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Infant visual recognition memory

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Abstract

Visual recognition memory is a robust form of memory that is evident from early infancy, shows pronounced developmental change, and is influenced by many of the same factors that affect adult memory; it is surprisingly resistant to decay and interference. Infant visual recognition memory shows (a) modest reliability, (b) good discriminant validity, with performance depressed by numerous peri-natal risk factors, including teratogens and premature birth, (c) good predictive validity, relating to broad cognitive abilities in later childhood, including IQ and language, and (d) significant cross-age continuity, relating to memory in later childhood (through at least 11 years). Infant visual recognition memory is related to, and may be to some extent accounted for by, processing speed, forgetting, and certain aspects of attention (particularly look duration and shift rate). There is growing evidence that infant recognition memory may be an early form of declarative memory that depends on structures in the medial temporal lobe.

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Introduction

Infant visual recognition memory is an early emerging and fundamental form of memory. Its defining feature, namely, responsiveness to novelty, reflects a core biological adaptation. And, in fact, the response to novelty is central to several

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prominent theories of cognitive development (e.g., Piaget, 1950) and intelligence (e.g., Sternberg, 1985). For Piaget (1950, 1952), knowledge structures are altered or elaborated by encounters with new events, through a process of accommodation. For Sternberg (1985, 1981), the ability to deal with novel task demands or situations plays a major role in the experiential portion of his triarchic theory of human intelligence. It has both a motivational aspect (interest or curiosity about new situations) and an information-extraction component (acquisition of novel information). Individual differences in infant visual recognition memory are meaningful, in that they correlate fairly well with several cognitive abilities in later childhood. Indeed, the response to novelty may constitute one source of the continuity in the nature of intelligence across the life span (Sternberg, 1985).

Research on infant visual recognition memory grew out of two seminal observations made by Robert Fantz. First, he observed that chimps showed differential visual fixation to paired stimuli, thereby opening the door to the study of visually directed behavior (Fantz, 1956). Second, he observed that preferences change over time and highlighted the importance of novelty (Fantz, 1964). He presented infants with one photo for 1 min, 10 times in succession. During each exposure, it was paired with a new one. Infants over 2 months of age gave decreasing attention to the constant pattern and increasing attention to the novel one, revealing a proclivity to attend to novel stimuli. This preference method is the backbone of the visual paired-comparison (VPC) task, the paradigm that revolutionized the study of visual recognition memory in infancy.

In this paper, we first provide a brief description of basic paradigms used to study visual recognition memory in infants, and then give an overview of the factors that influence performance, including data bearing on the nature of the infant's mental representation, and current findings on the long-term duration and short-term capacity of infant memory. Following this, we consider findings on individual differences in visual recognition memory, including reliability, stability, and discriminant validity. We then describe the predictive relations of infant visual recognition memory to intelligence and specific abilities in later childhood and consider some mechanisms that might account for these individual differences. Finally, we consider the evidence indicating that infant visual recognition memory is an early form of declarative memory and highly dependent on structures in the medial temporal lobe, in particular the hippocampus and/or surrounding cortices (the parahippocampal, entorhinal, and perirhinal cortex).

Basic paradigms

Fagan (1970), in extending Fantz's pioneering work on the study of recognition memory, developed the VPC task. In this task, infants are initially familiarized with two identical stimuli presented side-by-side (or a single visual stimulus) and then tested for recognition by simultaneously presenting the previously viewed stimulus along with a new one. Typically, infants look more on test at the new stimulus than the old one. Recognition memory is inferred from this differential responsiveness to the two test stimuli. The primary measure of recognition memory is a novelty score,

defined as the percentage of looking during the test that is directed to the novel target (Fagan, 1974; Rose & Feldman, 1990).

Preference for the novel stimulus is thought to arise when infants, having completed assimilation of the information in the familiar stimulus, turn their attention to encoding information in the new one. It is presumed that infants form a mental representation of the stimulus during familiarization. This presumption is based on the observation that attention wanes with the repetition of an event and recovers when the event changes. To explain this phenomenon, Sokolov (1963) proposed a comparator model in which a mental representation is formed over time. When infants first encounter a new stimulus, they try to match it with a stored representation. If a match is found, attention is inhibited. If no match is found, attention remains engaged until enough information is assimilated from the stimulus to render it no longer novel. Thus, preference for a new stimulus can be taken as evidence for a stored representation of the old one.

A transitory preference for the familiar stimulus is sometimes seen early in processing, or when infants are young, familiarization times brief, or stimuli complex. Regardless of circumstances, novelty responses generally emerge with lengthier familiarization times (Richards, 1997; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982; Wagner & Sakovits, 1986). As discussed below, infants will also sometimes revert to familiarity preferences as memory wanes (Bahrick, Hernandez-Reif, & Pickens, 1997; Bahrick, 1995; Courage & Howe, 1998, 2001).

To help ensure that novelty scores reflect processing and recognition memory, and not methodological factors, several controls are generally incorporated into VPC tasks. First, preliminary testing is done to ensure that, at the outset, members of each pair are approximately equal in attractiveness. Thus, the paired test stimuli are presented without any prior familiarization; if they are equivalent in attractiveness, infants' attention to each member of the pair will be roughly equivalent. Second, the familiarization stimuli are counterbalanced, so that each member of the pair serves equally often as familiar and novel across infants in a group. Third, on test, the left-right placement of the novel and familiar stimuli are reversed mid-way through to control for position preferences.

In a task similar to VPC, habituation, a stimulus is repeatedly presented until attention wanes. In the most common variants, trials continue until looking declines to some absolute value (e.g., two successive fixations of less than 4 s, see McCall, Kennedy, & Dodds, 1977) or, as is more often the case, declines to some relative value (e.g., three consecutive trials each 50% shorter than the first three trials). This latter variant is called the infant-controlled procedure (Horowitz, Paden, Bhana, & Self, 1972). Once attention has declined, a new stimulus is introduced. Memory is indexed by the extent to which attention recovers (or dishabituates) to the new stimulus. This recovery reflects discrimination of the old and new and, depending on the length of the intervening interval, immediate or delayed memory.

The advantage of VPC is that it requires the infant to remain in the testing situation for less time. This allows for the presentation of multiple problems within a single testing session without straining the infant's capacity for maintaining attention.

These simple assessments of recognition memory have revolutionized the scientific study of infant memory and cognition. They capitalize on a fundamental biological imperative—to detect and respond to something new in the environment. By varying the time allotted for familiarization, or studying the time taken to habituate, the VPC and habituation tasks have been used to assess developmental changes in speed of processing. By varying the study-test interval, retention has been measured. By introducing subtle differences between the familiar and test targets, stimulus discrimination and essential features of the remembered targets have been probed.

