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From Specificity to Flexibility[1]

Early Developmental Changes in Memory Generalization

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Memory specificity and memory generalization are opposite sides of the same coin. In order to remember an event, specific details need to be encoded into the memory representation. In order to generalize beyond the specific details of a memory, however, these details need to be retrieved and mapped onto a new setting and applied appropriately. Flexibility is crucial to the adaptability of learning and memory because it allows past experience to be applied to a range of future situations that are unlikely to be perceptually equivalent to the initial learning episode. Too much specificity leads to memory inflexibility, but on the other hand, too much flexibility leads to overgeneralization and memory retrieval errors. Specificity is crucial to protect the young child from potential harm where lack of inhibition may allow the child to apply learning in the wrong situations.

For all species, the ability to generalize beyond the specific details of a memory is the result of either acquired equivalence or perceptual confusion. In the latter case, the organism responds to perceptually, physically, or representationally different but similar stimuli because they cannot distinguish between the two. Acquired equivalence, however, is when the organism perceives the two stimuli as being different, but have learned by experience to treat them in the same manner; that is, they are functionally similar or that they are substitutable (Honey & Hall, 1989; Honey & Watt, 1999). Knowing how to respond appropriately to different stimuli is extremely important to learning and memory for all species. The age at which infants can generalize across contexts and cues is believed to be the beginning of a hippocampus-dependent higher-level memory system (Bauer, 1996; Bauer & Dow, 1994; Eichenbaum, 1997; McDonough, Mandler, McKee, & Squire, 1995; Tulving & Schacter, 1990).

There are a number of reasons why memory progresses from highly specific to more generalized representations across time. First, there are many age-related changes in basic memory systems that allow for an increasing amount of information to be more rapidly encoded,

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stored, integrated, and retrieved. Specifically, there are four basic principles of infant memory development: (1) infants become more rapid at encoding, (2) infants retain information for longer durations, (3) infants are able to use reminders to retrieve forgotten memories, and, most importantly for the current chapter, (4) infants are able to increasingly exploit retrieval cues to form more general memory representations (Barr & Hayne, 2000; Rovee-Collier & Hayne, 1987). As a result of gradual systematic changes in memory processing across the infancy period, the infant's mnemonic base expands rapidly, and simultaneously the increase in spreading activation allows for more rapid integration and generalization of information across time. Overall, the memory system becomes increasingly cognitively economical.

The present chapter will describe studies that show that the human memory system takes memory specificity as the default position and then gradually becomes more flexible to generalize to novel cues and situations. We will discuss the evidence for early memory specificity using operant conditioning, imitation, and object search experimental paradigms from birth to 3 years, because it during these early years that the memory system is most likely to demonstrate age-related changes in memory flexibility. Although there are other paradigms in which generalization has been extensively evaluated, such as habituation (for review, see Hayne, 2004; Rovee-Collier & Barr, 2010; Rankin et al., 2009), the three paradigms we have chosen to focus on illustrate the repeating pattern of specificity to generalization during early childhood despite large task-related differences. Additionally, all three paradigms use nonverbal motor response, allowing for a comparison of results across tasks and ages for pre- and early-verbal infants and toddlers. We will discuss the pathways from specificity to flexibility beyond maturational change—focusing on ways that infants are able to generalize across changes in cues or context. We will then examine a practical implication of understanding memory specificity, learning from media. Finally, we will discuss future directions and implications of memory specificity and flexibility for the developing child.

Theoretical Conceptualization

As an infant develops and encounters familiar and novel objects, successful learning and memory performance is contingent on a balance between remembering the specific features of that object and being able to apply that knowledge across different cues and contexts. Responding appropriately to perceptually distinct materials and knowing when to generalize across stimuli are at the core of memory and learning. Researchers generally assume that a memory is a hypothetical collection of attributes that represent what the subject noticed at the time of original encoding (Estes, 1973, 1976; Roediger, 2000; Spear, 1978; Underwood, 1969), and the *encoding specificity principle* assumes that the memory of the target event will be retrieved only if the cues encountered at retrieval match the same attributes seen during the original representation (Tulving, 1983, 1984; Tulving & Thomson, 1973). This has been supported by many studies demonstrating that changes in either stimuli or environmental context at the time of retrieval significantly disrupt memory performance (Godden & Baddeley, 1975; Tulving, 1983). The notion of generalization of learning across cues and contexts has been central to memory theorists since the time of Thorndike (1932); accuracy of memory is highest when specific details are retained and veridical retrieval cues are most likely to ensure long-term retention. Furthermore, only veridical cues allow for reactivation or priming of the memory. The ability to retrieve memories despite changes in cues and context, allowing learning to be generalized to novel situations, has been referred to as *representational flexibility* (Eichenbaum, 1997).

Historically, researchers have suggested that representational systems emerge relatively late in infancy (e.g., Baldwin, 1894/1915; Piaget, 1962). More recently, Hayne (2006) has described marked developmental changes in representational flexibility that occur even into early childhood. That is, early in development, successful memory performance is dependent on the perception of a close match between the cues at the time of encoding and the cues at retrieval; even a minor mismatch at testing can disrupt performance. Memory performance becomes more flexible across development, and older participants show an increased ability to tolerate differences between conditions at encoding and retrieval and are able to use novel cues to retrieve a target memory. For adults, the match that is necessary between cues is sometimes minimal and can often be a conceptual match instead of a perceptual match (Tulving, 1984).

Many researchers contend that the ability to generalize across contexts and cues marks the emergence of declarative or explicit memory that is hippocampus dependent (Bauer, 1996; Bauer & Dow, 1994; Cohen & Eichenbaum, 1993; Eichenbaum, 1997). Richmond and Nelson (2007) argue that the hippocampally dependent development of relational memory, in particular, may account for the protracted developmental course of memory flexibility. That is, across development, children will increasingly form hierarchical and relational representations of events rather than simply encoding specific attributes of an event (for review, see Richmond & Nelson, 2007). Eichenbaum and Bunsey (1995) have suggested that young children often have difficulty transferring knowledge from one situation to another because, early in development, the child combines elements of an episode into a unitary representation instead of encoding the elements separately. High encoding specificity is the common outcome of each of these proposed developmental memory mechanisms. This high level of encoding specificity by young infants may prohibit the infant from accumulating information over consecutive learning opportunities, since it is rare for events to occur in the same manner.

Hayne (2006) argues that neural developmental changes are accompanied by gradual experiential developmental change because, over time, infants are presented with opportunities to encode information in a variety of contexts and begin to take advantage of a wider range of retrieval cues. The *developmental representational flexibility hypothesis* posits the existence of an active developmental process whereby performance is dependent upon age, task, and experience. By this account, high levels of memory specificity are due to a mismatch between encoding cues present during the demonstration and retrieval cues presented at the test. The retrieval cues must be matched to the infant's current developmental ability and knowledge base; the types of retrieval cues will determine whether memory specificity or memory flexibility is observed across age and task. To test representational flexibility during early childhood, a number of experimental paradigms have manipulated the perceptual characteristics of the stimuli (e.g., color or form) and/or the environmental context of the testing situation.

