Implicit Memory in Childhood:

Reassessing Developmental Invariance

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To appear in M.L. Courage & N. Cowan (Eds.),

The Development of Memory in Childhood, 2nd edition.

London: Psychology Press

It's like riding a bike: once you've learned it, you'll never forget how to do it.

Although it is uncertain whether this adage has been tested empirically, personal experience of the authors suggests that the passage of many years is indeed insufficient to destroy bike-riding ability. Recently, skills such as bike-riding have been termed *implicit memory*, and their retention has been contrasted with what is seen with *explicit memory* tasks, in which participants are aware that they are making a memory decision, as occurs when answering the question, "Who taught you to ride a bike?". Implicit memory has been described as encompassing various tasks, including not only acquisition of motor skill, but also priming (as when something comes quickly and easily to mind because it has been encountered previously) and classical conditioning. (For a typical graphic depiction of these distinctions, see Squire & Zola, 1996). There has been considerable interest in typologies of this kind as supporting investigations of the architecture of human memory that are informed by combinations of evidence from behavior and neuroscience, and that encompass research with a variety of human and non-human populations.

The terms explicit and implicit memory were proposed by Graf and Schacter (1985; also see Schacter, 1987). In the 30 years since the introduction of these terms, several debates have occurred over the necessity to posit multiple memory systems (e.g., Tulving, 2002) and the possibility that such dissociations are based on tasks rather than processes (Roediger & Blaxton, 1989; Toth & Hunt, 1999). However, the distinction seems to have withstood the test of time, and is in wide use today (e.g., in introductory psychology, physiological psychology, and cognitive psychology texts). Operationally, explicit memory refers to tasks in which people are asked to evaluate their memory, either by saying that they did or did not encounter something before (i.e., recognition test), or by producing a previously-

encountered stimulus or fact (e.g., autobiographical recollections, free recall, cued recall). In contrast, when the task does not refer to a study episode (e.g., naming tasks, priming measures, stem completion, sequence learning, conditioning), we refer to the results as a measure of implicit memory.

Developmentally, it has been claimed that implicit memory is present robustly from the start of life, and does not undergo the kind of age-related changes that are commonly seen in explicit memory (Reber, 1989). In fact, this theme was the dominant conclusion of the chapter by Alan Parkin (1998) covering implicit memory in the first edition of this volume. The claim has several attractive characteristics. First, explicit memory improves dramatically over the course of childhood (for a review see Kail, 1990), and many standard explicit tasks such as recall and recognition are simply too difficult to use with children younger than three years of age. Although there is increasing recognition that explicit memory is present in infancy (for a review, see Bauer, 2006), implicit memory measures still seem to offer a potentially more sensitive way to determine what information young children have encoded, while still employing measures that can also be used with adults. Second, implicit memory seems to offer a way of understanding a paradox in cognitive development, namely, the fact that early competence is often discerned using looking time measures while, in contrast, studies examining deliberate actions and explicit predictions often show protracted phases of immaturity (see Keen, 2003). That is, perhaps initial knowledge is implicit in nature, but considerable experience with the world is necessary to create explicitly accessible information that can be used to make judgments.

There is actually considerable uncertainty, however, concerning whether implicit memory is as developmentally robust as investigators believed at first. There are several reasons to rethink this position. First, it was based primarily on studies of perceptual priming, without much consideration of other types of implicit memory, or of conceptual priming (Roediger & Blaxton, 1989). Second, it became associated with other propositions that are not logically entailed by it, notably the idea that implicit memory is resistant to decay or interference (as in the bike riding example). Third, it was based on studies of children that began at quite an advanced age from the point of view of discussion of developmental origins of knowledge or invariance over the life span—rarely younger than 3 or 4 years of age.

Our aim in this chapter is to reconsider the development of implicit memory in a more differentiated way than was possible when Parkin's chapter in the first edition was written. However, a complete review of implicit memory development is beyond the scope of one chapter; indeed, an entire book on the topic has been written (Rovee-Collier, Hayne, & Colombo, 2000). We have chosen to restrict our scope in several ways. First, we will not discuss the development of explicit memory except when it is useful to make contrasts with implicit performance, because many other chapters in this book deal with aspects of explicit memory such as autobiographical or source memory. Second, we will concentrate on developments in childhood rather than address in detail the issue of what infant memory measures are implicit and which are explicit, which has a complicated history of its own (see chapter 2 in this book and also chapters 5-8 in Oakes and Bauer, 2007).