A thumbnail sketch of the characteristics of infant visual recognition memory

In this section, we will selectively and briefly review some of the central findings concerning visual recognition memory in infancy.

Immediate recognition

Much of the research on infant visual recognition memory has been concerned with factors that influence immediate recognition and how they change with age. Prominent among these factors are the time needed to encode what is seen (familiarization time) and stimulus complexity. With respect to familiarization time, it is now well established that older infants need less familiarization time than younger infants to achieve comparable novelty scores (e.g., Colombo, Mitchell, & Horowitz, 1988; Fagan, 1974; Richards, 1997; Rose, 1983; Rose et al., 1982). Studies that have examined performance as a function of age have found that (a) recognition memory increases systematically between three and twelve months (Richards, 1997; Rose, 1983; Rose et al., 1982), (b) less familiarization time is needed to achieve comparable novelty scores as age increases (Colombo et al., 1988), and (c) significant novelty scores can often be achieved within an age simply by increasing familiarization time (Fagan, 1974). In a study manipulating familiarization time explicitly, Rose (1983) tested 6- and 12-month-olds for recognition of 3-dimensional geometric forms. All infants were given four problems, one each with 10, 15, 20, and 30 s familiarization. Whereas 6-month-olds achieved significant novelty scores only after 20 and 30 s of familiarization, the 12-month-olds showed significant novelty scores at all familiarization times. Thus, the older infants recognized the stimuli with half the familiarization time required by the younger infants (10 vs. 20 s).

Stimulus preferences also change dramatically with age, with older infants preferring more complex stimuli than younger infants, such as patterns with greater numbers of elements or more angles (e.g., Brennan, Ames, & Moore, 1966; Fantz, Fagan, & Miranda, 1975; Karmel, 1969). In an elegant set of studies, Fagan (1970, 1971, 1972, 1974) showed the interplay of age, stimulus complexity, and familiarization time on recognition. First, he found evidence for an interaction of age and stimulus complexity, with older infants recognizing more complex stimuli than younger infants. He used three types of stimuli which, in order of increasing complexity, were: simple abstract patterns, each made up of very different elements; more subtle

patterns, created by re-arranging the same set of elements into different configurations (small squares rotated to form a matrix of squares or diamonds); and photographs of faces (a man and a woman). Whereas the simplest stimuli were recognized by 2–3-month-olds, the pattern re-arrangements were not recognized until 4 months, and the faces not until infants were 5–6 months of age. Second, he showed that the difficulty of the task was reflected in the increasing amount of time the 5–6-month-olds needed to recognize the more complex pairings: less than 4 s for simple patterns, close to 17 s for the more subtle patterns, and 20–30 s for photos of faces.

Overall, it is clear that recognition memory improves over the first year of life. Older infants recognize more complex stimuli and do so more quickly.

The nature of the representation

What features or characteristic of the stimulus are stored and recognized? Is there simply a veridical engram, tightly tied to the actual stimulus, or is a more flexible or abstract representation stored? The latter would seem to be the case, since numerous studies using the VPC task find that information is stored in a way that allows for recognition of instantiations of the stimuli that vary considerably from the original target. So, for example, 7-month-old infants recognize 3/4 poses of faces they have previously viewed only in frontal pose (Fagan, 1976; see also Cohen & Strauss, 1979), 6-month-olds recognize pictures and line drawings of 3-dimensional displays (Rose, 1977, 1983), and 6–10-month-olds form prototypes when viewing multiple exemplars from a single category (e.g., Roberts & Horowitz, 1986; Rubinstein, Kalakanis, & Langlois, 1999; Sherman, 1985) generalizing well beyond the stimuli they had seen. By 12 months, infants habituated to line drawings of common objects recognize versions that are missing 33%, 50%, and even as much as 66% of their contour (Rose, Jankowski, & Senior, 1997). Indeed, infants were even able to recognize the complements of 50% contour-deleted figures (i.e., figures that had the same global shape but contained none of the original elements), suggesting that the stimuli are represented mentally as configural wholes (see also Colombo, Freeseaman, Coldren, & Frick, 1995; Freeseaman, Colombo, & Coldren, 1993; Quinn & Johnson, 2000). There is also evidence that by the same age, 12-months, infants integrate information over space and time to extract information about shape (Rose, 1988). For example, after watching the contour of a shape being traced out by a moving point source of light, infants showed significant novelty responses when presented with two solid objects, one with the shape they had just seen traced and one with a novel shape.

It is clear that infants recognize instantiations of objects even when the input is degraded or considerably altered, and where the physical similarities between the original object and its depiction are quite different. Debate has often centered on whether the engram that provides the foundation for subsequent recognition is itself abstract, perhaps stored in a propositional format, or whether it is veridical, and infants extract the 'gist' of what they see (see also Edelman & Bulthoff, 1992 for a discussion of viewer-dependent and viewer-independent representations).

Recently, connectionist models have become popular for explaining how recognition can proceed based on partial input (Elman et al., 1997; Mareschal & French,

2000; McClelland, 2000; Shanks, 1997). Such models envision an event or object as represented by a pattern of activity over a set of processing units composed of three types: input (receive information from outside); output (send information outside the network); hidden (used in forming the internal representation). “The behavior of the network is determined by the connection weights between all the units. As the weights change the behavior changes. Hence, learning consists of adjusting the connection weights in the network” (Mareschal & French, 2000, p. 62). When previously learned information is encountered, the spread of activation across the units is repeated, leading to retrieval. In the case of partial information, retrieval occurs as long as a sufficient number of units are activated.

Delayed recognition and forgetting

Infants have been found to recognize what they’ve seen over surprisingly long time intervals. The most compelling evidence for long-term recognition comes from a set of studies by Fagan (1973), who exposed 4–5-month-olds to different stimuli for relatively lengthy familiarizations (2 min) and examined recognition after varying delays. Infants in one study were exposed to abstract patterns and tested for recognition after delays of 1 and 2 days (Fagan, 1973, Experiment 1). Infants recognized the patterns at both delays. In a second study, infants exposed to a photograph of a face (man or woman) recognized it after all delays tested: 1, 2, 7, and 14 days later (Fagan, 1973, Experiment 2). Thus, in these studies, recognition was demonstrated after delays of 2 days for abstract patterns and 2 weeks for faces. With habituation, where stimuli are assumed to have been thoroughly encoded, recognition for faces was found with delays of both 2 min and 24 h in 3-month-olds (Pascalis, de Haan, Nelson, & de Schonen, 1998), and with delays of 1 and 2 min in infants as young as 3 days (Pascalis & de Schonen, 1994; Slater, Morison, & Rose, 1984).

