

Exploring Memory in Infancy: Deferred Imitation and the Development of Declarative Memory

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Imitation is an important means by which infants learn new behaviours. When infants do not have the opportunity to immediately reproduce observed actions, they may form a memory representation of the event which can guide their behaviour when a similar situation is encountered again. Imitation procedures can, therefore, provide insight into infant memory. The deferred imitation paradigm requires a modelled action to be reproduced following a delay, without prior motor practice. As such, deferred imitation procedures have been proposed to tap declarative memory abilities in non-verbal populations such as infants. Contrary to the popular belief that infants form sparse or ill-defined memories, deferred imitation research reveals that infants store and retrieve highly detailed memory representations. The specificity of detail encoded into the representation can, however, cause memory retrieval to fail at young ages. Developing the ability to identify event components which are central (the target stimulus) versus details which are peripheral (the exact context in which learning occurred) is therefore an important aspect of memory development. Using deferred imitation procedures to study the transition from constrained to flexible memory representations can thus facilitate our understanding of the development of declarative memory during the infancy period. Copyright © 2006 John Wiley & Sons, Ltd.

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Imitation is a powerful tool for learning that is employed throughout the lifespan. An infant babbling into a toy telephone is copying her parent's actions. A child learning a new nursery rhyme will reproduce the words and actions the teacher models. An adult who is unsure of the appropriate social behaviour on a formal occasion will watch how others behave and act accordingly. Social species have a

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vast potential to learn from the experience of others, both through covert observation and overt teaching. The acquisition of information through observational learning is, therefore, not only seen in humans. Chimpanzees, for example, learn to use tools and process food in complex ways by watching and imitating their conspecifics (Goodall, 1986; Itani and Nishimura, 1973). Observing and copying the actions of someone who has already mastered the solution to a novel problem is highly economical in contrast to trial-and-error learning, which can be slow and costly.

Although imitation is an important learning procedure at all ages, it has perhaps the greatest effect on learning and behaviour during the infancy period. For example, young Japanese macaques are more likely than older macaques to incorporate potato washing into their behavioural repertoires after observing conspecifics producing the behaviour (Kawai, 1965). Similarly, in studies of language acquisition, adult chimpanzees learn to use symbolic tiles to form sentences slowly and with great effort. In contrast, an infant who observed his mother being taught the use of these symbols fast became proficient at manipulating and combining the symbols (Rumbaugh and Savage-Rumbaugh, 1994). These studies suggest that infants in particular may be especially proficient at using imitation as a learning mechanism. Consistent with this idea, diary studies of human infants reveal that 12–18-month-olds learn 1–2 novel behaviours a day through observational learning (Barr and Hayne, 1996).

IMITATION AND COGNITIVE DEVELOPMENT

For developmental researchers, the importance of studying imitation is not simply to examine the acquisition of new motoric behaviours; it also provides insight into cognitive development in non-verbal populations. Using this procedure to examine cognitive issues requires a precise definition of imitation, the most appropriate of which is perhaps Thorpe's, which emphasizes the importance of novelty in the imitative act:

'the copying of a novel or otherwise improbable act or utterance, or some act for which there is clearly no instinctive tendency' (Thorpe, 1963, p. 135).

The first psychologist to realize the importance of imitation to studies of human cognitive development was Piaget (1962). Piaget emphasized deferred imitation, the ability to imitate an action from memory, as particularly important in establishing that mental representations (and not a type of behavioural echo) were being used to drive imitation. For example, infants frequently do not have the opportunity to immediately reproduce the actions they have observed, especially when the model is a peer producing the actions with objects. In this situation, the infant must create a memory representation of the observed actions that can guide his behaviour when he encounters these objects himself in the future. Through observations of his own children, Piaget concluded that deferred imitation was first evidenced between 18 and 24 months of age, marking the beginnings of representational cognition. According to Piaget, the co-development of deferred imitation, language, and object permanence reflected a stage-like change in the infant's ability to use and manipulate symbols. Prior to this stage, Piaget postulated that the infant did not have the cognitive structures necessary to store information and was limited to reproducing actions in the here-and-now.