We first review what the support was for Parkin's (1998) claim that "procedural memory appears age invariant" (p. 124). Most of the evidence for the invariance claim came from studies in which implicit memory was tested using perceptual priming tasks. These findings of equivalent priming effects across childhood have largely been supported subsequently, but there have also been studies showing developmental change in *conceptual* priming tasks that have received much recent attention. We argue, however, that this work entangles issues of priming with issues of conceptual growth and additions to semantic memory, so that the data do not actually challenge the invariance claim in a fundamental way. We then conclude the section on priming with a discussion of what is known about the interplay of implicit with explicit memory, where there does appear to be considerable, and rather late, developmental change. In the second major section, we review findings regarding another kind of implicit memory, different from priming, not covered in the first edition of the book, and for which there is clear evidence that memory *does* change developmentally, namely, sequence learning. We close the chapter with a brief review of some developments in neuroscience, implicit memory in clinical populations, and suggestions for future research.

Priming Effects

One of the most striking aspects of the implicit memory construct is that it encompasses many compelling everyday experiences. When a familiar face pops out of a crowd, perceptual priming may be

at work. When a seemingly novel idea comes to mind, and we later realize that the idea was proposed by someone else in conversation a few days ago, a different kind of priming is at work—conceptual rather than perceptual (as well as, sadly, an embarrassing rather than an adaptive aspect of priming). In this section, we consider the developmental invariance hypothesis for perceptual priming, followed by an examination of conceptual priming (including its effects on false memory), closing with consideration of how children come to realize that processing fluency, i.e., the speed and easy with which an item is perceived, may be a clue to making explicit memory judgments.

Perceptual Priming

Perceptual priming is studied experimentally in situations in which we can be sure that stimuli have been encountered, but in which it is likely that they will not be explicitly remembered. We can then seek evidence that the stimuli are processed more quickly and easily as a function of prior exposure, despite the lack of recall, or even recognition. For example, when participants have recently studied the word "tulip", they can read it faster when it appears on a screen, identify it at a higher level of perceptual masking, or respond to it more quickly on a lexical decision task, compared to a group that has not recently seen the item. Similarly, on a stem completion task, participants are more likely to solve the stem "tu___" with "tulip" than people who have not recently seen the word "tulip." These effects can occur independently of whether they recognize the word on a later recognition test, list it in a recall test, or can accurately remember that the word was viewed as a picture during a source monitoring test (for a review of the effects of encoding and retrieval variables on memory performance, see Richardson-Klavehn & Bjork, 1988; Roediger & McDermott, 1993). Further, unlike explicit tasks such as recall, these priming effects seem to be relatively stable throughout adulthood (e.g., Fleischman, Wilson, Gabrieli, Bienias, & Bennett, 2004).

Much initial work on implicit memory development focused on applying the paradigms typically used with adults to work with children. Some of this work has been verbal (Billingsley, Smith, & McAndres, 2002; Komatsu, Naito, & Fuke, 1996; Perez, Peynircioglu, & Blaxton, 1998). For example, participants may be asked to complete word stems or fragments after studying a list of items. Some of these may be completed with studied items while others would be completed with novel items. Priming is

measured by an increased likelihood in completing items with studied words. Such techniques are not suitable for children who cannot read, however. To modify the methods, studies with children as young as three have used pictorial stimuli (Billingsley, et al., 2002; Cycowicz, Friedman, Snodgrass, 2000; Hayes & Hennessey, 1996; Parkin & Streete, 1988; Perez, et al., 1998). For example, Billingsley, et al. (2002) demonstrated that children and adults perform similarly on two implicit tests: both verbal (category generation) and pictorial (identification) tasks. Working only with pictures, Parkin and Streete (1988) showed common objects to children aged 3, 5, and 7 and later had the children identify distorted pictures that were slowly made clearer. In such a paradigm, priming is represented by faster naming of pictures that have been recently presented. In general, particularly when levels of explicit memory performance were made equivalent (e.g., by reducing the length of the study list for younger children), perceptual priming effects were equivalent across age.

Along the same lines, Drummey and Newcombe (1995) showed pictures to 3- and 5- year old children as well as adults and later tested their ability to recognize the objects at various degrees of perceptual degradation. The degree of priming (higher masking level for identification for studied versus unstudied pictures) was fairly consistent for the three groups of participants. The participants were also asked for recognition judgments, and this measure of explicit memory showed expected age-related improvement. Similar results were reported by Hayes and Hennessey (1996) who also used implicit (picture identification) and explicit (recognition) memory tasks. In their study, children who were 4, 5, and 10 years of age studied a list of pictures and returned 48 hours later for a memory test. During the test, participants first attempted to identify pictures at varying degrees of blurriness. After identifying a picture, participants made a recognition judgment. There was no difference in the degree of priming among the 4-, 5-, and 10- year-olds. That is, the advantage of having studied a picture on subsequent identification tasks was similar for all three ages. However, recognition memory improved from age 4 to 10. Notably, in both studies, the implicit measure of picture identification was not correlated with the explicit measure of recognition; when there are such correlations, developmental invariance may not be found because explicit memory improvements may create what appear to be implicit memory effects (Parkin, 1998).