Once established, infant memories appear to be surprisingly resistant to interference. Three studies, all done with 3–4-month-olds, used a design with three phases: familiarization (or habituation)-interference-test (Cohen, DeLoache, & Pearl, 1977; Fagan, 1977; McCall et al., 1977). In the interference phase, there were variations in the duration of exposure to the distracter (20–40 s) and/or the similarity between distracters and targets. In one study (Cohen et al., 1977) neither variable had any effect on performance; in the other two, recognition was disrupted only when infants had thoroughly processed the distracters (McCall et al., 1977) or when the distracter was highly similar to the target (Fagan et al., 1977). Even then, the disruption was only temporary.

When memories seem no longer accessible, they nonetheless can often be re-instated by brief reminders (Cornell, 1979; Fagan, 1977; Martin, 1975). For example, Cornell (1979) found that, following a 48-h delay, a brief reminder was sufficient to re-activate a memory that had otherwise become unavailable (see also Fagan, 1977). Additionally, Martin (1975) found that 5-month-olds habituated faster to a stimulus on the second day than on the first day, suggesting that they had remembered the stimulus over the 24-h period. Also, memories are accessible after longer delays when familiarization is distributed over time (Cornell, 1980). When 5–6-month-olds were

given 20 s of massed practice (four 5-s exposures to a face, each separated by 3 s), they recognized it only when the delay was brief (5 s), but when given distributed practice (four 5-s exposures, each separated by 1 min), they recognized it even after delays of 1 h.

In an effort to specify more closely the temporal progression of the memory trace, two groups of investigators have increased the delay between familiarization and test to one or more months, delays considerably longer than those used in previous studies. In the first such study, Bahrick and Pickens (1995) examined 3-month-olds' retention of dynamic visual displays after delays of 1 min, 1 day, 2 weeks, 1 month, and 3 months. With 3–4 min of familiarization, infants showed significant novelty preferences at 1 min, null preferences (i.e., hovering around 50%) at 1 day and 2 weeks, and somewhat surprisingly, significant familiarity preferences at 1 and 3 months. This pattern of results, in which preferences show a transition from Novelty → Null → Familiarity with increasing delays, has now been reported in three other studies with infants of this age and with familiarization times as brief as 30 s (Bahrick, 1995; Bahrick et al., 1997; Courage & Howe, 1998, 2001). Moreover, Bahrick et al. (1997) found that preferences could be shifted upwards with a retrieval cue (e.g., from null back to novelty), indicating that the accessibility of the trace could be enhanced even after relatively long delays. This ordering of preferences found during memory decay, Novelty → Null → Familiarity, is just the reverse of that sometimes found during memory formation. The familiarity response, which appears either near the outset of the encoding process or the end of the decay process, is thought to index a partial or incomplete engram. The results from these studies indicate that memory traces remain viable over a considerably longer period than previously thought.

There is also evidence showing that retention increases over the first year of life, at least in instances where familiarization times are relatively brief (e.g., Cornell, 1974; Diamond, 1990; Fagan, 1972; Rose, 1981). For example, Cornell (1974) found that, with 10 s familiarization, 4-month-olds could not recognize faces after a 2-min delay whereas 5–6-month-olds could. Similarly, Rose (1981) found that 6-month-olds recognized patterns and faces (5 and 20 s, respectively) immediately, but not after a 2–3 min delay while 9-month-olds recognized the targets after all intervals. Finally, Diamond (1990) found that, after being habituated to objects, 4-month-olds recognized them after a 10 s delay, but not at delays of 15 s, 1 min, and 10 min. By contrast, 6-month-olds recognized them with delays up to 1 min and 9-month-olds recognized them with delays as long as 10 min. Although, as noted above, infants as young as 5–6-months can recognize stimuli for as much as two weeks when given extended familiarization (Fagan, 1973), shorter study times have predominated in the few studies to examine developmental trends. Overall, there is little systematic work on developmental changes in retention and the trade-offs between age, type of stimuli, number of stimuli, and familiarization time have not been well studied.

In general, recognition memory has been found to be surprisingly robust over periods of minutes, hours, and even weeks, resistant to interference, improved with distributed practice, and accessible after delays as long as one and three months. What

is lacking is a cohesive body of data on developmental changes in visual recognition memory which details how well, how long, and how much is remembered by infants of different ages.

How much information can infants keep in mind at once?

Short-term memory capacity, a central component of working memory, has only recently begun to be studied in infants. Thus far, to our knowledge, there are only two such studies. In one, Rose, Feldman, and Jankowski (2001b) used a span task to examine short-term memory capacity in infants at 5, 7, and 12 months. Infants were presented with sets of 1, 2, 3, or 4 items (colorful toy-like constructions); after all items of a set were presented, each was successively paired with a new one to test for recognition. Memory capacity, indexed by the highest number of items having a novelty score >55% in any one span, increased over the first year of life. While fewer than 25% of the sample at 5 and 7 months could hold 3–4 items in mind at once, nearly half could do so by 12 months. At all three ages, infants showed pronounced recency effects (better recognition for the final item), mirroring results common for older children and adults with other tasks of visual short-term memory (Logie, 1995). In the other study assessing short-term capacity, Cornell and Bergstrom (1983) assessed 7-month-olds' retention of a 3-item list over delays of 5 s, 1 min, and 5 min. Infants recognized two of the three items after the two shorter delays (exhibiting both primacy and recency effects) but only one item after the lengthier 5 min delay (exhibiting a primacy effect).

Together, these two studies suggest that number of items held in memory at one time increases with age and that infants hold more items over a shorter period than over a longer one.

Individual differences

Psychometric properties of visual recognition memory: reliability and stability

Much of the early work using the VPC task was experimental in nature, with studies designed to illuminate the cognitive capabilities of infants in general, and to describe how these abilities change with age. In such studies, variance associated with differences among individuals is disregarded because it is considered irrelevant 'noise'; the reliability and stability of the measures used is not an issue. When assessing individual differences, on the other hand, one must take into account such psychometric properties as reliability and stability. Reliability is the ratio of a measure's true variance to its error variance; it sets an upper limit on how well two measures can correlate with one another. Specifically, the maximum correlation that can be expected between two measures is the square root of the product of their reliability coefficients. A measure's stability, reflected in cross-age correlations, represents the degree to which individual differences in the characteristic being measured endure over time.

A measure's reliability can never be gauged directly, but can only be estimated (Nunnally, 1978). Several methods have been used. Low-end or conservative estimates, such as α coefficients and split-half reliability coefficients, examine the internal consistency of items within a battery and depend on inter-item correlations. For problems on the VPC task, both reliability coefficients have been disappointingly low. Average inter-item correlations have ranged from .02 for a battery of 9 problems in 8-month-olds (Rose & Feldman, 1987) to, at best, .24 for a battery of 10 problems in 7-month-olds (Colombo, Mitchell, O'Brien, & Horowitz, 1987). Alpha coefficients and split half reliabilities are correspondingly low (Fagan & McGraith, 1981; Mundy, Seibert, Hogan, & Fagan, 1983; Rose, Feldman, & Jankowski, 2001a).