Subsequent experimental studies indicated that Piaget's observational technique underestimated the abilities of infants and young children. Controlled experimental procedures, first used by Meltzoff (1985, 1988), fulfilled the requirement for novelty identified by Thorpe by directly linking imitative behaviour to a single novel learning experience. In the deferred imitation paradigm, an experimenter demonstrates a series of novel actions and the participant's ability to reproduce those actions is assessed either immediately or following a delay. The performance of infants in the demonstration condition is compared to the performance of an independent group of infants in a control condition who have not seen the target actions prior to the test (Barr and Hayne, 2000; Meltzoff, 1985). The deferred imitation paradigm can be contrasted with elicited imitation, a modification of deferred imitation developed by Bauer and colleagues (Bauer, 1996; Bauer and Mandler, 1989), in three key ways. In elicited imitation tasks, infants practice the demonstrated actions before the retention interval, raising the possibility that imitation after the delay reflects memory for self-produced actions. Furthermore, the demonstration period continues until the infant exhibits successful immediate imitation, creating the potential for large variations in experience with the stimuli. Finally, the demonstration is accompanied by narration, and infants are given verbal encouragement to produce the target actions during the test. This is in marked contrast to deferred imitation, where all infants receive the same amount of experience with the stimuli, no practice occurs before the retention interval, and no verbal cues are given at either encoding or retrieval. The extent to which these differences affect performance remains to be determined. However, the fact that deferred imitation employs fewer cues and aids to performance suggests that it provides the more rigorous test of infant memory for actions after a delay. The deferred imitation technique will therefore be the primary focus of this review.

Under controlled experimental conditions, infants as young as 6 and 9 months of age have been shown to exhibit deferred imitation of actions demonstrated with objects over a 24-h delay (Barr *et al.*, 1996; Collie and Hayne, 1999; Learmonth *et al.*, 2004; Meltzoff, 1988). When the demonstrated actions do not involve objects, imitation is seen even earlier. For example, 6-week-old infants imitate facial expressions over a 24-h delay (Meltzoff and Moore, 1994). However, it seems that imitating gestures is very different from imitating actions-with-objects. Actions-with-objects are imitated more than gestures by infants aged between 6 and 18 months (Abravanel *et al.*, 1976). Actions-with-objects involve a triadic interaction between demonstrator, observer and object, which requires a different type of joint attention than the dyadic interaction involved in imitating gestures. Furthermore, behaviours like facial movements and body gestures have a relatively high baseline rate, raising the possibility that 'imitation' of these actions is simply response facilitation (Byrne and Russon, 1998). Such criticism is harder to level at studies of imitation involving actions-with-objects, in which near-zero baseline rates indicate that the behaviours produced are novel to the infants (Hayne, 1998). Research examining imitation of actions-with-objects thus provides the most conservative estimate of imitative ability and cognitive processing.

In addition to pursuing the youngest age at which deferred imitation abilities are observed, interest has turned to the parameters and limits of this ability. Many researchers now suggest that deferred imitation is better viewed as a continuously developing ability rather than the stage-like development that Piaget proposed (e.g. Hayne, 2004; Rovee-Collier *et al.*, 2002). For example, infants' retention span and encoding speed gradually increase with age, and the

Table 1. Age-related changes in the encoding, retention and organization of memory traces in deferred imitation tasks

Age	Retention interval	Number of demonstrations required for this retention interval	Proportion retaining order information
6 months	24 h (e.g. Barr <i>et al.</i> , 2001; Barr <i>et al.</i> , 1996)	6 (90 s)	4/12 subjects (Barr <i>et al.</i> , 1996)
9 months	24 h (Collie and Hayne, 1999; Barr <i>et al.</i> , 1996)	3 (45 s)	14/31 subjects (Carver and Bauer, 1999)
12 months	1 week (Hayne and Campbell, 1997)	3 (60 s)	*
14 months	At least 1 week (Meltzoff, 1995)	1 (15 s)	70/90 subjects (Bauer <i>et al.</i> , 2000)
18 months	2 weeks (Hayne and Campbell, 1997; Herbert and Hayne, 2000a)	3 (60 s)	*
24 months	3 months (Herbert and Hayne, 2000a)	3 (60 s)	*

*No relevant data available.

order of event sequences is recalled more accurately with age (see Table 1). Such gradual changes suggest a continuous developmental progression in mnemonic processing.