As we have seen, evidence that has been accumulating since the first edition of this book continues to suggest that perceptual priming is relatively stable throughout development. One exception is that Cycowicz, Freidman, Snodgrass, and Rothstein (2000) have reported evidence for developmental improvements between the ages of five and nine on a picture identification task. However, the task was harder than that used in other studies – participants were under time pressure, and the investigators acknowledge that differences in retrieval speed may have caused the apparent improvement in priming. Further, the youngest children still demonstrated significant priming for the repeated objects.

Findings of equivalent priming rates across age have been taken as evidence that the implicit memory system is older evolutionarily than the explicit system (Reber, 1989) and that it is an independent memory system (e.g., Schacter & Graf, 1985). The idea that perceptual priming is equivalent across the lifespan has not, however, been tested at ages younger than 3 years or so. Although recent data suggest that priming effects exist in infancy (Myers, Clifton & Clarkson, 1987; Perris, Myers & Clifton, 1990; Rovee-Collier, 1997; Snyder, 2007; Webb & Nelson, 2001), their magnitude has not been cleanly compared to effects shown by older children, and in fact, such an enterprise is fraught with methodological and conceptual difficulty. For example, work by Clifton and colleagues have shown that infants maintain some memory of motor responses for actions completed in infancy for long periods of time. However, studies with older children and adult rely primarily on verbal or pictorial measures of priming. It is certainly possible that new and more sensitive techniques may show some early changes in the magnitude of perceptual priming. Given the current state of the evidence, it appears that Parkin was correct in his assessment in this book's first edition: perceptual priming effects are similar from the preschool years on, and remain stable throughout normal aging. However, true developmental invariance beginning with infancy has yet to be assessed.

Conceptual Priming

Perhaps because the issue of developmental invariance of perceptual priming, at least from 3 years on, seems relatively settled, much recent research in implicit memory development has focused on the contrast between perceptual priming and conceptual priming. Conceptual priming often shows marked improvements with age. For example, although children of different ages show equivalent priming rates

for recognizing a picture of a bear that has been presented earlier, young children are often less likely than older children to subsequently complete the stem b________ with the word "bear" (e.g., Komatsu et al., 1996). Similarly, when asked to list words that fit the category "vegetable" older children and adults are more likely to respond with words that were recently presented, relative to younger children (e.g., Billingsley et al., 2002; Perez et al., 1998). Whereas perceptual priming is based on the physical overlap between prior and subsequent presentation, conceptual priming is assumed to be based upon the activation of related concepts in memory. Using the example of the category generation task mentioned above, a person who has recently been presented with the words "eggplant" and "corn," should be more likely to include these two items in a task asking for a list of vegetables.

The evidence for developmental invariance of conceptual priming has been mixed. Some work in conceptual priming suggests that it is age invariant while other work suggests developmental changes. A direct comparison between perceptual and conceptual priming was conducted by Perez et al. (1998), who also studied perceptual and conceptual memory of an explicit nature. In their study, preschool and elementary school age children as well as adults participated in four memory tests (perceptual explicit: pictorial cued recall; conceptual explicit: category cued recall; perceptual implicit: picture identification; conceptual implicit: category production). The advantage to the design of this study was having all four measures available for each participant. Perez et al. found that neither the perceptual nor the conceptual implicit tests showed improvement with age. Similarly, Billingsley et al. (2002) found equivalent priming across age with a category generation task. Unfortunately, the youngest group of participants was 8-10 years of age. It may be that younger children would have shown lower performance on the task. However, other researchers do report differences in conceptual priming during development. For example, Perruchet, Frazier, and Lautrey (1995) showed that children improved in measures of conceptual priming when the exemplars were atypical but not when they were typical members of the category. This finding has since been replicated several times (e.g., Mecklenbrauker, Hupbach, & Wippich, 2003; Murphey, Mckone, & Slee, 2003).

Although these changes have been argued to be evidence for conceptual priming development, we would argue that perhaps this is an unfair test of priming. That is, it is not priming that is changing,

but rather the concepts that these paradigms attempt to test. For example, it has been well documented that the categorical structure of concepts such as animals grows with age. Thus, preschool children may show conceptual and perceptual priming invariance, if tested with suitable materials. Further, we suspect that children may even be able to show *better* conceptual priming than adults when the stimuli are made to be relevant to their lives (e.g., for many toddlers today the popularity of *The Wiggles* probably makes Dorothy a better prime for “Dinosaur” than for “Wizard”). Although many of the papers that find age differences are willing to attribute them to differences in memory, we believe that it is unfair to consider these tasks assessments of conceptual priming capacity.