Correlations between novelty scores on different problems may be low because of moment-to-moment fluctuations in attention, which is considerable in infants, or because each problem taps a somewhat different aspect of the same domain (Rose & Feldman, 1987, Rose, Feldman, & Wallace, 1988). In either case, composite scores comprised of multiple problems correlate with one another much better than do individual problems (because the error variances from individual problems cancel one another and enhance the true variance in the composite).

A better way to estimate reliability for novelty scores is with test-retest methods using composites. Moderate test-retest reliabilities have been reported for composites from the VPC task over periods of weeks and even months. For example, Colombo et al. (1988) found test-retest correlations from one week to the next of $r = .40$ and $.51$ at 5 and 7 months for composites of five problems; the test-retest correlation over the two month period (from 5 to 7 months) was $.34$. Rose and Feldman (1987) and Rose, Feldman, McCarton, and Wallace (1998) found month-to-month correlations ranging from $r = .30$ to $.50$ between 6, 7, and 8 months for composites of 6 and 9 problems. Since correlations are generally higher the shorter the test-retest interval, and these intervals are relatively long, the true reliability may be even higher than these estimates.

Overall then, the reliability of composites of VPC problems appears to be better estimated by test-retest methods than by measures of internal consistency.

Discriminant validity

Many factors known to increase risk for cognitive impairment in later childhood have also been found to depress infant visual recognition memory. Prematurity has been the most widely studied risk factor (e.g., Rose, Feldman, McCarton, & Wolfson, 1988; Rose, Feldman, Wallace, & McCarton, 1991; Rose et al., 2001a), although similar results have been found with other non-optimal perinatal circumstances, such as long labor and low Apgar scores (Caron, Caron, & Glass, 1983), as well as with genetic abnormalities, such as Down Syndrome (Cohen, 1981; Miranda & Fantz, 1974), prenatal exposure to various teratogens, such as cocaine (Jacobson, Jacobson, Sokol, Martier, & Chiodo, 1996; see also Singer et al., 1998, 1999) and PCB (Jacobson, Fein, Jacobson, Schwartz, & Dowler, 1985) and nutritional deficiency (Rose, 1994).

In the studies using preterms, infants have generally been tested at their corrected age, that is, age from the expected date of birth, so that performance differences are not confounded with biological maturity. In one of the earliest studies in this area, Sigman and Parmelee (1974) compared preterms (birthweight averaging around 1900 g) and full-terms at 4 months on four problems, each of which paired a previously exposed 24×24 checkerboard with a different novel stimulus. The mean novelty score for full-terms was higher than that for preterms, and while full-terms exhibited recognition memory, as indicated by a mean novelty score significantly greater than chance, preterms gave no evidence of recognition memory at all. Rose (1980) found similar results at 6 months, where preterms (birthweight averaging 1580 g) and full-terms were tested with abstract patterns and faces. In the first of two studies, where the two groups were given equivalent familiarization times (5 s for Abstract Patterns and 20 s for Faces), only full-terms exhibited significant novelty preferences. In the second study, where preterms were given more familiarization time (20 s for Patterns and 30 s for Faces), they showed recognition, with novelty scores that were above chance and comparable to those of full-terms. These findings were reinforced and extended in a study where 6- and 12-month-old preterms and full-terms were tested for recognition of 3-dimensional shapes after familiarization times of 10, 15, 20, and 30 s (Rose, 1983). At both ages, the preterms (birthweight averaging around 1800 g) exhibited significant novelty scores, but again needed longer familiarization time than full-terms to do so (30 vs. 15 s at 6 months; 20 vs. 10 s at 12 months). Thus, while both groups encode the stimuli faster as they got older, preterms continue to do so at a slower pace than full-terms.

These results were replicated in two recent longitudinal studies, both of which used fairly large cohorts. In the first study ($N \cong 100$), very low birthweight preterms (<1500 g at birth) and their normal full-term controls were seen at 7 and 12 months. There were 9 problems at 7 months, three each with 2-dimensional abstract patterns, photographs of faces, and 3-dimensional geometric forms as stimuli, with familiarization times of 5 s for abstract patterns and 20 s for each of the other two types of stimuli. There were also 3 problems at 12 months, all using geometric forms and all with 15-s familiarization. Preterms had lower novelty scores than full-terms at both ages (Rose et al., 1988; Rose, Feldman, Wallace, & McCarton, et al., 1991). In the second longitudinal study ($N \cong 200$), low birthweight preterms (<1750 g at birth) and their full-term counterparts were assessed at 5, 7, and 12 months. There were 9 problems at all ages, five with faces and four with abstract patterns, with familiarization times reduced between 7 and 12 months (from 5 to 3 s for patterns, and 20 to 10 s for faces). At all ages, preterms had lower novelty scores than the full-terms (Rose et al., 2001a).

Even within full-terms, various perinatal complications depress visual recognition memory. For example, Caron et al. (1983) found poor recognition memory for a heterogeneous group of full-terms who had experienced a variety of birth difficulties, such as low Apgar scores, abnormally long labor, being small-for-gestational age, etc. Additionally, Singer, Drotar, Fagan, Devost, and Lake (1983) found poor performance in a small group of organic failure-to-thrive infants.

Similar impairments have been found associated with Down Syndrome. In a classic study, Miranda and Fantz (1974) examined 3-, 5-, and 8-month-olds: infants with Down Syndrome showed significant novelty preferences at later ages than normal infants. Similarly, Cohen (1981) found slower habituation and less dishabituation at 4, 5, and 6 months in infants with Down Syndrome compared to normal controls.

Evidence that chemical teratogens impair visual recognition memory was reported by Jacobson et al. (1985), using a large sample of 123 7-month-olds exposed prenatally to PCB. They found that novelty scores decreased systematically, in dose-dependent fashion, as exposure to PCB increased. More recently, they also found lower novelty scores in infants who had experienced heavy prenatal exposure to cocaine (Jacobson et al., 1996; see also Singer et al., 1998, 1999).

Evidence that nutritional insult may impair infant performance comes from a study with a sample of 123 5–12-month-olds living in India (Rose, 1994). In this study, weight and length, two anthropometric measures commonly used to index nutritional status in developing countries, were related to visual recognition memory. Underweight infants not only showed poorer visual recognition memory than heavier infants, but also failed to show the clear age-related improvements found among the heavier infants. These effects held even after controlling for birthweight, previous illness, and parental education.

Overall then, there is now ample evidence that visual recognition memory is depressed by many of the same peri-natal insults (e.g., teratogens, premature birth) that put the infant at risk for later cognitive deficits.