Paradigms Used to Study Memory Specificity during Early Childhood

Operant conditioning

Rovee-Collier and her colleagues have demonstrated that infant memory develops gradually across the infancy period by using operant conditioning procedures and have found that retention increases systematically across time (for review, see Rovee-Collier, Hayne & Colombo, 2001). Unlike classically conditioned responses, which are reflexive, operantly conditioned responses are voluntary, and there is no biological relation between the reinforcer and the response it influences. Infants must spontaneously perform the response at a low or moderate rate in order for the response to be followed by a reinforcer (reward) that increases its rate. Two operant conditioning paradigms have been extensively studied during infancy, the mobile conjugate reinforcement paradigm and the train paradigm.

The mobile conjugate reinforcement paradigm has been standardized to assess infants' capacity for long-term memory. In this paradigm, infants are trained at home for two 15-minute sessions, 24 hours apart. In session 1, a ribbon is tied to the infant's ankle and the other end of the ribbon is placed on a hook in the child's view, but is not connected to the mobile so that the infant's kicking does not move the mobile. That is, the ribbon is connected to an empty stand. For the first 3 minutes, the infants' operant level or *baseline* level of kicking is recorded. Next, the ribbon is switched to the same hook as the mobile, and now the infant's kicks conjugately move the mobile, and the number of kicks is recorded for 9 minutes during the *acquisition phase*. Finally, the baseline condition is reinstated for 3 minutes. Session 2 is identical to the first, but in the final 3-minute non-reinforcement period, the infant's final level of learning and immediate retention is measured (*immediate retention test*). After a delay (1 or more days), infants receive a 3-minute *long-term retention test* with the original mobile or one that differs in some way. During the *long-term retention test*, the ribbon is once again connected to the empty stand, and kicking does not move the mobile. Infants kick robustly if they recognize the mobile and respond at baseline if they do not. Because the retention test occurs during a non-reinforcement period, responding reflects only prior learning and not savings (Rovee-Collier, 1997).

During these delayed recognition tests, infant memory is highly dependent upon the match between retrieval cues and encoding cues. Hayne and colleagues found that two- and three-month-olds demonstrated retention after a 24-hour delay when tested with the same five-object mobile used during the original training, but demonstrated absolutely no retention if more than a single novel object was substituted into the mobile at test (Hayne, Greco, Earley, Griesler, & Rovee-Collier, 1986). Even more precise discrimination is possible; for example, three-month-olds did not recognize a pink block mobile displaying black plus signs that were 25% smaller or larger than the plus signs that were on the training mobile (Gerhardstein, Adler, & Rovee-Collier, 2000). Similarly, when only the cloth liner in the crib was changed, retention by three- and six-month-olds was disrupted (Bhatt, Rovee-Collier, & Weiner, 1994; Borovsky & Rovee-Collier, 1990). To examine how retention was affected by changes to both the mobile and the environmental context, six-month-olds were tested under three conditions: same mobile and same context, different mobile and same context, and different mobile and different context. Infants exhibited retention only when both the mobile and the context at test matched cues at encoding (Borovsky & Rovee-Collier, 1990; Hill, Borovsky, & Rovee-Collier, 1988). Taken together, as predicted by the *developmental representational flexibility hypothesis*, these findings demonstrate the highly specific nature of infant memory during the first year of life and are consistent with the need for veridical or near-veridical cues to be present at test for very young infants to exhibit retrieval.

Because infants outgrow this task after six months, an upward extension of the mobile task was developed for older infants where, instead of kicking to move a mobile, the infant presses a lever to move a miniature train. The same operant conditions are used and, during non-reinforcement periods, the lever is deactivated. When nine-month-olds are tested in the operant train paradigm, they exhibit no retention whatsoever if they are tested with a train that differs from the one encountered during original encoding. As the infant develops, their memories become more flexible, and, by 12 months of age, toddlers can exhibit the same level of performance with either the familiar or novel train present (Hartshorn et al., 1998). Examining the environmental context, a change from one room to another disrupted retention of the train task by six-month-olds but not by older 9- and 12-month-old infants (Hartshorn et al., 1998).

Imitation Paradigms

Two experimental imitation protocols were developed in parallel during the 1980s: elicited imitation and deferred imitation. Both protocols measure the ability to reproduce an action that was previously modeled by another individual after a delay. Elicited imitation, developed by Bauer and colleagues, refers to the fact that behavior is brought under experimental control by the presentation of specific experimental stimuli. This protocol includes an immediate imitation phase to assess whether young children have encoded the target actions prior to the onset of the delay interval (e.g., Bauer & Shore, 1987). The deferred imitation procedure was originally described in Piaget's (1962) theoretical account of the stages of sensory-motor development and subsequently was operationalized by Meltzoff (1985, 1988a). Deferred imitation refers to the fact that the imitation test occurred after a delay. This protocol does not include an immediate imitation phase to eliminate self-produced actions from serving as additional retrieval cues for remembering (Meltzoff, 1990). Both protocols have been widely used to document the development of memory and have demonstrated that infants and toddlers readily learn and reproduce novel action sequences demonstrated by an adult (e.g., Barr, Dowden, & Hayne, 1996; Bauer & Dow, 1994; Meltzoff, 1985), peer (Hanna & Meltzoff, 1993), or televised model (Barr & Hayne, 1999). Depending on which protocol is adopted, differences in the patterns of results have emerged, leading to the continued distinction between the protocols within the memory development literature (e.g., Bauer & Lukowski, 2010; Hayne, 2004; Hayne & Simcock, 2009; Jones & Herbert, 2006; Lechuga, Marcos-Ruiz, & Bauer, 2001; Rovee-Collier & Barr, 2010). For review of other aspects of early memory using imitation, see the chapter by Lukowski and Bauer in this handbook.

In the elicited imitation protocol, the experimenter models a series of actions with novel objects, and the infant is given the opportunity for immediate imitation before the test phase. During the demonstration, infants receive narration of the target actions, as well as verbal prompts at the test phase. Both reproduction of the target actions and the order in which the target actions are reproduced is measured (Bauer & Shore, 1987; Bauer & Mandler, 1989). In tests of elicited imitation, infants often serve as their own controls; memory is inferred when infants perform more actions from the target sequence than from a sequence that is new to them. This within-subjects design reduces variability due to between-group individual differences.

When testing memory specificity, the immediate imitation phase allows the researchers to untangle perceptual confusion (generalization as a function of forgetting of the original sequence) from acquired equivalence (flexibility of retrieval for the new sequence accompanied by memory for the original sequence). For example, Bauer and Dow (1994) examined 16- and 20-month-olds' ability to generalize using the elicited imitation protocol. The infants were shown six action sequences on three sets of stimuli and participated in an immediate imitation phase after the demonstration. The infants were tested a week later with three original target objects and three novel target objects. Both the 16- and 20-month-olds were able to generalize across color and imitate the target actions on the novel stimuli, as well as demonstrate recall of the original sequences. Similarly, using three-step imitation sequences, Bauer and Lukowski (2010) found that 16- and 20-month-old infants were able to generalize across color and shape one month after demonstration. Although the researchers found that infants at this age could generalize at the long-term test, the number of target actions produced and the order of target actions (pairs of actions) were lower compared to memory for the original test sequences. By including an immediate test phase, as well as testing infants using both original and variants of test sequences, Bauer and colleagues demonstrated that generalization could not be attributed to forgetting of the specific details of the original demonstration.