One line of research that is relevant to developmental changes in category structure is work by Sloutsky and colleagues (Fisher & Sloutsky, 2005; Sloutsky & Fisher, 2004). In this work, an incidental encoding task is used, in which many exemplars of the same animal are presented (e.g., pictures of cats). During a surprise recognition memory test, children outperform adults. That is, they are better able to recognize the pictures of cats that were presented in the study list relative to pictures of other cats that were not presented. The explanation for this pattern is that adults naturally categorize the pictures as "cats" while the children maintain more of the individual features of each item in memory. Contrasts of this kind suggest that changes in conceptual priming ability may be better understood by changes in categorization and semantic organization.

Our point about the role of knowledge in age differences in conceptual priming was also made by Murphey et al. (2003), who argue that conceptual priming reflects changes in knowledge accessibility. Murphey et al. also suggest that priming may be a way to test knowledge levels in children (p. 159).While this is true, an equally important question in studying implicit memory development should be the *capacity* for perceptual and conceptual priming across childhood. That is, is it possible to test conceptual priming in a way that is fair to both adults and children independent of pre-experimental knowledge? We advocate for attention to the basic *mechanisms* supporting priming as well as to the outcome of priming tasks. Given the vast age-related changes in semantic structures and general knowledge, future work aimed at investigating differences in conceptual priming needs to be first concerned with finding measures for which children of different ages have equivalent knowledge for the concept.

One way to achieve this goal would be to look at novel category learning. This would control the level of knowledge for each category for both children and adults. Additionally, this would allow for a paradigm that can test both conceptual and perceptual implicit memory in the same children while controlling exposure duration. To our knowledge, research has not yet been conducted with such a design. Rather, work with novel categories has focused on generalization and reasoning (e.g., Sloutsky, Kloos, & Fisher, in press) That is, instead of testing for priming effects, these studies have focused on the way that young children learn about classification of novel items. These stimuli should prove very useful in research on priming as well.

Age Differences in False Memory

Increases in conceptual priming with age are not an unmixed blessing. In the false memory illusion (e.g., Deese, 1959; Roediger & McDermott, 1995; for a review see Gallo, 2006), related lists of words are presented that center around a topic (e.g., bed, rest, dream). The critical theme word that ties the list together is never presented (e.g., sleep). Adults are very likely to falsely recognize or to recall the word "sleep" on a memory test, but children do so to a much lesser degree (e.g., Holliday & Weekes, 2006; Howe, 2006). As in Sloutsky’s work on categorization in young children, the false memory effect is an example of children outperforming adults on a memory task. It is assumed that one explanation for this pattern of results is that children do not have the semantic organization that would cause the word "sleep" to be more familiar after presentation of related words (e.g., Brainerd, Forrest, Karibian, 2006).

Another difference between children and adults in false memory may involve a shift from phonological to semantic processing across childhood. In work by Dewhurst and Robinson (2004), children (ages 5, 8, and 11) studied lists of categorized words and were then given a free recall task. The youngest children made significantly more phonological than semantic errors (e.g., were more likely to recall “head” after studying “bed” than to recall “sleep” after studying “bed,” “rest,” and “dream.”) The pattern was the opposite in 11-year olds: they were more likely to recall the semantically related words. Semantic and phonological errors were balanced for 8-year-olds. These results suggest that the way in which children are storing information shifts from a phonological to a semantic base over time.

Further evidence for links between categorization and false memory has been reported by Holliday et al. (2006). In these studies, participants receive lists of categorized words similar to those used in the DRM paradigm described above. Rather than taking a standard recognition test, in which the goal would be to respond “no” to a critical item such as “sleep,” participants are asked to take recognition tests that ask them not only to respond positively to items that were presented during the study phase but also to items that are semantically related to those that were studied. Between the ages of 5 and 14 there are dramatic increases in the likelihood of responding positively to words that are highly related (e.g., sleep). This suggests that children are better able to determine how items are related to one and other along semantic dimensions with increases in reasoning skills and better semantic knowledge. The finding also supports the possible reason for the equivalent category generation in children between the ages of 8-10 that was reported by Billingsly et al. (2002). That is, by middle childhood, there is a better semantic network from which to achieve conceptual priming.