Prediction

Relation of infant visual recognition memory to broad cognitive abilities in childhood

Infants' visual recognition memory reflects a truly cognitive effort, as indicated by its anticipation of later cognitive abilities. Measures of recognition memory (i.e., novelty scores) have substantial predictive validity for broad cognitive abilities such as IQ and language in later childhood. Indeed, the median predictive correlation of infant visual recognition memory with later cognition is around $r = .45$ (McCall & Carriger, 1993). The measures used as outcomes have included receptive and expressive language at 2.5, 3, 4, and 6 years (Rose, Feldman, Wallace, & Cohen, 1991; Rose, Feldman, & Wallace, 1992; Thompson, Fagan, & Fulker, 1991b), vocabulary scores at 4, 7, and 11 years (Fagan, 1984; Fagan & McGrath, 1981; Rose & Feldman, 1995), and IQ at 3, 4, 5, 6, and 11 years (DiLalla et al., 1990; Fagan & Haiken-Vasen, 1997; Rose et al., 1988, 1992; Rose, Feldman, Wallace, & McCarton, 1989, 1991; Rose & Feldman, 1995; Thompson et al., 1991b).

One of the first studies to show a relation between visual recognition memory and later cognition was by Fagan and McGrath (1981). These investigators presented follow-up data for four samples of children who had participated some years earlier in experimental studies on visual recognition memory (N 's ranged from 19 to 35). In the earlier studies, each subject had received two or three problems when they were between the ages of 4 and 7 months. Their infant scores correlated .33 to .66 with

performance on the Peabody Picture Vocabulary Test and/or other vocabulary scales administered when the children were between the ages of 4 and 7 years. These findings were confirmed in a later study (Fagan, 1984). Two additional studies, both using VPC problems from the Fagan Test of Infant Intelligence, have reported predictive relations between infancy and 3-year IQ. In one, DiLalla et al. (1990) found that visual recognition memory at 7 months (but not at 9 months) correlated .29 with 3-year IQ ($N = 208$ twin pairs). In the other, Thompson et al. (1991b) found that the scores obtained by averaging over administrations of the VPC tasks at 5 and 7 months correlated .25 with 3-year IQ and .30 with 3-year language proficiency ($N = 113$).

Two early studies by Rose and Wallace (1985a, 1985b) also found measures of visual attention related to later IQ. Both studies had relatively small samples, made up largely of preterms. In one (Rose & Wallace, 1985a), 6-month measures of visual recognition memory correlated between .53 and .66 with outcomes consisting of 2-year Bayley scores and 3-, 4-, and 6-year IQ ($N = 14$ –35). In the second (Rose & Wallace, 1985b), 1-year measures of visual recognition memory had similar correlations with these same outcomes ($N = 19$ –26).

These initial findings were confirmed in the large-scale longitudinal study discussed above of very low birthweight preterms (<1500 g at birth) and their full-term controls. Infants who had been given a battery of VPC problems at 7 and 12 months were followed to 11 years, with assessments at several intervening ages. For preterms and full-terms alike, 7-month visual recognition memory predicted Bayley scores at 2 years, and IQ at follow-up ages 3, 4, 5, 6, and 11 years: r 's ranged from .37 to .65 (Rose & Feldman, 1995; Rose, Feldman, & Wallace, 1988, 1992; Rose, Feldman, Wallace, McCarton, 1989, 1991). Visual recognition memory at 1 year predicted later IQ, but less strongly than the 7-month scores, possibly because the composite at 1 year comprised fewer problems. In this same study, visual recognition memory from both ages also predicted receptive and expressive language at 2.5, 3, 4, and 6 years, as measured with the Reynell Scales of Language Development (Reynell, 1969) and the Test of Language Development-Primary (Told-P; Newcomer & Hammill, 1982), and vocabulary at 11 years, as measured with the Peabody Picture Vocabulary Test (Rose & Feldman, 1995; Rose, Feldman, Wallace, & Cohen, 1991; Rose et al., 1992).

Importantly, these predictive relations between infant visual recognition memory and later IQ, language, and vocabulary were similar for the preterm and full-term groups, and were maintained after controlling for socio-economic status, maternal education, 7-month or 1-year Bayley, and medical risk (in the preterms). Moreover, the infant-childhood relations remained significant even when children with neurological handicaps and/or very low IQ (<70) were removed.

The ability of infant measures to predict later cognition suggests that the roots of later cognitive abilities can indeed be found in infancy.

Relation of infant visual recognition memory to other forms of memory in later childhood

Inasmuch as memory is a basic building block of cognition, infant recognition memory may predict broad cognitive abilities in childhood in part due to continuity

with later memory (Rose & Feldman, 1997). Indeed, there are now several studies showing cross-age continuity in this very basic cognitive ability (Colombo, Mitchell, Dodd, Coldren, & Horowitz, 1989; Thompson et al., 1991b; Rose & Feldman, 1995, 1997). First, Colombo et al. (1989) found that novelty scores on VPC tasks at 7 months (but not 4 months) were related to spatial memory at 16 months. In the spatial memory task, the toddlers had to find an object that was hidden under one of three cups; a 15 s delay intervened between the time the object was hidden and the infant was allowed to search. Infants who had higher novelty scores at 7 months were more successful on the memory task at 16 months ($r = .51$).

Second, Thompson et al. (1991b) constructed a composite score from VPC tasks administered at 5 and 7 months and found it to be related to measures of immediate and delayed memory in the third year of life. The measures of childhood memory were composites comprised of picture recognition and name-face association drawn from the Specific Cognitive Abilities Test (SCA: DeFries & Plomin, 1985; see also Thompson, Detterman, & Plomin, 1991a). In picture recognition, the child examines line drawings of 40 common objects for 1 min. Half the objects are then intermixed with an equal number of foils for a test of immediate recognition; the remaining half are presented 15 min later, intermixed with other foils, for a test of delayed recognition. Name-face association involves recalling the names associated with each of 8 photographs of adults faces. Higher novelty scores were associated with better recognition and recall at 3 years ($r = .30$).

Third, using age-appropriate versions of these same tasks of picture recognition and name-face association, Rose and Feldman (1995) found that 7-month visual recognition memory was related to memory at 11 years ($r = .28$). They also found (Rose & Feldman, 1997) that the same infant measure was related to 11-year measures of memory from a computer-administered battery, the Cognitive Abilities Test (CAT: Detterman, 1988, 1990). This test included measures of memory for spatial location and serial position, and a version of the Sternberg memory search task. Memory for spatial location was assessed by a learning task in which the child memorized the spatial position of all stimuli in increasingly larger horizontal arrays. Memory for serial position was assessed by a probed recall task in which stimuli were again displayed in a horizontal array; here, however, the array length remained invariant (6 stimuli) and the target and distracter stimuli changed on each trial. In the Sternberg task, the child held a set of 1–4 stimuli in working memory and then had to indicate whether a probe was or was not a member of the previously memorized set. The 7-month novelty score correlated .28 with a factor that included measures of 11-year memory from each of these tasks.