IMITATION ACROSS SPECIES

Both animal imitation and neonatal human imitation literature feature discussion of whether or not a specific copying behaviour can be classed as true imitation (e.g. Tomasello, 1999; Meltzoff and Moore, 1997). Alternative explanations for a contingency between observer's and demonstrator's actions range from local/stimulus enhancement, where demonstrator's actions serve to increase interest in, and the spontaneous exploration of, the object, to emulation, where the observer learns how to solve the problem without copying the exact means by which the demonstrator reached the end goal. This distinction is held to be crucial because different forms of observational learning rely on different socio-cognitive mechanisms. With human infants, the use of appropriate control and baseline groups in most research using action-with-object imitation rules out the possibility of local/stimulus enhancement (see Meltzoff, 1985). The possibility of emulation rather than imitation remains more controversial. Comparisons between the order in which actions are demonstrated and reproduced provides a potential solution. Action sequences can be characterized as either enabling, where the order of the actions is constrained such that the performance of each action is dependent on the successful production of the previous action, or arbitrary, where the temporal order of actions has no effect on the final result (Barr and Hayne, 1996; Wenner and Bauer, 1999). Thus, in enabling sequences,

either imitation or emulation could lead to a match between the actions of the demonstrator and the observer. However, a match in the experimenter's and the observer's specific means and the end goal for arbitrarily ordered sequences suggests true imitation. Future across-species comparisons of performance with enabling and arbitrary sequences may thus provide insight into the cognitive process by which they learn and copy.

Irrespective of the debate surrounding the definition of true imitation, comparisons between the imitative abilities of infants and non-human animals can help identify developmental trajectories in representational cognition that may be unique to humans or common across species. Recent deferred imitation research with non-human primates has displayed striking similarities to the findings of developmental change obtained with human infants performing action-with-objects imitation. For example, encultured chimpanzees show gradual improvements over the juvenile period in the ability to defer imitation of actions-with-objects, as do human infants (Bjorklund and Bering, 2003; Barr *et al.*, 1996). This learning can also be generalized to novel-but-similar objects, as with older human infants (Bjorklund *et al.*, 2002; Herbert and Hayne, 2000b). Learning about event order is also not uniquely human, as monkeys can learn the order of a sequence of pictures after observing a conspecific perform the same task for a food reward (Subiaul *et al.*, 2004). In the human literature, imitating the order of an action sequence after a delay is seen as a key indication that performance relies on declarative memory (Bauer *et al.*, 2003). Whilst there are demonstrable differences in the facility with which primates and children imitate (for review see Whiten, 2002), such parallels suggest deferred imitation may rely on similar cognitive processes across species.

DEFERRED IMITATION AND DECLARATIVE MEMORY

The ability to perform deferred imitation provides a non-verbal index of recall because the infant is able to reproduce the actions of an event that is now absent (Meltzoff, 1990). As memory performance is based on a brief observation of the target actions, without prior motor practice or trial-and-error learning, many researchers have argued that deferred imitation provides a measure of declarative memory (e.g. Barr and Hayne, 1996; Hayne, 2004; Meltzoff, 1990). Declarative memories are memories for facts and events, often contrasted with non-declarative or procedural memories which involve the acquisition of habits and skills through recent or repeated exposure to a stimulus. The declarative and non-declarative memory categories were primarily established to explain the dichotomous performance of patients with temporal lobe amnesia on memory tasks. Temporal lobe amnesics perform normally on procedural memory tasks, but perform poorly on declarative memory tasks (for review see Squire, 2004), suggesting that the temporal lobe is crucial to declarative memory. The finding that patients with temporal lobe amnesia or developmental amnesia associated with a reduction in hippocampal volume also have difficulty with an adult-appropriate version of the deferred imitation task provides support for the idea that deferred imitation tasks are a non-verbal measure of declarative memory (McDonough *et al.*, 1995; Adlam *et al.*, 2005). Furthermore, the pattern of retention exhibited in the deferred imitation paradigm conforms closely to that seen in declarative memory paradigms. For example, retention is influenced by the age of participants, and the retention interval over which it is assessed (for review see Hayne, 2004; Rovee-Collier *et al.*, 2002).