In the deferred imitation protocol, the experimenter models a series of actions, and the infant is not given the opportunity to interact with the objects until after the delay during the test phase. Unless specifically manipulated, infants typically are not provided with verbal prompts during the demonstration or the test phase. Like the elicited imitation procedure, reproduction of the target actions and order of actions is measured (Hayne, 2004; Lukowski, Wiebe, & Bauer, 2009; Rovee-Collier & Barr, 2010). Independent control groups do not see the demonstration of the target actions, and their performance is used as an index of spontaneous production of the target behavior or baseline. Deferred imitation is operationally defined as the demonstration group performance significantly exceeding that of the control group.

Infants also demonstrate a considerable amount of memory specificity in deferred imitation tasks. In the puppet task, for example, an experimenter demonstrates three target actions using a handheld puppet. The infant sees the experimenter remove a felt mitten that was placed on the puppet's hand, shake the mitten ringing a large jingle bell inside, and then replace the mitten on the puppet's hand. At test, the infant's performance is based on whether they can replicate any of the three steps within 90 seconds. When shown a live demonstration of a sequence of actions using the puppet task, six-month-olds can recall and imitate these steps after a 24-hour delay when tested with the original puppet (Barr et al., 1996; Hayne, MacDonald, & Barr, 1997), but fail to demonstrate recall if the puppet changes in color or shape. This ability to generalize across stimuli for the puppet task emerges at around 12 months for changes in color, and 18 months for changes in color and shape (Hayne, Boniface, & Barr, 2000). When an even greater disparity between the two puppets is introduced, however, 18-month-olds again fail to generalize between puppets but generalize to the greater perceptual difference between puppets by 21 months (Hayne et al., 1997).

Like the ability to generalize across stimuli, the ability to transfer learning across context also develops with age. Six-month-old infants have demonstrated the ability to transfer knowledge from one room in their home to another (Learmonth, Lamberth, & Rovee-Collier, 2004), but are not successful when transferring information from their home to a laboratory setting (Hayne et al., 2000). That is, when the context is familiar, generalization occurs sooner than when the change in context is novel. Older infants seem to have less difficulty generalizing across such large contextual changes. Twelve-month-olds can easily generalize across context from a highly perceptually salient polka-dotted tent to a plain undecorated laboratory room after both a 1-week and 4-week delay (Klein & Meltzoff, 1999), or from a laboratory to home setting after a 24-hour delay (Hayne et al., 2000) and a 1-week-delay (Klein & Meltzoff, 1999).

Changes to both cue and context reduce memory performance (Barnat, Klein, & Meltzoff, 1996; Hayne et al., 2000). For example, Barnat and colleagues (1996) examined the effect of cue and context change on deferred imitation by 14-month-olds. In Experiment 1, the experimenter demonstrated the target actions on miniature objects inside a distinctive polka-dotted tent. Infants were tested in a standard laboratory room with full-sized objects after a 10-minute delay and performed significantly above baseline, generalizing across context and object size. In the second experiment, infants were tested in a different context and with objects that differed in both size and color. Although infants performed significantly above baseline, their performance was impaired compared to that of a no-change control group. That is, as the number of cue and context changes increased, imitation performance decreased. Studies using imitation paradigms provide support for a *developmental representational flexibility hypothesis* and have shown that the ability to generalize across cues and contexts within imitation paradigms are dependent on age, task, and experience.

Object Search Tasks

High levels of memory specificity can be demonstrated in older toddlers using symbolic object search tasks developed by DeLoache and colleagues. In the standardized search paradigm (e.g., DeLoache, 1987, 1991, 1995; DeLoache & Burns, 1994; DeLoache & Marzolf, 1992; Marzolf & DeLoache, 1994; Troseth & DeLoache, 1998; Uttal, Schreiber, & DeLoache, 1995), children are provided with an extensive orientation procedure that attempts to show them the correspondence between a test room and a model of a room that is the exact replica of the larger room. After the orientation, the experimenter shows the child where he/she will hide the toy in the model room. Then the experimenter goes into the test room and hides the toy in the exact same location as the model room. During this hiding event, children are given explicit instructions—"Watch—I'm hiding Little Snoopy here. I am going to hide big Snoopy in the same place in his big room," (p. 109, DeLoache, 1995). Immediately after the experimenter has hidden the toy in the test room, the child is asked to retrieve the "Big Snoopy" from the test room. Only the first search is scored, and if the child successfully searches for the toy in the correct location, they have shown that their retrieval is not specific to the context of learning, demonstrating representational flexibility.

Despite the fact that 18-month-olds can succeed in a typical hide-and-seek game (DeLoache, 1980), once symbolic differences between the hidden object and the to-be-searched object are introduced, performance decreases markedly. After the child had been shown the toy hidden in the model of the room, they are given the opportunity to find the toy in the test room. Three-year-olds found the toy 77% of the time, whereas 2.5-year-olds were only correct on 15% of the trials. Even with explicit language cues describing the similarity between the model of the room and the test room, the 2.5-year-olds were not able to make the connection between the model and the test rooms. When asked to retrieve the toy in the original hiding location in the model room, both 2.5- and 3-year-olds were very successful in finding the toy, indicating that the discrepancy between ages is not due to differences in memory for the location of the toy at the time of encoding (DeLoache, 1989a, 1989b).

In a follow-up study, DeLoache, Kolstad, and Anderson (1991) found that the more physically similar a model is to the corresponding larger space or room (and vice-versa), the more likely that children succeed in retrieving the object from the room. Conversely, when the number of the spatial relations between the scale model and the room increases, 3-year-olds, who have previously mastered the model to room task, fail on a more difficult version of the task (Marzolf, DeLoache, & Kolstad, 1999). Taken together, these findings provide additional support for *a developmental representational flexibility hypothesis,* demonstrating once again that decreasing the similarity between the encoding and retrieval conditions leads to higher levels of memory specificity.

Summary of Paradigms

Overall, studies have demonstrated age-related increases in generalization in various paradigms, including operant conditioning (Borovsky & Rovee-Collier, 1990; Hayne et al., 1986; Hartshorn et al., 1998), imitation (Bauer & Dow, 1994; Bauer & Lukowski, 2010; Hayne et al., 2000; Hayne et al., 1997), and object search (DeLoache & Burns, 1994; Marzolf et al., 1999; Troseth & DeLoache, 1998) paradigms. These studies provide substantial empirical evidence demonstrating that older infants and young children can transfer information across changes in feature (e.g., color, size, and texture) (Adler, Gerhardstein, & Rovee-Collier, 1998; Hayne et al., 2000; Hayne et al., 1997), shape (object) (Herbert & Hayne, 2000), context (Borovsky & Rovee-Collier, 1990; Hanna & Meltzoff, 1993; Hayne et al., 2000; Herbert & Hayne, 2000; Klein & Meltzoff, 1999; Rovee-Collier, 1997), and combinations of cue and context change (Barnat et al., 1996; Hayne et al., 2000).

Across paradigms, although the precise ages differ, the pattern of results from high levels of specificity to more flexible memory retrieval is very similar across development (see also Barr & Hayne, 2000, for a similar argument regarding long-term retention). For the operant conditioning paradigms, memory specificity is shown between three and six months of age but memory becomes more flexible between 9 and 18 months (Hartshorn et al., 1998). For the deferred imitation paradigm, memory specificity is seen from 6 to 12 months of age, with increasing flexibility shown around 18–30 months of age (Bauer & Dow, 1994; Bauer & Lukowski, 2010; Hayne and colleagues, 1997, 2000). Memories during an object search task are highly specific during 2–2.5-years of age and become more flexible at 3 years (DeLoache, 1987, 1989a, 1989b, 1991). It is important to note that task demands across these paradigms vary widely. In operant conditioning, infants are required to make an association between an action and an outcome; in the imitation paradigm (analogous to a cued recall task), the target objects cue the target actions; and in the object search task, children are required to spatially map, encode, and update location information. Not surprisingly, as these task demands increase, younger children are more likely to fail. What is noticeable, however, is that in each case, children start with very specific representations.