The previous examples using the DRM paradigm highlights measures of memory change in which participants actively generate responses. Such situations are generally conceptualized as belonging to the class of explicit memory, although it is possible that related associates are automatically activated (Underwood & Riechardt, 1977). To date, only one study has looked at memory for critical lures using implicit memory techniques (Diliberto-Macaluso, 2005). In this work, fourth and fifth grade children performed stem completion tasks under either explicit or implicit instructions. That is, participants were either encouraged to complete the lists with words that had been presented earlier, or were simply told to list words that came to mind. The children showed high levels of priming for the critical words in both the explicit and implicit conditions. This result fits nicely with the results of Billingsly et al. (2002), who found intact conceptual priming in 8-10 year old children, and suggests that by age 10, semantic associations are better formed. More work along these lines with younger children would be welcome.

The Interaction of Priming and Explicit Memory

Although implicit and explicit memory may be functionally distinct (e.g., Rauch et al., 1997; Grafton, Hazeltine, & Ivry, 1995), in adults there is interplay between the two types of memory. For example, participants may use the experience of priming as a clue for explicit memory decisions. That is,

priming leads to an experience of processing fluency (e.g., Jacoby & Dallas, 1981; Morrell & Morton, 1974) in which things that have been experienced recently are perceived quickly and easily relative to novel items. Thus, ease of processing is a cue to recognition memory judgments. Adults readily apply this knowledge to memory decisions (e.g., Jacoby & Whitehouse, 1989; Rajaram, 1993; Unkelback, 2006; Westerman, 2001; Whittlesea & Williams 1998). The timing of the acquisition of this ability in childhood has yet to be fully determined but a few studies have begun to examine the trajectory of the understanding of the way in which recognition memory works.

Drummey and Newcombe (1995) showed a series of pictures to 3- and 5- year old children and an adult control group. Three months later, the children participated in both an implicit (identification) and explicit (recognition memory) task. Pictures were gradually made less blurry until a child recognized the item. At that time, the item was put into full focus and a recognition judgment was made. As mentioned earlier, both the adults and the children showed a priming effect, identifying pictures that had been presented during the study phase at a blurrier state than novel pictures. Only adults, on the other hand, used the priming from the identification task to guide recognition decisions. That is, the children were not more likely to recognize the items they were able to detect at a higher level of blurriness as having been presented. This result suggests the link between perceptual fluency and recognition memory is not evident in children until at least after the age of five.

Recent research by Guttentag and Dunn (2003) suggests that middle childhood is the time at which the link between fluency and recognition first appears. Similar to the procedure of Newcombe and Drummey (1995), participants (aged 4, 8, and adult) studied pictures during the encoding phase. During the recognition phase, the children had to identify the object as it came into focus. Some of these had been presented during the study phase and others had not. Again, children in both age groups (four and eight years of age) showed a priming effect. That is, pictures that had been seen recently could be identified at earlier levels of fragmentation (more degraded). However, only older children were more likely to recognize these items as having been presented earlier. That is, it isn’t until later in development that children realize the relationship between implicit memory effects (priming) and prior occurrence. The

time of this transition has yet to be fully identified although it seems to occur between 5 and 8 years of age, and is an important area for future research.

Presumably, the understanding of the relationship between prior exposure and ease of later recognition is an example of metamemory, knowledge of the way that memory works. Middle childhood is the developmental period during which we observe increases in various kinds of metamemory knowledge, such as expectations for the memorability of a stimulus (e.g., Ghetti, 2003; Ghetti, Papini, & Angelini, 2006; see chapter 6 on metamemory development). In these studies, participants study lists of items that are from two categories. One category has many exemplars (e.g., pictures of 20 different animals such as horse, bear, bird), termed "low salience," and the other has few exemplars (e.g., pictures of a car, hammer, house, and shoe), termed "high salience." The idea behind these designations is that items from a category with many exemplars will be less distinct than items from a category with fewer exemplars. Thus, when making a judgment about what has been presented before, participants can use their knowledge about the makeup of the study list to guide their decisions. During a recognition test, participants are better at rejecting lure items from the high salience category (e.g., a screwdriver, which is related to the items on the high-salience list) relative to lure items from the low salience category (e.g., cat). Ghetti and colleagues attribute this ability to a metacognitive knowledge that the unique exemplars are more memorable and thus are easy to reject on the test phase. At the age of 7, participants are in a transition state where they sometimes apply this knowledge and other times do not. By the age of ten, participants perform identically to adults on the recognition test. Thus, a part of memory development is understanding the way that previous experience relates to subsequent memory performance. Although young children are affected by prior exposure, as measured by many implicit tasks, they are not able to use this knowledge to guide memory decisions until several years later.