CONTINUITY VERSUS CHANGE

Characterizing deferred imitation as a declarative memory task implies that age-related changes in performance may be attributable to changes in the medial temporal lobe. Early research suggested that structures in the medial temporal lobe that are crucial for declarative memory become mature in a step-change at around 9 months of age (Nelson, 1995). However, the continuity of change in early mnemonic abilities revealed by deferred imitation fails to support this view. More recent studies of brain maturation in both humans and primates support the idea of continuous change. Most of the hippocampus is cytoarchitecturally mature before birth, and adult levels of synaptic number and density are reached by around 6 months (Seress, 2001). In contrast, development of the dentate gyrus (a region that plays an important role in processing inputs to the hippocampus) is not complete until 4–5 years of age (Eckenhoff and Rakic, 1991). A recent review of the neurobiological basis of the development of declarative memory in human infants concludes that 'the medial temporal components of the network would be expected to reach maturity between the second and sixth postnatal month', with continuous development thereafter (Bauer, 2004, p. 360). Similarly, a recent review of the maturation of the hippocampal region in non-human primates concludes that 'although structural elements and synaptic connections necessary for memory formation are present in newborn primates, modifications of hippocampal circuits from birth to adulthood provide a basis for hippocampally dependent memory processes to continue to mature' (Bachevalier and Vargha-Khadem, 2005, p. 2). Seemingly, in infancy, gradual improvements in the deferred imitation task are matched by gradual development of the medial temporal structures that subserve declarative memory in adult humans.

REPRESENTATIONAL FLEXIBILITY

Representational flexibility, the ability to retrieve memories with cues and in contexts that are not identical to those originally encoded, is a crucial feature of declarative memory (Eichenbaum, 1997). Flexibility is central to the adaptability of learning and memory because it enables past experience to be applied to a range of future challenges that are unlikely to be perceptually identical to the initial learning episode. This requires the identification of the most important details of the learning phase, such that they can facilitate retrieval of that memory across changes in more peripheral details. While a vast range of stimuli are present during the deferred imitation demonstration (e.g. the target object, the demonstrator, features in the extended environment), only a few of these stimuli are truly central to the task itself. For example, the exact size and colour of the target object and the visual appearance of the room in which learning occurs are less crucial to the event than are the actions performed with the object. In order to create a flexible and functionally useful memory trace, the important features of the learning situation must be identified and given priority over the peripheral details in the ensuing memory representation.

Even early in infancy, highly specific details about the target stimulus are encoded into the memory representation. For example, 6-month-olds can defer imitation over a 24-h delay when they are tested with the original demonstration stimulus (Barr and Hayne, 1996; Hayne *et al.*, 1997). However, if the test stimulus differs in colour and form from the demonstration stimulus then 6-month-olds show no evidence of retention (Hayne *et al.*, 2000). This failure to generalize

reveals that each of these specific details were encoded into the infants' memory representation, but suggests that details such as the stimulus colour were encoded with equal importance as the target actions. With age, infants become increasingly able to exploit their knowledge with test stimuli that differ from the original demonstration stimuli. By 12 months of age, for example, infants can generalize across a change in colour but not a change in form, and by 18 months of age infants can generalize across changes in both colour and form (Hayne *et al.*, 1997).

Much like the ability to generalize across changes in the surface features of stimuli, flexibility across contextual change develops with age. Early studies of contextual flexibility were designed to identify the youngest age at which infants could defer imitation across a context change. For example, Hanna and Meltzoff (1993) demonstrated that 14-month-olds could generalize across a change from the laboratory to their home, or from daycare to home. Twelve-month-olds also show impressive contextual flexibility, transferring their knowledge from their home to the laboratory across a week-long retention interval (Klein and Meltzoff, 1999). However, younger infants have more difficulty generalizing across such large contextual changes. Whilst 6-month-olds can transfer their knowledge from one room to another in their home (Learmonth *et al.*, 2004), they fail to generalize across a transition from their home to the laboratory (Hayne *et al.*, 2000). Such studies reveal that even young infants encode contextual information into their memory representations, and illustrate the difficulties with identifying an age at which memory becomes flexible: infants of different ages can generalize across context changes of different type and magnitude.