Thus, infant visual recognition memory relates to memory in childhood and adolescence.

Continuity in visual recognition memory per se

Infant recognition memory also relates specifically to later recognition memory. In the sample Rose and colleagues followed longitudinally to 11 years, the children were also assessed with a task modeled after one used by Fagan to measure visual recognition memory in 5-year-olds (Fagan, 1984). In this task, children were

presented with increasingly larger sets of cartoon faces. Recognition was tested at the end of each set by successively pairing each item with a novel one and asking the children to indicate which of the two they had seen earlier. Not only did the 7-month novelty score correlate with this 11-year measure ($r = .35$), but the continuity in visual recognition memory remained significant after controlling for all other measures of memory at 11 years (Rose, Feldman, Futterweit, & Jankowski, 1997). In other words, some of the variance in the infancy measure was related uniquely to later visual recognition memory.

Clearly then, there are enduring differences in the ability to retain information, and at least one aspect of this enduring difference may be quite specific – namely, visual recognition memory.

What factors might contribute to individual differences in infant visual recognition memory?

There are a number of factors that influence infants' performance on VPC tasks, any or all of which may contribute to individual differences. Among the most likely possibilities are forgetting, speed of processing, and attention deployment (see also Rose & Orlan, 2001; Rose & Tamis-LeMonda, 1999). We will consider each in turn.

Forgetting

While, as we have already noted, memory declines over time in infants, just as it does in older children and adults, there has been relatively little work concerning individual differences in retention. However, data from a study by Courage and Howe (2001) addresses this issue and suggests that differential forgetting could account for individual differences in infant performance. In that study, where 3.5-month-olds were assessed for retention after delays of 1 min, 1 day, and 1 month, a pretest was also included to identify individual differences in attentional style, as indicated by look duration. Based on the mean length of look on pretest, infants were identified as 'long-lookers' (above the groups' median) and 'short-lookers' (below the median). Whereas previous research had shown that short-lookers process stimuli more quickly and/or efficiently than long lookers (Colombo, 1993; Colombo, Mitchell, Coldren, & Freeseaman, 1991; Freeseaman et al., 1993), Courage and Howe (2001) found that short-lookers also retain the information better than long lookers, even over delays as brief as 1 min. These results suggest that forgetting could contribute to individual differences in visual recognition memory.

The possibility that individual differences in retention influence performance on the VPC task is also supported by the relations found between the infant task and memory in later childhood. As discussed earlier, measures of infant visual recognition memory were found associated with spatial memory at 16 months (Colombo et al., 1989), sequential memory at 6 years (Rose et al., 1992), immediate and delayed recognition and recall memory from the SCA at 3 and 11 years (Thompson et al., 1991b; Rose & Feldman, 1995), visual recognition memory at 11 years on a variant of the VPC task (Rose, Feldman, et al., 1997), and memory for serial position and spatial location from the CAT at 11 years (Rose & Feldman, 1997).

Speed of processing

The construct of processing speed is also often evoked as an explanatory mechanism for variation among infants on visual recognition memory (e.g., Colombo, 1993; Rose & Feldman, 1995, 1997; Rose et al., 2001a), although the definition and scope of 'speed' varies considerably. Processing speed is generally thought of as a basic aspect of the human cognitive architecture (Kail & Salthouse, 1994). Empirically, changes over age in speed of processing tend to be similar over a wide range of tasks (Hale, 1990; Kail, 1986, 1988), and deficits in processing speed are thought to underlie cognitive difficulties in many areas. In our own work, we have found that slower processing speed is an important contributor to the relatively low childhood IQ found in high-risk preterms (Rose & Feldman, 1996).

Since the stimuli used in most adult studies of visual recognition are relatively simple, the time allotted for encoding is not generally a prominent factor. In infants, on the other hand, there is evidence that processing speed plays a central role in performance on VPC tasks. Much of this evidence has been indirect, drawn from the pronounced sensitivity of infant performance to variations in familiarization time. As noted above, there are dramatic age-related decreases in the amount of familiarization time needed for infants to evidence significant novelty scores, and there is an apparent trade-off between the amount of time needed to recognize a target and its complexity. For many risk groups, poorer performance is tied to slower encoding of the target stimuli. As noted above, for low birthweight infants we found that performance can improve dramatically when familiarization times are increased (Rose, 1980, 1983). These findings are consistent with the literature showing that preterms are slower to habituate than full-terms (Ross, Auld, Tesman, & Nass, 1992; Spunnen, Kurtzberg, & Vaughan, 1985).

Recently, Rose and colleagues (Rose, Futterweit, & Jankowski, 1999; Rose and Orlian, 1997; Rose, Feldman, & Jankowski, 2002; Rose, Jankowski, & Feldman, 2002) devised a procedure to more directly gauge processing speed in infancy. In this task, a hybrid of the VPC and habituation tasks, infants see a series paired faces, one of which remains the same across trials while the other changes. Trials continue until infants reach a criterion of consistent novelty preference, defined as four out of five consecutive trials having a novelty score >55% (with looks directed toward both targets). Using this new procedure, an age-related decline in the number of trials to criterion was found in two studies, one with 5-, 7-, and 9-month-old full-terms (Rose et al., 1999), the other with a sample of preterms and full-terms followed longitudinally at 5, 7, and 12 months (Rose et al., 2002). In this latter study, although there were similar age-related improvements for the two groups, at each age preterms took longer to reach criterion than full-terms. This finding was consistent with those from earlier studies suggesting that preterms are slower at encoding. Importantly, those infants in the longitudinal study who took more trials to reach criterion also had lower novelty scores on a VPC task at each age: $r = -.24$, $-.23$, and $-.23$ at 5, 7, and 12 months, respectively (controlling for birth status: Rose, Feldman, & Jankowski, 2003). These findings reinforce the notion that processing speed plays an important limiting role in infants' recognition memory.

Another line of evidence supporting the idea that processing speed is an important contributor to infant visual recognition memory is the relation of infant performance on VPC tasks to measures directly tapping speed in later childhood (Rose & Feldman, 1995, 1997). In the 11-year follow-up mentioned earlier, there were measures of speed from both the paper-and-pencil SCA battery (match-to-sample and letter finding) and from the computerized battery of CAT tasks (decision time for short-term memory search and match-to-sample tasks, tachistoscopic threshold, simple and choice reaction time). Infant (7-month) visual recognition memory was related to these 11-year speed measures even with general cognitive ability (IQ) partialled, and the relations were as strong as they were to the 11-year memory measures.