With such constraints on learning due to specificity, how does the emergence of a highly flexible memory system develop? Both basic memory mechanisms and experiential mechanisms related to encounters with changes to stimuli account for the gradual transition from specific to more flexible memory recall.

A good example of a basic memory mechanism that influences memory specificity in both adults and infants is "gist." Prior studies conducted with much younger infants have shown that, after longer delays, infants tend to remember the gist of a memory rather than the more specific details of the event. Studies using operant conditioning (Bhatt & Rovee-Collier, 1996; Borovsky & Rovee-Collier, 1990; Hartshorn et al., 1998; Rovee-Collier & Sullivan, 1980) and imitation paradigms (Barr, Rovee-Collier, & Campanella, 2005; Barr et al., 1996) show that three-to-six-month-old infants do not spontaneously generalize to a novel test cue after a 24-hour delay. With longer delays, as infants gradually forget the specific details, they increasingly respond to ("recognize") a novel cue until they finally treat them equivalently (Barr et al., 2005; Rovee-Collier & Sullivan, 1980). It is therefore tempting to argue, that decalage may be contributing to age- and task-related differences in performance; that is, although infants may look like they are solving a generalization problem early in development, they may be solving the problem via a different developmental process than older infants and children. Early in development, generalization could occur via a process of perceptual confusion, but it is not until later in development that generalization occurs via a process of acquired equivalence. In fact, members of most species exhibit a flattening of generalization gradients over time, irrespective of task (Riccio, Ackil, & Burch-Vernon, 1992; Riccio, Rabinowitz, & Axelrod, 1994; Thomas & Burr, 1969). Retrieval of gist incurred by long delays is likely due to perceptual confusion rather than perceptual equivalence, and is likely to occur across the lifespan.

Experiential mechanisms, in contrast, refer to various techniques that can help facilitate generalization across different cues or environmental contexts. These mechanisms can provide overlap between the cues available at the time of encoding and the cues present at test by enhancing the degree of physical or representational similarity between the different cues. In the following section describing pathways to flexibility, we present data to demonstrate acquired equivalence at different ages and with different paradigms.

Pathways to Flexibility: Experiential Mechanisms

In order for a novel object to cue retrieval, the infant must recognize the similarity between the test object and the attributes stored as part of the original memory representation. This is difficult for infants to do because infants have acquired fewer associations between memory attributes than older children or adults. According to Hayne's (2006) *developmental representational flexibility hypothesis*, increasing the availability of cues increases the likelihood of generalization. Infants' sensory-motor learning capacity can be capitalized upon in the course of their everyday interactions with the world to expand their mnemonic base and increase memory flexibility across time. For example, sensory preconditioning increases the number of overlapping visual cues, learning across different environments increases the number of overlapping contextual cues, immediate imitation increases the number of self-produced motor cues, and language increases the availability of overlapping auditory cues. Different types of cues will be more effective at different ages, depending on the infant's current knowledge base and their motor, language, and representational processing abilities. These additional cues help the infant to match cues at the time of encoding and retrieval, leading to acquired equivalence—facilitating the generalization and laying the foundation for a highly flexible memory system.

Perceptual Visual Cues

A number of experimental techniques provide the infant with additional visual cues during encoding. Categorization and sensory preconditioning are described as examples of how providing additional visual cues promotes acquired equivalence between perceptual cues. Hayne, Rovee-Collier, and Perris (1987) used category training to show three-month-olds three different mobiles. Infants were trained for 3 minutes on mobile A, followed by 3 minutes on mobile B, and 3 minutes on mobile C; this was repeated over two consecutive days of training. At test, infants generalized performance to a novel member of the category, mobile D, and kicked above baseline rates. Infants did not generalize to a novel mobile that was not a category member. This is a clear example of acquired equivalence. Given enough information, very young infants can generalize beyond the perceptual features.

During sensory preconditioning (SPC), a perceptual association is formed between two stimuli or events that occur together, and this association can help infants generalize across different conditions. "Preconditioning" refers to the fact that the association is formed by simply presenting objects together before infants learn about the functional significance of the objects. Because associations are latent, however, the subsequent conditioning (training) procedure provides an overt means of expressing memory for the pre-exposed information. The SPC paradigm has three phases: (1) two neutral objects are paired, (2) the child learns a specific response for one of the objects [A], and (3) the child is tested with the other object [B]. If the child performs the same response on B, then it can be concluded that transfer of responding from one object to the other was mediated by an association between the two objects that had been formed when they were paired in phase 1. This conclusion is dependent on a finding of no response transfer between two objects that were pre-exposed separately (unpaired) in phase 1. The following examples provide concrete illustrations of this process, exemplifying how exposure to multiple pieces of information can be used by the infant to facilitate appropriate generalization of information.

The initial demonstration of SPC in human infants using an imitation paradigm was by Barr, Marrott, and Rovee-Collier (2003). In the first phase, the experimental group was pre-exposed to two hand puppets, a cow and a duck, placed side-by-side (paired) for 1 hour everyday for 7 consecutive days. The control group saw the puppets for an equal amount of time, but they saw the puppets one at a time at different times of day (unpaired). In the second and third phases, the experimental and control groups were treated identically. In phase 2 (1 day later), an adult demonstrated the target actions on one puppet, the cow, and infants were given the opportunity to practice the target actions. In phase 3 (1 day after demonstration), infants were tested with the other puppet, the duck. The researchers found that the paired group imitated the target actions, but the unpaired group did not. The transfer of learning from cow to duck indicated that a cow–duck association had been formed in phase 1. Barr et al. (2003) also found that infants associated the paired puppets after only a 1-hour pre-exposure for two consecutive days.

In a subsequent experiment, Campanella and Rovee-Collier (2005) used SPC and examined whether this association could be maintained across time. At three months, infants were exposed to puppets A+B paired for 1 hour per day for 7 days, and on day 8, the experimenter modeled the three target actions on puppet A. On day 9, and five more times over the next three months, the infants were simply reminded of puppet A for 30 seconds but did not see another demonstration of the target actions (a reactivation treatment). At six months of age, when infants were capable of performing the target actions, they were tested with puppet B. Despite not seeing the target actions or puppet A for three months, infants performed significantly above baseline controls. In contrast, both the unpaired A–B control group, who had been pre-exposed to puppet A and B at different times, and the reactivation control group, who had never seen a demonstration of the target actions, did not differ from baseline controls at test. The authors showed that if learning occurred even when infants were not capable of producing the target actions, the memory of both the association between the puppets and the target actions could be maintained across long periods of development.

Finally, the Rovee-Collier research group examined how long infants would remember the association between the two objects before seeing the target actions demonstrated. Rovee-Collier and Giles (2010) reported that infants could also associate puppets A and B if exposed to them for only 1 hour on a single day and wanted to determine how long infants could remember the association. Various delays were imposed between the pre-exposure phase (phase 1) and the demonstration of the target actions on puppet A (phase 2), until the infants failed to imitate the target actions on puppet B (phase 3). The longest interval after which infants could successfully transfer responding from puppet A to B was 7 days after a 1-hour pre-exposure on 2 consecutive days or 3 days after a single 1-hour pre-exposure session.