Summary

In summary, we can draw three conclusions on the development of priming. First, there is consistent evidence for developmental invariance of perceptual priming from 3 years on. However, perceptual priming at younger ages has not been extensively studied, so it is difficult to be sure that the system is as early appearing and evolutionarily basic as has been claimed. Second, performance on

conceptual priming tasks clearly changes with age. However, these age differences may derive from changes in conceptual knowledge or language development rather than from changes in the priming mechanism per se; studies using novel materials would be needed to assess this issue. In the case of false memory, perhaps ironically, increases in conceptual knowledge lead to decreases in accuracy**.** Finally, development of the relationship between implicit and explicit memory seems to occur in middle childhood, although evidence on this issue is quite sparse.

Sequence Learning and Statistical Language Learning

There are several other types of implicit memory as well as priming. We have chosen one of these types, sequence learning, as an example of another type of implicit memory measure that should be reviewed for evidence for developmental invariance or change. Statistical learning has received much recent attention in the area of language acquisition, but the paradigms used to investigate it have much in common with sequence learning tasks generally acknowledged to be implicit memory tasks.

Sequence learning refers to research in which the stimuli are presented in a pattern that is based upon some sort of statistical regularity or a rule. Typically, these studies train participants on a sequence of events and then test the learning that has occurred. These studies are considered implicit memory tasks because participants typically claim to be ignorant of the rules or regularities guiding the training materials. However, they are able to react more quickly for items that are consistent rather than inconsistent with the training stimuli (e.g., Nissen & Bullemer, 1987; Nissen, Willingham, & Hartman, 1989).

The few developmental studies we have of this kind of sequence learning do show age-related improvement. Thomas et al. (2004; also see Thomas & Nelson, 2001) tested children aged 7-11 and adults using a visual target detection paradigm. Participants were instructed to respond as quickly as possibly whenever a target appeared on the screen. During some blocks of trials, stimuli presentation was random. During other critical blocks of training, patterns in the stimuli order were present. Learning these patterns allowed both children and adults to respond more quickly when the target appeared, despite being unable to report the pattern. Thomas et al. collected both behavioral (learning curves and response times) and neurological data (fMRI). Both children and adults learned the sequence during critical trials, but the

magnitude and speed of improvement was larger for the adults. This suggests that children are capable of learning the sequence but do not do so as effectively as adults. Interestingly, the fMRI data showed both differences in the regions associated with learning in responses of the motor system. Thus, it may be that the age differences in speed of responding (a measure of priming) were partially due to differences in motoric responses. However, there may be other causes as well because the effects were still significant after controlling for this variable.

As with conceptual priming, a challenge in examining sequence learning is to devise ways to level the playing field for children and adults by selecting tasks that are equally suitable for each group. One example of a task that is suitable for very young subjects is work by Saffran and colleagues (e.g., Saffran, Aslin, & Newport, 1996; Thiessen, Hill, & Saffran; Thiessen & Saffran, 2003; also see Johnson & Jusczyk, 2001), who have focused on sensitivity to statistical regularities as a mechanism for understanding the development of language. In these studies, infants listen to a sequence of nonsense syllables governed by underlying statistical regularities. Consider the sequence "bidakupadotigolabubidaku." In this example, "bi" is followed by "da" whereas "pa" is followed by "do." During test, infants show a novelty preference for those sequences that violate the rules (e.g., "bido" or "pada"). That is, infants will pay attention longer or increase their rate of sucking on a pacifier when sequences are played that violate the rules established during the training phase relative to those that follow the established statistical regularities. This learning happens quickly, with only a few minutes of exposure to the training stimuli.

Such findings are widely viewed as giving insight into the nature of language learning, but they may also be a form of implicit memory (for a similar idea, see Perruchet & Pacton, 2006). Infants appear to be sensitive to the structure of the auditory sequences and use this information to notice violations from what has been previously presented. This form of learning seems to be present from early in development (e.g., 5 months). Further, the sensitivity to statistical regularity is not limited to the auditory domain. Work by Fiser and Aslin (2002) investigated visual sequence learning in infants. Like the work in the auditory modality, the results of these studies have shown that infants are able to detect regularities in their visual environment.

Why is there a difference between the auditory statistical learning data, which do not suggest changes in implicit memory and the visual sequence learning data, which do suggest changes across childhood? One possible explanation involves a shift from auditory dominance to visual dominance in memory (Napolitano & Sloutsky, 2004; Robinson & Sloutsky, 2004; Sloutsky & Napolitano, 2003). Using a recognition memory paradigm, Sloutsky and colleagues have found that whereas adults show a bias in memory towards visual stimuli (pictures of common objects), children do not show this bias. Rather, they seem to be biased towards the auditory information that was presented. In these studies, participants are presented with pictures of objects that are paired with an auditory stimulus. Participants have to make judgments for later pairings as to whether the object occurred with a certain sound during the study phase. These pairings may contain correct combinations, repairing, or may include a novel portion for the object or the sound. Relative to adults, children around the age of four perform better at recognizing when an auditory portion is new. That is, they are less susceptible than adults to falsely recognizing an old object with a new sound. Although this bias seemed to be absent by ages 7-11 (the age groups tested in the 2004 Thomas et al. study), it may be that for a paradigm such as sequence learning, the auditory modality dominance is longer lasting (e.g., Conway & Christiansen, 2005).