Attention

Attention is a fundamental prerequisite for visual recognition memory, as it is for all cognitive functions. The way infants distribute their attention, as reflected in look duration and shift rate, has been found to relate to individual differences in visual recognition memory. As noted earlier, some infants, ‘short lookers,’ have characteristically short looks and high shift rates (frequent shifts of gaze between the paired targets), whereas other infants, ‘long lookers,’ have characteristically long looks and lower shift rates, that is, their looks tend to be more narrowly distributed. Both aspects of attention show marked age-related changes. Mean look duration decreases by as much as 40% from 5 to 12 months and shift rates increase by as much as 90% over the same period (Axia, Bonichini, & Benini, 1999; Colombo & Mitchell, 1990; Colombo et al., 1988; Rose et al., 2001a, 1999; Ruff, 1975). Over the same period, shorter looks and higher shift rates are consistently associated with better recognition memory (Rose et al., 2001a). Moreover, within an age, short lookers tend to process information faster than long lookers (Colombo, 1993; Colombo et al., 1991; Freeseaman et al., 1993; Jankowski & Rose, 1997; Rose et al., 1999), and retain information over longer delays (Courage & Howe, 2001).

There are at least two avenues by which individual differences in look duration and shift rate might influence performance on the VPC task. First, short lookers may be quicker to obtain information from the attended location, and shift their gaze more quickly because they are faster processors. If this is the case, then it is actually processing speed that drives look duration (Colombo et al., 1991; Freeseaman et al., 1993; Rose et al., 2001a). The idea that short lookers are fast processors derives from early studies linking look duration to the rapidity of habituation. Second, short lookers may be better able to inhibit or disengage attention because of faster maturation of the structures underlying inhibitory control, while long lookers become ‘stuck’ on one spot (Hood & Atkinson, 1993; Johnson, Posner, & Rothbart, 1991; McCall, 1994; McCall & Mash, 1995). This possibility is supported by findings that short lookers are faster than long lookers to change their focus of attention from a central target to a peripheral one when the central target remains on, in ‘competition’ with the peripheral one (Frick, Colombo, & Saxon, 1999). Ease of disengagement might facilitate the uptake of information by allowing for a broader distribution of attention (Jankowski & Rose, 1997; Jankowski, Rose, & Feldman, 2001). In effect then, short looks may be a by-product of the growth of inhibitory

processes. Shift rates, which account for additional variance in visual recognition memory, over and above that accounted for by look duration (Rose et al., 2001a) could additionally reflect the infant's propensity to more actively compare targets (Rose et al., 1988; Ruff, 1975).

Even within a look, there are fluctuations in attention that are differentially related to performance on VPC tasks. In particular, Richards (Frick & Richards, 2001; Richards, 1997) identified three sequential phases of attention in infants looks based on psychophysiological measures of heart rate. These are: (a) an orienting phase, where heart rate is at baseline, (b) a sustained attention phase, in which heart rate decelerates, and (c) an attention termination phase, where the heart rate accelerates, returning to baseline. When a stimulus is presented during the phase of sustained attention, infants recognize it with less familiarization time than they need when it is presented in other phases, suggesting that more focused cognitive activity might be expended in this phase, resulting in faster processing. One way such findings might help explain differences in visual recognition memory across infants would be if short lookers spent a greater proportion of looking time in sustained attention than did long lookers. However, in the one study that examined this issue to date, this was not the case (Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001).

Visual recognition memory as a measure of declarative memory

Until recently, the work on memory in infants and adults has proceeded along parallel tracks, in large part because differences in methods of study made it difficult to compare findings. While infant memory is studied exclusively with non-verbal methods, the adult work has used primarily verbal methods. A convergence between the two fields became possible with the development of animal models of memory, which rely on non-verbal analogues of adult memory tasks. With this advance, both fields could now use similar methodologies. This development has led to greater appreciation of the similarities between infant and adult memory, and to a cross-fertilization of ideas between the two fields. For example, some of the tasks traditionally used with human infants, such as VPC, are now used to study the effects of brain lesions in animals and adult humans. In this section, we first review the theoretical distinctions prominent in adult memory, and then consider the neurophysiological basis for visual recognition memory in humans and non-human primates.

Typologies of memory

Although it is still a matter of some debate (for overview, see Rovee-Collier, Hayne, & Colombo, 2001), adult memory is not generally considered a unitary ability. A number of different taxonomic systems for the classification of memory have been proposed, with each distinct type of memory serving different functions and characterized by different rules of operation (Sherry & Schacter, 1987). The two most

common distinctions are declarative (explicit) vs. procedural (implicit) memory (Schacter & Tulving, 1994; Squire, 1987). Declarative or explicit memory is characterized by memories accessible to conscious recollection and, according to Tulving (1985) includes memories for facts and general knowledge (semantic memory) and memories that are autobiographical, in that they refer to events one has personally experienced (episodic memory). Procedural or implicit memory is an umbrella category covering a number of disparate forms of memory, all of which share the property of being inaccessible to consciousness. Included here are memories involving knowledge of how to perform skilled activities, such as bike riding and typing, classical conditioning, and memories that are demonstrated by priming. In priming tasks, subjects are given brief perceptual exposure to a list of words, and then instructed to complete a word fragment or word stem with the first word that comes to mind. Priming is indicated when subjects use previously seen items in their responses more frequently than would be expected by chance.

The distinctions between declarative and procedural memory have been supported by research using subjects from three populations: adults with specific brain injuries; normal human adults with intact brains; and animals with induced brain lesions (Zola & Squire, 2000). First, declarative memory is severely compromised in amnesiacs, as was first shown in the landmark study of Scoville and Milner (1957), who found severe loss of recent memory in a patient (HM) who had undergone bilateral hippocampal lesions for the treatment of epilepsy. This study was the first to link severe memory loss with damage to the medial temporal lobe. Comprehensive testing of HM showed that perception and other aspects of cognition were otherwise normal. One of the first studies to show dissociation of memory systems in severely amnesic patients was that of Warrington and Weiskrantz (1970), who found that such patients failed tests of recognition or recall but succeeded on tests of priming. Such findings, which have become commonplace in more recent years, strongly suggest that there are two distinct memory systems that depend on different brain structures. Second, numerous studies have shown dissociations between the two types of memory in normal adults (for review, see Richardson-Klavehn & Bjork, 1988), with the same experimental manipulations having different effects on tasks of recognition and recall (declarative memory) on the one hand and priming (procedural memory) on the other. Third, animal models of amnesia have led to the identification of specific areas in the medial temporal lobe that, when lesioned, lead to impaired recognition and recall but do not prevent the normal development of procedural memory (see Nelson, 1997; Zola & Squire, 2000).