Infants can also generalize across large contextual changes. Examining generalization during the first year of life, Learmonth and colleagues (2004) looked at what circumstances infants in the first year may generalize to different test contexts. When the change in context is great (e.g., from home to laboratory) six-month-old infants are not successful in transferring information (Hayne et al., 2000; Hayne et al., 1997), but specific cues in their environment can help them generalize. Using an elicited imitation protocol, where infants participated in an imitation phase immediately after the demonstration, researchers tested four groups of six-month-old infants in their home using different contextual cues: (1) in the same room with a different mat, (2) in a different room with the same mat, (3) in a different room with a different mat, and (4) different room with no mat. All groups except for the different room and different mat group were able to generalize after a 24-hour delay. That is, the six-month-olds were able to use the cue of the room or the mat to help them generalize across the different contexts.

Learmonth and colleagues reported that their findings differ from those of operant conditioning studies because the experimenter functioned as an additional cue in their study, which may have facilitated generalization. In the operant tasks, the experimenter's role is insignificant where the researcher is not fully seen during the training and testing; in contrast, in the puppet studies, the same experimenter is seen during the demonstration and test sessions. The authors note that this additional contextual cue may be sufficient enough to outweigh the disruptive effect of changing the room or the mat but not enough to outweigh the joint effect of simultaneously changing both the room and the mat at the time of testing. In a follow-up study, when the experimenter was changed, performance was again disrupted (Learmonth, Lamberth, & Rovee-Collier, 2005).

Using a deferred imitation protocol, Jones and Herbert (2008) examined the effect of a unique learning and test environment on generalization, which would increase the number of contextual visual perceptual cues for the infant to use during retrieval. Twelve-month-old infants were brought into a distinctive experimental room. The infants were shown a demonstration of the three-step action sequence using the puppets, and then taken back to the waiting room. After a delay, they were brought back to the same distinctive room and tested with a novel puppet. This design was different to previous studies where the entire session (demonstration, delay, and test) occurred in the same location. Generalization was significantly higher under these conditions than when the context of learning was associated with other events. The researchers concluded that although 12-month-olds encoded specific details from the stimulus and its context in memory, salient retrieval cues may be the most important factor for generalizing across stimuli, and when retrieval cues are less veridical, contextual cues may prove to be essential for the young infant.

Motor Cues

Imitation studies have examined the differences between the elicited and deferred imitation protocols in relation to both long-term memory and generalization. Immediate imitation enables the child to handle the target object – providing the child with additional cues, such as texture and self-produced motion cues, at the time of encoding that facilitates generalization to the novel test stimuli. Barr and Hayne (1996) examined the effect of immediate imitation on long-term memory with 18-month-olds using two three-step sequences. In this study, half of the infants participated in an immediate imitation phase (elicited imitation protocol), and half the infants did not (deferred imitation protocol). The researchers did not find an effect of immediate imitation, and both groups performed equally after the 1-week delay. This result suggests that infants in both groups were able to successfully encode the information from the demonstration and that immediate imitation does not increase the absolute number of target actions produced during the retention test (Barr & Hayne, 1996).

Immediate imitation has, however, been shown to facilitate generalization in several studies. Studies using the puppet task have shown that, although infants can exhibit deferred imitation of the target actions when tested with the same puppet, there are clear age-related differences in imitation when a novel puppet was introduced at the test session (Hayne et al., 1997; Hayne et al., 2000). Specifically manipulating the effect of immediate imitation, Hayne, Barr, and Herbert (2003) tested 18-month-old infants in an imitation paradigm where half the infants participated in an immediate imitation phase (elicited imitation protocol) and half the infants did not (deferred imitation protocol). The results indicated that the opportunity to imitate the target actions did indeed influence memory generalization on the three-step sequence. Infants who participated in the immediate imitation phase generalized to a novel test stimulus when they were tested after a 24-hour delay, whereas infants who did not participate in an immediate imitation phase did not. Similarly, Yang, Sidman, and Bushnell (2010) examined generalization with 14- and 16-month-olds on a series of 1-step imitation tasks and found that generalization performance did increase when infants participated in an immediate imitation phase. The researchers note that, although their sample of infants were also able to generalize without participating in immediate imitation phase, conflicting with results from Hayne et al. (2003), this may be due to differences in task demands across studies. Hayne and colleagues (2003) used a longer 24-hour delay and three-step sequences, whereas Yang and colleagues (2010) used one-step sequences. Within the same study, Yang and colleagues ran another experiment where, after the demonstration, the experimenter labeled the target actions instead of giving the infant the opportunity for immediate imitation. The researchers wanted to increase the infant's attention to the target action, but this manipulation had no effect on generalization. This suggests that, for 14–16-month-olds, the additional motor cues rather than language cues, facilitated generalization. Taken together, these findings suggest that, because the immediate imitation phase did not affect retention when infants were tested with the same stimuli, improved generalization performance is most likely attributable to cues generated from self-produced actions during the immediate imitation phase.

Looking at even younger infants, Learmonth and colleagues (2004) found that participation in an immediate imitation phase also facilitated generalization by 9- and 12-month-old infants between two distinctive hand puppets (a black-and-white cow and a yellow duck with an orange bill) when they were tested after a 24-hour delay. Without immediate imitation, generalization across these two very distinct puppets does not occur on average until 21 months (Hayne et al., 1997). If cognitive load is decreased from a three-step to a one-step sequence, nine-month-olds can generalize without immediate imitation (Lukowski et al., 2009). Researchers have suggested that immediate imitation influences memory performance by enhancing the strength of the underlying memory representation. Infants who are not given the opportunity to imitate after the demonstration encode only the visual information about the object (e.g., color, experimenter's actions, etc.), whereas when infants imitate immediately after the demonstration, they are also able to encode tactile information (e.g., weight, texture, etc.) in addition to the visual characteristics. Because infants imitate at the time of encoding and retrieval, the conditions of encoding and retrieval are the same, so self-produced motion cues match (Learmonth et al., 2004). These extra cues allow the infant to access multiple retrieval cues at the time of test and increase their chances of generalization despite visual changes to the stimuli.

Immediate imitation alone may not be sufficient for six-month-olds, whose memories are extremely specific, to generalize across stimuli. For example, Learmonth, and colleagues (2004) found that six-month-olds needed both immediate imitation and additional perceptual cues to generalize across a novel context. Similarly, Barr and colleagues (2003) found that infants needed both immediate imitation as well as the perceptual association of the cues via SPC in order to generalize across cues. The unpaired group who did not see the objects perceptually associated, but imitated the target actions on puppet A immediately after the demonstration, were unable to generalize to puppet B. Whether or not SPC would be effective at six months in the absence of immediate imitation is not known.