A second possibility for the discrepancy between auditory and visual sequence learning with regard to developmental invariance may be the nature of the response. In work in statistical language learning, infants do not have to actively make a response. In contrast, the visual sequence learning study required participants to point to a screen as quickly as possible after the presentation of a target stimulus. Perhaps if a natural response such as eye movements was measured, there may be evidence that adults and children perform equally well. Similarly, if older children were asked to discriminate rule abiding and rule violating sequences in a verbal forced choice discrimination (a task more active and thus more akin to the sequence learning task), it may be that developmental differences would emerge.

In summary, the results of statistical learning studies and of sequence learning studies seem to be in contrast, with early competence in the former and late learning in the latter. However, the claim of developmental invariance requires more than early competence; we need in addition to be concerned with the magnitude of effects. To date, the statistical learning work has not focused much on the issue of

comparative magnitude in adults and children. One recent study suggests possible developmental differences: Kam and Newport (2005) found that 5- to 7-year-old children were more likely than adults to regularize input containing inconsistent grammatical morphemes. A possible reason is that adults are striving to probability match their output with the input, while children who have less good sequence memory may simply adopt the predominant pattern. Obviously, however, artificial language learning is importantly different from other statistical learning studies, so it would be nice to have age-comparative studies that used more uniform methodologies and sampled ages more densely.

Neuroscience and Implicit Memory Development

Advances in neuroscience have been invaluable in understanding the neuroanatomy of memory systems. The explosion of research using imaging techniques such as fMRI and the wider availability of less expensive measurements such as eye tracking and ERP readings has allowed concrete descriptions of the time course and nature of implicit and explicitly memory (e.g., eye tracking: Richardson & Kirkham; 2004; ERP: Reynolds & Richards, 2005). For example, by comparing the fMRI scans of persons with known explicit but not implicit memory deficits (e.g., amnesics) to those with normal functioning in both areas, it may be determined what structures are necessary to support the two types of memory judgments. However, these advances in neuroscience also highlight some of the questions about the implicit/explicit distinction. That is, implicit memory covers several different types of memory judgments including priming, skill learning, and conditioning and each is generally associated with its own brain structures: neocortex, striatum, and amygdale/cerebellum, respectively (e.g., Squire & Zola, 1996). Perhaps the best opportunity offered by advances in neuroscience is for the memory community to stop lumping all these tasks together and instead look at each category of implicit memory and learning as its own entity.

We have chosen here to discuss the neuroscience of perceptual priming, where given the evidence of developmental invariance at the behavioral level, there is also some evidence for relative equivalence of physiological response in perceptual priming tasks. In a study with older (9 and 10 year old) participants, Fox and Newcombe (1994) showed photos of preschool classmates and novel children for an autobiographical recognition test. While performing the recognition test, skin conductance responses were measured. In general, participants were only slightly above chance in recognizing their classmates.

However, they did show evidence of implicit memory as evidenced by changes in skin conductance to novel and familiar faces. Further, this response was similar regardless of recognition memory performance. That is, whether or not participants were correctly identifying a person as a part of their past, they showed evidence of recognizing the face. Recently, these results have been replicated with younger children (26 –48 months) using a similar procedure (Stormark, 2004). In this study, children saw a slideshow containing photos of former nursery school classmates mixed with novel children. Similar to the results of Fox and Newcombe (1994), it was reported that children showed recognition differences in a skin conductance and heart rate measures even when they did not do so for explicit recognition judgments. That is, even though participants were unable to recognize their former classmates verbally, they showed physiological signs of recognition.

Evidence of implicit memory through a physiological response has also been reported in infants. Webb and Nelson (2001) collected ERP data from six month old infants while they were viewing a slideshow of upright and inverted faces. Some of these faces were repeated, allowing for an assessment of perceptual priming. Despite a relatively long list of items and a lag of up to 12 faces before repetition, infants still showed sensitivity to repeated stimuli. This is strong evidence for a very early emergence of repetition priming capability. Further, this study represents a gold standard in testing the idea of priming invariance. It demonstrates a method that is suitable across a wide age range and is not dependent upon the development of other abilities such as language or semantic knowledge. Thus, we now have the opportunity to evaluate the invariance claim by determining whether adults have a similar magnitude of response as children and even as infants.