The fact that visual recognition memory as assessed with the VPC task emerges earlier than other abilities also considered to be dependent on the hippocampus and related structures (e.g., cross-modal transfer; deferred imitation; delayed non-match to sample), led to the suggestion that there may be two types of explicit memory (Nelson, 1997). In the early form (pre-explicit memory), found principally in the first 6–8- months of life, novelty preferences may be less mature form (Nelson, 1997; Webster, Ungerleider, & Bachevalier, 1991). Nelson (1997) considers the more mature form to involve other brain areas, including TE and additional structures of the limbic system (e.g., dentate).

Neuroanatomical basis for visual recognition memory

There are several lines of evidence indicating that recognition memory relies on the same brain substrate that underlies declarative or explicit memory, namely, areas in the medial temporal lobe, including the hippocampus, amygdala, and the perirhinal, anterior and parahippocampal cortices (for reviews see Nelson, 1995; Rovee-Collier et al., 2001). One line of evidence comes from studies of monkeys tested on VPC and delayed non-match-to-sample (DNMS) tasks; another comes from studies of adult human patients with acquired amnesia.

The VPC task, though widely used with human infants, has also proven useful for assessing visual recognition memory in monkeys. In adult monkeys, novelty preferences have been observed with delays of 10 s (Bachevalier, Brickson, & Hagger, 1993), 10 min (Buffalo et al., 1999), and 24 h (Pascalis & Bachevalier, 1999). Employing the same stimuli and procedures used with human infants, Gunderson and colleagues (Gunderson & Sackett, 1984; Gunderson & Swartz, 1985, 1986) found that, by 4 weeks of age, pigtail macaques could recognize patterns after 30 s delays (Gunderson & Sackett, 1984). By 6 weeks they could do so after a 24-h delay (Gunderson & Swartz, 1985). Moreover, with a fixed delay, older monkeys recognized the stimulus with less familiarization time than younger monkeys (Gunderson & Swartz, 1986), as is the case with human infants (Rose, 1983). Monkeys with lesions to the amygdaloid complex and hippocampus (Bachevalier et al., 1993, 1990; Pascalis & Bachevalier, 1999; Zola et al., 2000) and with lesions to the perirhinal cortex (Buffalo et al., 1999) have impaired performance on the VPC task, beginning with delays as brief as 10 s.

The DNMS task, another task commonly used to study visual recognition memory in non-human primates, has yielded findings that parallel those obtained with VPC. On each trial of this task, a single stimulus is presented and then, following a delay, it is paired with a new one. The monkey must reach for the new object to obtain the reward hidden beneath. Monkeys are trained until they come to systematically select the new object (non-match) and then are tested with trial-unique stimuli. (Given that motoric abilities develop earlier in non-human primates than in humans, this task has been more widely used to study visual recognition memory in infant monkeys than in human infants.) Monkeys with lateral medial temporal lesions that include the hippocampus have considerable difficulty on the DNMS task even with delays as brief as 15 s (e.g., Alvarez, Zola-Morgan, & Squire, 1995; Bachevalier & Mishkin, 1984; Malkova, Mishkin, & Bachevalier, 1995; Zola et al., 2000; Zola-Morgan & Squire, 1985), as do monkeys with lesions in the perirhinal cortex (e.g., Buffalo et al., 1999; Malkova, Bachevalier, Mishkin, & Saunders, 2001; Murray & Mishkin, 1998), while tasks indicative of implicit memory are spared.

The most comprehensive study to date used both the VPC and DNMS tasks and showed that visual recognition is impaired when lesions are limited to the hippocampal region (the hippocampus proper, the dentate gyrus, and the subiculum: Zola et al., 2000). This study examined performance in different groups of monkeys with lesions made either by an ischemic procedure, radio frequency, or ibotenic acid. Ibotenic acid, a relatively new method of creating lesions, has the advantage of dam-

aging cell bodies of the hippocampus while sparing white matter and adjacent structures. None of the lesions interfered with perception, the ability to respond to novelty, or immediate memory, as indicated by a high level of performance on VPC after a 1 s delay (mean novelty = 65%), a level of performance equivalent to that of controls. However, the performance of lesioned monkeys on the VPC task was poorer than that of controls at all three of the longer delays (10 s, 1 min, 10 min). On DNMS, the performance of control and lesioned animals was comparable at 8 s but then steadily diminished for lesioned animals as delays increased (15 s, 1 min, 10 min, 40 min), although to a lesser extent than was the case for performance on the VPC task. The results were similar no matter which of the three techniques was used to lesion the hippocampus. Because impairment was evident after shorter delays on the VPC task than on DNMS, the authors suggested that VPC is more sensitive to hippocampal damage than DNMS. Pascalis and Bachevalier (1999) corroborated the greater sensitivity of VPC in a study where lesions to the hippocampus and parahippocampal cortical areas were made neonatally and the monkeys tested as adults. The lesioned monkeys showed preference for novelty on the VPC task at delays of 10 s (indicating that they had no difficulty encoding the stimulus, or responding to novelty), but chance performance at all longer delays (30 s, 1 min, 2 min, and 10 min, 24 h). By contrast, the same animals showed normal performance on the DNMS task at all delays used (30 s, 1 min, 2 min, and 10 min).

The findings from monkeys are consistent with those from adult amnesia patients who have sustained damage to the temporal lobe. When given the same sort of paired-comparison problems used for infants and monkeys, these patients perform at only chance levels with delays of 2 min between familiarization and test (McKee & Squire, 1993). In a more recent study, recognition memory in amnesic patients was impaired with a delay as brief as 6–10 s (Buffalo, Reber, & Squire, 1998).

Finally, in both of our longitudinal studies with human infants, the preterms who had respiratory distress syndrome (RDS), a condition often associated with hypoxia, performed more poorly than other preterms on VPC tasks (Rose et al., 2001a, 2001b; Rose, Feldman, McCarton, & Wolfson, 1988). Since neurons of the hippocampus are particularly vulnerable to hypoxic/ischemic insult (Volpe, 1995) these findings raise the possibility that damage sustained by the hippocampus may underlie the difficulties of the preterms with RDS.

In sum, the task that has formed the cornerstone of much of the work on infant cognition turns out to be an extraordinarily sensitive measure of medial temporal lobe function and as such, may be an excellent measure of explicit memory (or pre-explicit memory in infants, Nelson, 1995).

Conclusion

Visual recognition memory is a robust form of memory that is evident from early infancy, shows pronounced developmental change, and is influenced by many of the same factors that affect adult memory. Infant visual recognition memory shows significant predictive relations to later measures of broad cognitive abilities (including IQ and language) as well as continuity with childhood memory and, specifically,

recognition memory. Individual differences in factors such as processing speed, attention, and retention, appear to underlie individual differences in infant recognition memory. There is growing evidence that infant recognition memory may be an early expression of explicit memory that depends on structures in the medial temporal lobe.

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