Language Cues

Language cues, in some cases, also enhance generalization. Herbert and Hayne (2000) examined whether providing a verbal cue (nonsense word) during the demonstration and test phase of a deferred imitation task would enable the infant to generalize learning to a new stimulus. In this study, they used two three-step imitation tasks that were adapted from tasks originally developed by Bauer and her colleagues (Bauer, Hertsgaard, & Wewerka, 1995). In one task, the adult model constructed a rattle by placing a wooden block in a jar, placing a stick on the jar that was attached via Velcro, and then shaking the stick to make a noise. In the other task, the experimenter created an animal by pulling a lever to raise the ears, placing eyes on the face (attached via Velcro), and "feeding" the animal through a hole in the mouth. An experimenter would label one rattle or animal toy as a "meewa" and perform the target actions. Then, at test, infants were provided with a different set of objects to make a rattle or animal toy but provided with the same label, "you can also use these things to make a meewa." The researchers found that 24-month-olds were able to generalize learning, but 18-month-olds were not. Herbert and Hayne argue that the language cue does not enhance the original representation originally encoded during the demonstration, but acts as an additional retrieval cue to facilitate successful deferred imitation performance. With younger children, Herbert (2011) found that providing a label (i.e., "Look a puppet") coupled with words for the actions (i.e., "Off, Shake, On") increased 12- and 15-month-olds' generalization on the puppet task, compared to when empty language cues were provided during the demonstration (e.g., "Did you see that?") and test (i.e., "Here he is").

Additional Representational Cues

Apart from language cues, young children begin to match encoding and retrieval cues based on other representational cues, and not just perceptual or motor cues. Symbolic analogical transfer studies during early childhood have almost exclusively used the object-search task in which toddlers use the underlying solution to an easy version of a task to succeed on a harder version of the same task (e.g., DeLoache, Simcock, & Marzolf, 2004). DeLoache (1995) proposed that understanding one symbol-referent relationship facilitates understanding other, more difficult, symbol-referent relationships. Problem-solving tasks that involve reasoning by analogy have demonstrated that this is the case (DeLoache et al., 2004; Marzolf & DeLoache, 1994; Troseth, 2003). In these studies, young children first participate in an easy version of the object search task (e.g., small model to larger model) followed by a difficult version of the same task (small model to room). Results show that initial experience with the easy task allows young children to subsequently succeed on the more difficult task that is usually beyond their capabilities. In order to succeed on the difficult task, the children must recognize the underlying structural similarities between the two tasks, and successfully transfer and apply the solution from the original task to the related but novel task (Chen, Sanchez, & Campbell, 1997; Goswami, 1991; Halford, 1993; Perra & Gattis, 2008; Singer-Freeman & Bauer, 2008).

Summary of Experiential Mechanisms

Initially, the infant's memory is highly specific to cues and contexts, and it is only with time, additional cues, and familiarization that the infant's memories become more flexible. Some pathways to flexibility (e.g., immediate imitation) do not influence overall retention of the target memory but they still influence generalization. Additional perceptual, motor, and representational (e.g., analogical reasoning or language) cues help make the connection between the original memory representation and the novel object, resulting in acquired equivalence. Findings suggest that there are age-related differences in the number and/or type of cues required to generalize. As seen in the studies mentioned, very young infants may need a combination of perceptual and motor cues in order to generalize across cues (Barr et al., 2003; Learmonth et al., 2004), whereas for older infants either additional motor or perceptual cues alone may be sufficient (Barr & Hayne, 1996; Bauer & Dow, 1994), and for young children representational cues such as language or analogical reasoning may suffice (e.g., DeLoache et al., 2004; Herbert & Hayne, 2000). Although the cues may differ, the overall pattern of information processing is the same (see Rovee-Collier et al., 2001, for similar argument regarding the gradual emergence of explicit and implicit memory systems). Taken together, these findings provide support for a *developmental representational flexibility hypothesis,* suggesting a pattern from high specificity toward memory flexibility based on the number of potential retrieval cues available to the young child.

Practical Applications of Memory Specificity: 2D Media

A practical application of memory generalization is the ability to transfer information between various 2D media sources and the 3D real world. From early in development, picture books and television play an important role in infants' lives, and most infants are exposed to media on a daily basis. Recent large-scale parental surveys indicate that toddlers under 3 years of age watch around 1 hour of television each day and are read to for around $^1/_2$ an hour per day (Rideout & Hamel, 2006). Transferring learning from television and picture books to the real world is one everyday situation in which toddlers exhibit representational flexibility or lack thereof. In these cases, toddlers must encode information presented in a 2D format and later retrieve it when presented with the real 3D objects—a challenge for toddlers, as there is a mismatch between the cues available at encoding and retrieval.

Barr (2010) has argued that transfer of learning from 2D media is a clear example of representational inflexibility during early childhood, and, as such, perceptual, functional, and representational factors are likely to contribute to the media deficit. Researchers using a number of different experimental paradigms have demonstrated that infants, toddlers, and preschool children learn less from television, books, and touchscreen devices than from face-to-face interactions (for review, see Anderson & Pempek, 2005; Barr, 2010). The *media deficit effect* (or *representational deficit*) refers to the fact that infants' ability to transfer learning from 2D symbolic media to real-life situations is poor relative to their ability to transfer learning from a live interaction. The now well-documented media deficit effect is not apparent at six months of age, peaks around 15–30 months of age, and persists until at least 6 years of age (Barr & Hayne, 1999; Barr, Muentener, & Garcia, 2007a; DeLoache & Burns, 1994; Flynn & Whiten, 2008; Hayne, Herbert, & Simcock, 2003; Hudson & Sheffield, 1999; Kuhl, Tsao, & Liu, 2003; McCall, Parke, & Kavanaugh, 1977; Meltzoff, 1988b). Given the prevalence of 2D materials—including books, television, touchscreen devices, and computers—in homes and daycare centers, understanding the basis of the video deficit effect and its amelioration has obvious practical consequences for early education.

Perceptual characteristics of 2D images may be difficult for toddlers to understand: the images are smaller than the corresponding real objects, the resolution of the image is degraded relative to real objects, and the image lacks features such as depth cues typical of real objects (Barr & Hayne, 1999; Schmitt & Anderson, 2002; Suddendorf, Simcock, & Nielsen, 2007). In one study, for example, Barr and Hayne (1999) found that, although 15- and 18-month-olds imitated from video, they imitated more from the live demonstration than the video demonstration after a 24-hour delay. Similarly, 18-, 24-, and 30-month-olds imitated a novel three-step event from a picture book, but at rates significantly lower than when imitating from a live model (Simcock & DeLoache, 2006). Additionally, the nature of the illustrations in the picture book affected the toddlers' performance. The older children reproduced the target actions regardless of the iconicity of the pictures (e.g., color photos, drawings, line pictures), whereas the younger children required highly realistic pictures in order to do so (e.g., color photos). Recently, research using event-related potentials has found that 18-month-olds recognize familiar 3D objects significantly earlier in the attentional process than familiar 2D digital photos (Carver, Meltzoff, & Dawson, 2006). The slower processing of 2D information that then must be transferred to 3D test conditions might contribute to the media deficit effect.

Examining the effect of contextual cues with picture books, Simcock and Dooley (2007) tested toddlers in either a novel context (e.g., a different room) or with novel stimuli (e.g., a different rattle) after a short picture book demonstration. The 24-month-olds, but not 18-month-olds, performed more of the target actions than did their age-matched controls, and only the 24-month-olds were able to demonstrate retention when tested with changes to both the test stimuli *and* the context. Once again, this study demonstrated clear age-related changes in memory flexibility.

