more complete representation of the memory attributes and increases the likelihood of transfer (see also Carver, Meltzoff, & Dawson, 2006; Zack et al., 2009).

Visual Cues

Although 2D media are visually degraded relative to 3D objects, the use of realistic photographs provides more overlap between the 2D and 3D visual cues, enhancing transfer of learning. For example, when 18-, 24-, and 30-month-olds were read to from picture books, 18-month-olds imitated from books illustrated with color photographs, 24-month-olds imitated from books with color photographs and colored pictures, and 30-month-olds imitated from books with line drawings, colored pictures, and color photographs (Simcock & DeLoache, 2006). These findings show age-related changes in memory flexibility, with older children needing fewer overlapping visual cues between the 2D and 3D presentations to learn the target actions.

Auditory Cues: Nonverbal

Adults easily process and interpret the artificial electronic sound effects and music added to television programing and touchscreen applications. Unlike visual cues, which change from 2D to 3D presentations, auditory cues may not change fundamentally and could provide a bridge from the 2D to the 3D context. However, adding instrumental music to a televised demonstration disrupted imitation by 6-, 12-, and 18-month-olds, regardless of whether the music was played during demonstration alone or during both the demonstration and the test (Barr, Shuck, Salerno, Atkinson, & Linebarger, 2010). Infants did not imitate from television, no matter their age. Imitation was less frequent than when music was not included at all (Barr, Muentener, & Garcia, 2007). However, adding the same music to a live demonstration did not disrupt imitation (Barr et al., 2010). The music may have disrupted imitation from television because it increased the overall cognitive processing load without providing additional relevant cues to the target actions. In a second experiment, in addition to adding music, researchers added sound effects to match each target action in the video demonstration. In this experiment, 6- to 18-month-olds imitated more than their peers in the control group, showing that they imitated from television. The action-matched sound effects may have enhanced selective attention to the target actions. However, they still exhibited a transfer deficit: They did not perform as well as their peers in the live demonstration group (Barr et al., 2010). Taken together, these findings suggest that integrating auditory cues into memory representations acquired from 2D media is challenging for infants, and auditory cues need to be carefully matched to the target information.

Auditory Cues: Verbal

Verbal cues have been shown to be effective in facilitating transfer of learning from media, perhaps because they have semantic or referential meaning. For example, parents who label objects and ask questions while reading picture books to their babies are more likely to have infants with greater vocabulary scores (DeLoache & DeMendoza, 1987), and verbal cues generated from mother–child interactions enhanced 18-month-olds' imitation from television (Seehagen & Herbert, 2010). However, age-related differences exist in the effectiveness of verbal cues. Neither a nonsense label nor an object label facilitated 15-month-olds' imitation on a touchscreen transfer task (2D–3D or 3D–2D; Zack, Gerhardstein, Meltzoff, & Barr, 2013). Even though infants recognized the object labels and the referential cues, they could not overcome the transfer deficit, suggesting that the demands on cognitive resources were high when novice language learners were asked to process verbal cues in conjunction with using a novel 2D touchscreen device (Zack et al., 2013). However, nonsense verbal labels provided by either voice-overs or parents enhanced 2-year-olds' imitation from television (Barr & Wyss, 2008). Older infants understand and use language in a more flexible manner, increasing the utility of verbal cues to enhance retrieval (see also Krcmar, 2010).

IMPLICATIONS

Transfer of learning from 2D media during infancy is cognitively challenging, resulting in a transfer deficit that can be reduced through repetition and the addition of age-appropriate visual and verbal cues. This is consistent with the theory that age-related changes in memory flexibility contribute to infants' transfer deficit in imitation from media-based content. Examining transfer of learning from 2D media provides an intriguing window into infants' difficulty processing information from different sources (see DeLoache, 1995; Meltzoff, 1988). For episodic memory to develop, source information must bind selectively with other memory attributes (Drummey & Newcombe, 2002; Munakata & O'Reilly, 2003; Raj & Bell, 2010). During infancy, the context or source may be fused with other attributes of memory and when the context changes at test, memory retrieval is disrupted (Richmond & Nelson, 2007). Contextual transfer may be a precursor to source memory. Future studies could use media materials to systematically investigate memory binding of relations between memory attributes and precursors to source memory in very young children, but this hypothesis needs to be tested.

The 1990s saw a proliferation of television products for infants, but little empirical research on how infants learn from television. Similarly, the number of touchscreen applications for infants has increased dramatically in the past 5 years (Rideout, 2011), but we lack empirical research on infants' ability to learn from these devices. Touchscreen devices may enhance learning relative to learning from other 2D media because of the intuitive and interactive nature and contingent responsiveness of the touchscreen interface, but this hypothesis needs to be tested.

Also, little is known about how infants integrate information from multiple sources. Media formats are converging and the same content is being presented on different devices; even traditional picture books are frequently read on touchscreen devices. We need systematic research on how infants encode and retrieve information from multiple 2D sources to understand the effects of technology on infant learning.

The studies reviewed here have important practical implications. The AAP (2011) recommends minimal exposure to digital devices during infancy, but given their availability in homes in the United States and many other Western countries, exposure rates are likely to continue to be high. Therefore, the quality of infant-directed media deserves more attention. To be most effective, commercial products could repeat content, have realistic photographic images and familiar characters to enhance visual mapping between 2D presentations and the 3D objects, and feature labels and well-timed sound effects to enhance auditory mapping between 2D presentations and 3D objects. These features may reduce the contextual mismatch from 2D to 3D formats.

Parents and educators might not always understand that infant learning from 2D media is cognitively complex, and might perceive television, and increasingly touchscreen applications, as passive and easy to process, despite the overwhelming evidence of a transfer deficit from books, television, and touchscreens. Research on parent–child interactions during child-directed television programs indicates that infant looking time and engagement are strongly influenced by parents' gaze, engagement, and description of content (e.g., Demers, Hanson, Kirkorian, Pempek, & Anderson, 2013). These findings suggest that parents and educators could enhance infant learning when using all 2D materials, not just books, and that scaffolding is likely to enhance infant learning from these complex sources of information.

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