Examining the ability of infants to retrieve memories across changes in contextual details can provide important information about which contextual attributes are encoded in the memory representation, how they are organized, and the nature of their relation to the representation of the focal cue. Recently, research has begun to move towards mapping out the parameters of a continuous change in contextual flexibility across the first two years of life. Learmonth *et al.* (2004) demonstrated that even 6-month-olds can generalize when both learning and retrieval occur in their home environment, perhaps because the cue is the only novel element in a highly familiar and well encoded environment and thus easy to identify. However, when a novel contextual element (such as a coloured mat) is introduced into the learning situation, the novel cue becomes harder to differentiate from the context which now contains novel and familiar aspects. When a change in the new contextual feature is coupled with a change in room, the magnitude of the context change is too great and generalization fails at 6 months. In contrast, 9- and 12-month-olds can generalize across minor and major contextual change in a familiar environment, and changes from a familiar to a novel environment (Hayne *et al.*, 2000; Klein and Meltzoff, 1999; Learmonth *et al.*, 2004).

HIERARCHICAL MEMORY TRACES IN INFANCY?

Deferred imitation research reveals that young infants are often constrained by the specificity of their memory traces, and that representational flexibility (along with changes in retention interval, speed of encoding and recall of order information) develops gradually through the infancy period. However, representational flexibility has not just been a focus in the developmental literature: recent research on memory has emphasized the centrality of contextual flexibility

to declarative memory across the lifespan. For example, patients with temporal lobe amnesia show deficits in contextual encoding and flexibility that are central to their memory problems (Chun and Phelps, 1999; Ryan *et al.*, 2000). Eichenbaum and Bunsey (1995) proposed that this inflexibility results from an enhanced tendency to fuse elements of an episode into a unitary representation, rather than encoding different details separately before relating them together in a meaningful framework. The ability to associate central and peripheral details together, but weight them appropriately, appears crucial to flexibly retrieving a declarative memory trace. Indeed, a recent review of the adult literature on the effects of environmental context change concluded that environmental-context-dependent memory effects were less likely to occur when the immediate environment was suppressed by encouraging deeper processing of the focal cue (Smith and Vela, 2001). In other words, when a memory trace is organized in a more hierarchical fashion, with greater weight given to the focal cue, memory is more flexible across a change in context. It may thus be that young infants show a lack of representational flexibility because they have difficulty in representing cue and context appropriately in their memory traces. Infants may give equal weight to information about the focal cue and the context surrounding it, tending to bind the information in a more unitary representation. A lack of hierarchical encoding can not only explain a lack of representational flexibility, but could also be a contributing factor in the longer encoding time required by young infants and the shorter duration of retention. A longer encoding period may be required because infants are equally attending to, and encoding, the cue and contextual details. Retention may also suffer because equal attention was given to contextual information which is more likely to change over time, making retrieval increasingly difficult. Across development, we suspect that infants become increasingly able to create hierarchical memory representations, facilitating faster encoding, longer retention spans and greater representational flexibility.

INDIVIDUAL DIFFERENCES

The majority of deferred imitation research has focussed on developmental change in the cognitive processes of infants as a population. However, if changes in deferred imitation performance reflect changes in underlying cognitive processes, then individual differences, longitudinal stability, and predictive validity are extremely important. Other early memory processes have been linked to later cognitive abilities (such as the relationship between early visual recognition memory and later mnemonic capabilities, for review see Rose *et al.*, 2005), but the recent emergence of deferred imitation as a paradigm for assessing cognitive processes means that this type of longitudinal research is largely absent in the deferred imitation literature. There is some evidence that recall as measured by elicited imitation tasks is a discrete component of infant cognition at 12 months (Rose *et al.*, 2004), but this finding does not necessarily generalize to the more restrictive deferred imitation paradigm. Several longitudinal studies have, however, begun to consider the stability of deferred imitation, and the relationship it has to other abilities. Individual differences on deferred imitation tasks are relatively stable from 12 to 24 months (Nielson and Dissanayake, 2004), and from 9 to 14 months (Heimann and Meltzoff, 1996). Deferred imitation strongly related to vocal comprehension in 14-month-olds, and deferred imitation at 9 months is a strong predictor of gestural production at 14 months (Heimann *et al.*, in press). This implies commonalities between the cognitive