Just as in the imitation tasks, the media deficit is also exhibited in object search tasks (Deocampo & Hudson, 2005; DeLoache & Burns, 1994; Schmitt & Anderson, 2002; Schmidt, Crawley-Davis, & Anderson, 2007; Suddendorf, 2003; Troseth, 2003; Troseth & DeLoache, 1998; Troseth, Pierroutsakos, & DeLoache, 2004; Troseth, Saylor, & Archer, 2006; Zelazo, Sommerville, & Nichols, 1999). It is not until approximately 2.5 years of age that toddlers begin to use information from television and pictures to locate a toy hidden in a room. For example, using a standardized object-search paradigm, Troseth and DeLoache (1998) gave children an extensive orientation to the correspondence between the video of a room and the actual room. During the hiding task, the experimenter goes into the test room and hides a toy and the child views the hiding game on a television monitor in an adjacent room. Immediately after the toy is hidden, the child goes into the test room and is asked to retrieve the hidden toy. Two-year-olds are unable to find the hidden toy, but 2.5 year-olds are successful. In another series of studies, DeLoache and Burns showed children a photograph (either a wide angle view of the room or of the individual item of furniture) of the hiding location of the toy that was hidden behind an item of furniture in an adjacent room. The child was required to use this information to find the toy, and the results demonstrated that 30-month-olds were relatively successful at retrieving the hidden toy (68%), whereas 24-month-olds seldom found the hidden toy (6–27%) (DeLoache & Burns, 1994).

Increasing the task demands of the study also increased the age at which young children were able to retrieve the target object during the object search. Zelazo and colleagues (1999, Exp. 3) increased the difficulty of the object-search task by hiding the toy with the child in the room. The experimenter then told the child that they had decided to change the hiding location and that the experimenter would show the child where the new location was via videotape. In this instance, 3-year-olds failed the task, but 4-year-olds succeeded. Rather than looking in the location where they had viewed the experimenter hide it on the television, the 3-year-olds searched the location where they themselves had hidden the object. That is, they perseverated to the original location. Zelazo and colleagues concluded that the additional conflicting information of having previously participated in the hiding location placed an additional load on the memory system.

In addition to perceptual dissimilarities, there are other factors such as symbolic understanding and cognitive load that can decrease transfer of information from 2D pictures and videos to their corresponding real-world 3D objects (Barr, 2010; Troseth, 2010). The dual representation account (Simcock & DeLoache, 2008; Troseth, 2003; Troseth & DeLoache, 1998) focuses on the lack of symbolic understanding. DeLoache and colleagues (DeLoache, 1987, 1995, 2000, 2002; Uttal, Schreiber, & DeLoache, 1995) suggest that young children fail to transfer learning across symbolic changes because they do not fully understand the nature and common uses of symbolic information. They argue that symbolic objects (e.g., books, video) have a dual nature; they are simultaneously objects as well as representations of something else. A child must understand what the symbol is intended to represent and focus less on its physical properties, a difficult task early in development; thus, children demonstrate difficulty mapping (transferring) between the symbolic and non-symbolic representations.

Although toddlers do find it difficult to transfer information from 2D to 3D and vice versa, the same factors that can facilitate memory flexibility during live demonstrations can also be used to ameliorate the media deficit effect.

Visual Perceptual Cues

From a practical point of view, infants often watch the same video or read the same book repeatedly, and parents report that toddlers frequently ask to repeatedly view the same media (Mares, 1998; Rideout, Vandewater, & Wartella, 2003). Previous studies have found that repeated presentations of the same television program increase comprehension and attention by preschoolers (Abelman, 1990; Anderson & Levin, 1976; Anderson, Lorch, Field, & Sanders, 1981; Crawley, Anderson, Wilder, Williams, & Santomero, 1999; Skouteris & Kelly, 2006).

Repetition was hypothesized and found to enhance transfer of learning from books and television, and researchers concluded that this was due to the addition of extra perceptual cues. For example, in live demonstrations 12-, 18-, and 24-month-old infants presented with three demonstrations of the target actions could imitate those actions after a 24-hour delay, but six-month-olds needed twice the perceptual cues (six demonstrations) in order to show deferred imitation (Barr et al., 1996). Similarly, Barr, Muentener, Garcia, Fujimoto, and Chavez (2007b) found that doubling the exposure to a video (six demonstrations) increased levels of imitation performance by 12–21-month-old infants for the 2D group, and this performance equaled the live demonstration group who only saw the demonstration three times. Repetition, or increased exposure to additional perceptual cues, increased generalization from 2D to 3D. Simcock and DeLoache (2008) also found that doubling the number of exposures to the target actions from a book enhanced imitation performance from a book by 18- and 24-month-olds. Repetition likely enhances encoding, and therefore increases the chances of transfer because processing time during encoding increases, allowing for a better representation of the target actions to be encoded, and therefore more retrieval cues to be available at the time of test (see also Carver et al., 2006; Zack, Barr, Gerhardstein, Dickerson, & Meltzoff, 2009).

During object search tasks, toddlers perform well on the first hiding trial, but performance deteriorates on subsequent trials when a television is used. On the second trial, children often perseverate to the original hiding location because the memory representation formed from finding a real object competes with that formed when viewing a video-based 2D hiding demonstration on the second trial. Suddendorf (2003) hypothesized that, if the memory demands were reduced such that memory updating was not necessary, then 2-year-olds would be able to find a hidden toy after viewing it hidden on television. When Suddendorf made the search task less difficult by changing the search room on each trial, 2-year-olds succeeded on a televised object search task. The different search rooms provided contextual cues to the toddler to indicate a change in memory representation, and subsequently allowed the toddler to update the location of the toy. Overall, when a distinctive context is used, these additional contextual cues make it more likely that young children will transfer information (see Jones & Herbert, 2008 for similar argument).

Language Cues

In a follow-up study to Herbert and Hayne's (2000) study examining the effects of language cues on imitation performance, Barr and Wyss (2008), using the same procedure, found that 24-month-olds were able to use nonsense labels to generalize learning to novel exemplars when the information had been presented on television. Using two sets of stimuli, the experimenter labeled each set of stimuli either "meewa" or "thornby." The nonsense labels were provided either by a voice-over on the video (voice-over), or by parents during the video demonstration (video parent label). Performance was compared to parents labeling during a live demonstration (live parent label), or to a video with no label group. All video groups saw twice as many demonstrations as the live group. On the test day, the nonsense labels were repeated, and infants were presented with a novel version of the toy. The baseline control group was provided with the stimuli and nonsense label only at the time of the test. The live and video demonstration groups all performed significantly above baseline control. However, the video with no label group performed significantly worse than the live parent label group. Both video voice-over and video parent label groups performed as well as the live parent label group. Thus, in a generalization task, 24-month-olds can use a combination of verbal cues and repetition to overcome the video deficit and solve difficult imitation tasks (Barr & Wyss, 2008). Verbal labels at encoding and retrieval enhanced representational flexibility.

Seehagen and Herbert (2010) extended this paradigm to examine whether imitation scores by 18-month-olds would be higher if mothers were prerecorded using their own language rather than the experimenter's language, but results indicated no difference. It was important to note, however, that although the length of the demonstration and the use of specific target descriptors did not predict imitation, the total number of words that the mother used did positively predict imitation scores. The researchers then went on to develop a "motherstyle" narrative based on the descriptors that mothers had used. Experimenters then used this naturalistic narrative (e.g., "Look! What's this? You put the ball in here. And then you put this on there. And what do we do now? We shake it, wheee!" p. 171). When experimenters used this "motherstyle," 18-month-olds imitated the target actions from television significantly above both the baseline group and the experimental group who viewed the experimenter perform the target actions accompanied by empty narrative.