All of these studies (Fox & Newcombe, 1994; Stormark, 2004; Webb & Nelson, 2001) are consistent with the idea that perceptual priming is a stable and early developing form of memory (Reber, 1993) whereas explicit memory is prone to significant growth across childhood. These results also fit well with the behavioral data suggesting invariance in perceptual priming as was concluded by Parkin (1998) in the first edition of the book. However, just as implicit memory development work was started after explicit memory development research, the application of cognitive neuroscience techniques to development is still in its earliest stages. We expect that the next decade will show a sharp increase in this

research as it becomes clearer what differences in implicit memory are reliable and will be useful for understanding memory development. For example, there is little if any work on several types of implicit memory in children including mere exposure effects, semantic priming, and savings.

Beyond typical development: Implicit memory in clinical populations

A final contrast between explicit and implicit memory development may be drawn from the results of studies examining memory differences in clinical populations. Although the initial contrast between implicit and explicit memory came from studies demonstrating amnesic patients who had intact implicit, but not explicit, memory (e.g., Graf & Schacter, 1985), recent work has looked at such a dissociation in other populations. In general, the findings both in adult and childhood disorders mirror that of patients with amnesia: a stability in implicit memory performance despite deficits in explicit memory performance (or a larger difference in explicit memory performance than in implicit memory performance)s. Intact implicit and damaged explicit memory finding has been demonstrated in a variety of populations including autism (Lopez & Leekman, 2004; Renner, Klinger, & Klinger, 2000), Tourette's syndrome (Channon, Pratt, & Robertson, 2003), schizophrenia (Clare, McKenna, Mortimer, & Baddley, 1993), ADHD (Aloisi, McKone, & Heubeck, 2004), congenital and acquired brain disorder (Yeates & Enrile, 2005), and Down's syndrome (Carlesimo, Marotta, & Vicari, 1997; Vicari, 2001). Like many typical memory development studies, however, there appears to be a focus on implicit memory as defined by priming effects.

There are some exceptions to the focus on perceptual priming measures of implicit memory in clinical populations. One is work on children with Tourette's syndrome. Stebbings et al. (1995) reported that these children had a deficit in rotary pursuit, a type of skill learning. Similary, work by Vicari (2001) showed that depending upon which implicit task was measured, children with Williams syndrome either had spared implicit memory (when measured by a repetition priming task) or were impaired relative to controls (when measured with a skill learning task). This finding continues a theme in the literature that the use of a broad definition of implicit memory may lead to seemingly contradictory conclusions about memory development. Further, it hints to the problem of over simplification of the simple implicit/explicit distinction especially now that it is clear that different anatomical structures map onto the

different types of implicit memory. Additionally, showing these dissociations between different disorders and their impact on implicit memory measures highlights the importance of understanding the way in which different neurological impairments change the type of memory that is impacted. Although this may seem to be an obvious conclusion, that different disorders have different memory outcomes, it is not what would be predicted if implicit memory is viewed as a unitary phenomenon.

Future research should continue to pursue the questions of dissociations of implicit and explicit memory and whether or not the former changes significantly throughout life. If it is the case that perceptual priming is unchanged with development, the question of why such a system has emerged may be important. Is it because perceptual priming is an easier form of memory (e.g., Ratcliff, McKoon, & Verwoerd, 1989)? Or may it be that the current techniques of assessing it are not sophisticated to detect subtle changes? A second line of research should be concerned with the parameters of the retention of implicit memory. Perceptual priming effects have been shown to last for as long as three years (Lie & Newcombe, 1999) and motor skills may be retained as long or much longer (as was implied by our opening sentence). But are there different time frames for decay as a function of implicit memory divisions? Determining the shape of such functions may also shed light on the issue of developmental invariance for implicit memory. Given the increase in interest in implicit memory development in the past ten years, we hope that some of these questions will soon be answered.

Conclusion

We wish to conclude the second edition of this chapter by noting the advances since the original edition. First, there does seem to be good evidence for developmental invariance in procedural (implicit) memory when it is strictly constrained to perceptual priming. Second, there is promising evidence that at least some kinds of implicit memory exist from the earliest points of life. However, the issue of possible variation in magnitude of effects still awaits full exploration. Finally, the last decade has seen many advances in the neuroanatomical underpinnings of implicit memory and supports striking differences among the different kinds of implicit memory. We encourage the view that each form of learning and memory operates independently (for a different view, see Gupta & Cohen, 2002), and may have different developmental functions. Relative to Ebbinghaus's groundbreaking work on explicit memory, which has

had over 100 years to be fully explained, the work on implicit memory has barely begun. Thus, it is not surprising that there is still much work to be done in order to determine the child’s path to fully functioning implicit memory.

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