processes underpinning language development, and those tapped by deferred imitation. Furthermore, at 21 and 24 months, deferred imitation and pretend play are strongly correlated, and deferred imitation at 15 months can predict pretend play ability at 18 and 21 months (Nielsen and Dissanayake, 2004). Pretend play is typically studied separately from deferred imitation, but it is clear that the skills involved (copying a gesture produced on an object with the same or a similar object after a delay) are very similar. A better understanding of the links between these fields may enhance our appreciation of the cognitive capacities that underlie both behaviours.

CONCLUSION

Studies using the deferred imitation paradigm have revealed continuity in the development of declarative memory over the first two years of life. However, there is much still to do. Priorities in this research area include promoting links between human and non-human research, considering the neurological basis of developmental changes in deferred imitation and increasing the focus on individual differences. Furthermore, examining the links between the development of deferred imitation and other motor/cognitive processes is an important area for future research. For example, at 9 months of age the onset of independent locomotion brings with it changes in representational flexibility (Herbert *et al.*, 2003). Developmental studies over the first year of life may reveal other important effects of motor development on performance in the deferred imitation task. Similarly, explorations of the effects of a range of contextual changes over different retention intervals are only just beginning. The current data suggests that memory representations become increasingly hierarchical over the first two years of life, and that research with the deferred imitation paradigm is ideally suited to continue investigating this process.

REFERENCES

- Abravanel E, Levan-Goldschmidt E, Stevenson MB. 1976. Action imitation: the early phase of infancy. *Child Development* **47**: 1032–1044.
- Adlam A-L, Vargha-Khadem F, Mishkin M, de Haan M. 2005. Deferred imitation of action sequences in developmental amnesia. *Journal of Cognitive Neuroscience* **17**: 240–248.
- Bachevalier J, Vargha-Khadem F. 2005. The primate hippocampus: ontogeny, early insult and memory. *Current Opinion in Neurobiology* **15**: 168–174.
- Barr R, Dowden A, Hayne H. 1996. Developmental changes in deferred imitation by 6- to 24-month-old infants. *Infant Behavior and Development* **19**: 159–170.
- Barr R, Hayne H. 1996. The effect of event structure on imitation in infancy: practice makes perfect? *Infant Behavior and Development* **19**: 253–257.
- Barr R, Hayne H. 2000. Age-related changes in imitation: implications for memory development. In *Progress in Infancy Research*, vol. 1, Rovee-Collier C, Lipsitt LP, Hayne H (eds). Erlbaum: Hillsdale, NJ; 21–67.
- Barr R, Vieira A, Rovee-Collier C. 2001. Mediated imitation at 6 months of age: remembering by association. *Journal of Experimental Child Psychology* **79**: 229–252.
- Bauer PJ. 1996. What do infants recall of their lives? Memory for specific events by one- to two-year-olds. *American Psychologist* **51**: 29–41.
- Bauer PJ. 2004. Getting explicit memory off the ground: steps toward construction of a neurodevelopmental account of changes in the first two years of life. *Developmental Review* **4**: 347–373.