Finally, Simcock, Garrity, and Barr (2011) found that 18- and 24-month-olds could imitate from books and television regardless of whether or not the demonstration was accompanied by a description of the event (Experiment 1); infants' imitative performance was enhanced when specific verbal cues were provided prior to the test (Experiment 2); and toddlers could defer imitation even when pictures of a book were obscured and only verbal cues were provided (Experiment 3). It is not clear however, when language might first facilitate transfer of learning across dimensions. Zack, Barr, Dickerson, Gerhardstein, and Meltzoff (2013) assigned 15-month-olds to one of three conditions: empty language, nonsense label, and object label, and tested them on a touchscreen transfer task (2D to 3D or 3D to 2D). Although all groups performed significantly above baseline, the language cues (either providing a novel nonsense label or a well-understood label) did not facilitate transfer of learning for 15-month-olds.

Taken, together, the studies that have included language cues suggest that adding additional verbal retrieval cues can facilitate learning from media. First, although labels are typically very effective at 12–15 months in tasks involving live interactions (e.g., Booth & Waxman, 2002; Waxman, 2008), the representational load associated with the transfer of information from 2D to 3D and vice versa may mean that an additional symbolic cue (e.g., label) does not facilitate transfer of learning until approximately 18 months. At 18-months and older, memory representations are beginning to be more flexible and the ability to fast map labels to objects is rapidly developing (Bloom & Markson, 2001; Hayne, 2004). These findings are consistent with studies showing that preschoolers can acquire vocabulary from television (Naigles & Mayeux, 2001; Rice, Huston, Truglio, & Wright, 1990). Once again, the effectiveness of various types of retrieval cues in facilitating memory generalization is dependent upon infant age and task complexity.

Relational Cues

Providing additional relational cues for 2D media may also facilitate transfer between 2D representations and 3D real-world objects. Troseth (2003) provided 2-year-old children and their families with video cameras connected to their home television monitors for 2 weeks. Over the course of those two weeks, children experienced seeing themselves live on the television screens and effectively had practice understanding the relationship between the 2D screen and themselves. At the end of the two weeks, the toddlers were tested with the television version of the object search task, and practice significantly improved their performance. Similarly, Skouteris, Spataro, and Lazaridis (2006) showed that when 3-year-olds were trained, delayed video self-recognition was enhanced and video could provide meaningful information. That is, for young children to transfer learning from video to the real world, they may need to have some training or practice with 2D media to understand the correspondence between televised and real-world information.

Summary of 2D Media

Age-related changes in representational flexibility found in tasks using live demonstrations also apply to learning and memory from media demonstrations as well. That is, older children need less of an exact match to transfer learning from 2D television and pictures to 3D objects than younger children. As infants advance in age, so too does their ability to generalize. This generalization is often task specific and dependent upon numerous factors such as perceptual and contextual cues, motor cues, and representational cues. Children start watching television at a very young age, and the amount of child-directed programming is increasing in television, and now in other platforms including computers and touchscreens. The research on early media exposure for children is still a small but growing field, and there are many open questions including how developing perceptual, linguistic, and cognitive skills and symbolic understanding contribute to memory flexibility.

Future Directions

Numerous studies have verified the specificity of infants' memories, but future experiments should explore continuities in the development of memory specificity and flexibility from early childhood to adulthood. Studies could examine connections between early capacities for memory flexibility and later abilities on more complex analogical reasoning tasks (Bauer & Dow, 1994; DeLoache, 1995; Goswami, 1991). This line of investigation will likely be important for studying school readiness. Additionally, the neural mechanisms of cognitive specificity and flexibility in the youngest children are still relatively unknown (but see Bauer, 2007, 2008; Richmond & DeBoer, 2006; Richmond & Nelson, 2008; Riggins, Bauer, Georgieff, & Nelson, 2010). It is likely that rapid hippocampal development during the first few years of life, accompanied by increases in synaptic connectivity, contribute to developmental changes in cognitive flexibility. In particular, Richmond and DeBoer (2006) argue that, initially, attributes (such as cue, action, and context) of a memory representation encoded in the parahippocampal cortex might be fused, but later development of the dentate gyrus would allow the attributes to be encoded individually, thereby enhancing flexible retrieval (see Richmond & Nelson, 2008, for further discussion).

Individual differences in memory generalization should also be further explored. Past research has demonstrated that locomotor ability may influence cognitive flexibility during infancy. Herbert, Gross, and Hayne (2007) showed that nine-month-olds who were already crawling were significantly more likely to generalize between a cow and duck button box than infants who had not yet begun to crawl. Similarly, a "bilingual advantage" in memory generalization has been shown by 18-month-olds (Brito & Barr, 2012). Using the deferred imitation puppet task, the researchers demonstrated three target actions with one puppet (e.g., duck) to the infant, and then, after a 30-minute delay, tested the infant with a novel puppet (e.g., cow). Results indicated that 18-month-old bilinguals, but not monolinguals, were more likely to generalize across puppets. Additionally, percent exposure to second language (L2) predicted an infant's ability to generalize, and infants who were more "balanced" in their language exposure (e.g., 50% English, 50% Spanish) were more likely generalize across puppets. Future studies will test whether the bilingual advantage is better explained by perceptual confusion or acquired equivalence. Children who are flexible in their mental representations may be able to enhance their learning capabilities by being able to generalize across different problem-solving situations. This mental flexibility may be the product of simultaneously having to process two languages, and in so doing, increasing the bilingual child's capacity for learning. Studying the underlying neural mechanisms in bilinguals has already revealed important information regarding linguistic processing (Petitto et al., 2011), and may similarly have important information regarding the development of memory circuitry as a function of diverse input.

Overall Conclusions

Basic developments in memory functioning cannot entirely account for the findings presented within this chapter. Over and above cognitive load considerations, the reason for memory specificity is one of adaptation. Initially, infants have very poor levels of inhibitory control (Diamond, 1999), and memory specificity therefore is an adaptive and protective mechanism to keep infants from potential harm caused by responding to stimuli that may differ from those that they have originally encountered (Rovee-Collier, 1996). It may be as important for young children to demonstrate memory specificity in appropriate learning situations as it is for them to become more cognitively flexible across time (Bahrick, 2002; Learmonth et al., 2004). That is, memory specificity may be a behavioral compensation for immaturity of inhibitory neural circuitry. Failure, however, to develop memory flexibility across time will also become a maladaptive strategy and, at its extreme, may be exhibited in delayed cognitive development (Bauer, 2007; Riggins et al., 2010).

It is unlikely that specificity signals reliance on a more immature implicit memory system while flexibility heralds the emergence of the more mature explicit memory system. The pattern of results demonstrates that specificity is the default mechanism when infants and children encounter new learning situations and, similarly, specificity limitations can be overcome by experiential factors. These findings provide some support for the argument that both memory systems emerge gradually during infancy and early childhood. Furthermore, paradigms that examine transitions between specific and flexible memory representations may be useful in order to elucidate the development of neural mechanisms and connectivity between different developing structures that support implicit and explicit memory systems.

Our overall conclusion is that, early in development, the memory system is more conservative because representations are less detailed and less connected to one another, but there are behavioral mechanisms available to circumvent this lack of experience. The memory system is functional from early in development but, during infancy, without additional experiential information (e.g., language, long-term retention of information), researchers are able to differentiate between specificity and generalization/flexibility better than at any other time during development. This provides researchers with a unique opportunity to observe the unfolding of the development of the mnemonic network and inform our understanding of the adult memory system as well as the development of memory during early childhood.

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