- Bauer PJ, Mandler JM. 1989. One thing follows another: effects of temporal structure on one- to two-year-olds' recall of events. *Developmental Psychology* **25**: 197–206.
- Bauer PJ, Wenner JA, Dropik PL, Wewerka SS. 2000. Parameters of remembering and forgetting in the transition from infancy to early childhood. *Monographs of the Society for Research in Child Development* **65** (4, Serial No. 263), 1–204.
- Bauer PJ, Wiebe SA, Carver LJ, Waters JM, Nelson CA. 2003. Developments in long-term explicit memory late in the first year of life: behavioral and electrophysiological indices. *Psychological Science* **14**: 629–635.
- Bjorklund DF, Bering JM. 2003. A note on the development of deferred imitation in encultured juvenile chimpanzees (*Pan troglodytes*). *Developmental Review* **23**: 389–412.
- Bjorklund DF, Yungler JL, Bering JM, Ragan P. 2002. The generalisation of deferred imitation in encultured chimpanzees (*Pan troglodytes*). *Animal Cognition* **5**: 49–58.
- Byrne RW, Russon AE. 1998. Learning by imitation: a hierarchical approach. *Behavioural and Brain Sciences* **21**: 668–721.
- Carver LJ, Bauer PJ. 1999. When the event is more than the sum of its parts: nine-month-olds' long-term ordered recall. *Memory* **7**: 147–174.
- Chun MM, Phelps EA. 1999. Memory deficits for implicit contextual information in amnesic subjects with hippocampal damage. *Nature Neuroscience* **2**: 844–847.
- Collie R, Hayne H. 1999. Deferred imitation by 6- and 9-month-old infants: more evidence for declarative memory. *Developmental Psychobiology* **35**: 83–90.
- Eckenhoff M, Rakic P. 1991. A quantitative analysis of synaptogenesis in the molecular layer of the dentate gyrus in the rhesus monkey. *Developmental Brain Research* **64**: 129–135.
- Eichenbaum H. 1997. Declarative memory: insights from cognitive neurobiology. *Annual Review of Psychology* **48**: 547–572.
- Eichenbaum H, Bunsey M. 1995. On the binding of associations in memory: clues from studies on the role of the hippocampal region in paired-associate learning. *Current Directions in Psychological Science* **4**: 19–23.
- Goodall J. 1986. *The Chimpanzees of Gome*. Harvard University Press: Cambridge, MA.
- Hanna E, Meltzoff AN. 1993. Peer imitation by toddlers in laboratory, home, and day-care contexts—implications for social-learning and memory. *Developmental Psychology* **29**: 701–710.
- Hayne H. 1998. Out of the mouths of babes: a hierarchical view of imitation by human infants. *Behavioral and Brain Sciences* **21**(5): 692.
- Hayne H. 2004. Infant memory development: implications for childhood amnesia. *Developmental Review* **24**: 33–73.
- Hayne H, Boniface J, Barr R. 2000. The development of declarative memory in human infants: age-related changes in deferred imitation. *Behavioral Neuroscience* **114**: 77–83.
- Hayne H, Campbell BA. 1997. *Declarative memory during the first year of life*. Paper presented at the meeting of the Society for Neuroscience, New Orleans, LA.
- Hayne H, MacDonald S, Barr R. 1997. Developmental changes in the specificity of memory over the second year of life. *Infant Behaviour and Development* **20**: 233–245.
- Heimann M, Meltzoff AM. 1996. Deferred imitation in 9- and 14-month-old infants: a longitudinal study of a Swedish sample. *British Journal of Developmental Psychology* **14**: 55–64.
- Heimann M, Strid S, Smith L, Tjus T, Ulvund SE, Meltzoff AN. Exploring the relation between memory, gestural communication, and the emergence of language in infancy: a longitudinal study. *Infant and Child Development*, in press.
- Herbert J, Hayne H. 2000a. The ontogeny of long-term retention during the second year of life. *Developmental Science* **3**: 50–56.
- Herbert J, Hayne H. 2000b. Memory retrieval by 18- to 30-month-olds: age-related changes in representational flexibility. *Developmental Psychology* **36**: 473–484.
- Herbert J, Gross J, Hayne H. 2003. The effect of age and experience on deferred imitation in human infants. *Poster presented at the Annual Meeting of the International Society for Developmental Psychobiology*, New Orleans, USA.
- Itani J, Nishimura A. 1973. The study of infrahuman culture in Japan. In *Precultural Primate Behaviour*, Menzel E (ed.). Karger: Basel Switzerland; 127–141.

- Kawai M. 1965. Newly acquired pre-cultural behaviour of the natural troop of Japanese monkeys on Koshima Islet. *Primate* 6: 1–30.
- Klein P, Meltzoff AN. 1999. Long-term memory, forgetting and deferred imitation in 12-month-old infants. *Developmental Science* 2: 102–113.
- Learmonth A, Lamberth R, Rovee-Collier C. 2004. Generalization of deferred imitation during the first year of life. *Journal of Experimental Child Psychology* 88: 297–318.
- McDonough L, Mandler JM, McKee RD, Squire LR. 1995. The deferred imitation task as a nonverbal measure of declarative memory. *Proceedings of the National Academy of Science* 92: 7580–7584.
- Meltzoff AN. 1985. Immediate and deferred imitation in fourteen- and twenty-four-month-old infants. *Child Development* 56: 62–72.
- Meltzoff AN. 1988. Infant imitation and memory: nine-month-olds in immediate and deferred tests. *Child Development* 59: 217–225.
- Meltzoff AN. 1990. The implications of cross-modal matching and imitation for the development of representation and memory in infants. In *The Development and Neural Bases of Higher Cognitive Functions*, Diamond A (ed.). New York Academy of Science: New York; 1–31.
- Meltzoff AN. 1995. What infant memory tells us about infantile amnesia: long-term recall and deferred imitation. *Journal of Experimental Child Psychology* 59: 497–515.
- Meltzoff AN, Moore MK. 1994. Imitation, memory, and the representation of persons. *Infant Behaviour and Development* 17: 174–186.
- Meltzoff AN, Moore MK. 1997. Explaining facial imitation: a theoretical model. *Early Development and Parenting* 6: 179–192.
- Nelson CA. 1995. The ontogeny of human memory: a cognitive neuroscience perspective. *Developmental Psychology* 31: 723–738.
- Nielson M, Dissanayake C. 2004. Pretend play, mirror self-recognition and imitation: a longitudinal investigation through the second year. *Infant Behavior and Development* 3: 342–365.
- Piaget J. 1962. *Play, Dreams and Imitation in Childhood*. Norton: New York.
- Rose SA, Feldman JF, Jankowski JJ. 2005. The structure of infant cognition at 1 year. *Intelligence* 33: 231–250.
- Rose SA, Feldman JF, Jankowski JJ. 2004. Dimensions of cognition in infancy. *Intelligence* 32: 245–262.
- Rovee-Collier C, Hayne H, Colombo J. 2002. *The Development of Implicit and Explicit Memory*. John Benjamins Publishing Company: Amsterdam, Netherlands.
- Rumbaugh DM, Savage-Rumbaugh ES. 1994. Language in comparative perspective. In *Animal Learning and Cognition*, Mackintosh NJ (ed.). Academic Press: San Diego, CA; 307–333.
- Ryan JD, Althoff RR, Whitlow S, Cohen NJ. 2000. Amnesia is a deficit in relational memory. *Psychological Science* 11: 454–461.
- Seress L. 2001. Morphological changes of the human hippocampal formation from midgestation to early childhood. In *Handbook of Developmental Cognitive Neuroscience*, Nelson CA, Luciana M (eds). The MIT Press: Cambridge, MA; 45–58.
- Smith S, Vela E. 2001. Environmental context-dependent memory: a review and meta-analysis. *Psychonomic Bulletin and Review* 8: 203–220.
- Squire LR. 2004. Memory systems of the brain: a brief history and current perspective. *Neurobiology of Learning and Memory* 82: 171–177.
- Subiaul F, Cantlon JF, Holloway RL, Terrace HS. 2004. Cognitive imitation in rhesus macaques. *Science* 305: 407–410.
- Thorpe WH. 1956/1963. *Learning and Instinct in Animals*. Methuen: London.
- Tomasello M. 1999. Emulation learning and cultural learning. *Behavioral and Brain Sciences* 21: 703–704.
- Wenner JA, Bauer PJ. 1999. Bringing order to the arbitrary: one- to two-year olds' recall of event sequences. *Infant Behavior and Development* 22(4): 585–590.
- Whiten A. 2002. Imitation of sequential and hierarchical structure in action: experimental studies with children and chimpanzees. In *Imitation in Animals and Artifacts*, Dautenhahn K, Nehaniv CL (eds). MIT Press: Cambridge, MA; 191–209.