Infant and Child Development
*Inf. Child Dev.* **15**: 207–210 (2006)
Published online in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/icd.437

**Commentary**

# *Mechanisms of Change: Exploring not only When and What, but also How Declarative Memory Develops*

**Jenny Richmond* and Tracy DeBoer**
*Institute of Child Development, University of Minnesota, USA*

**Age-related changes in representational flexibility are a characteristic feature of declarative memory development. The authors suggest that a qualitative shift in the nature of infants' memory representations accounts for increasing memory flexibility with age. We will argue that a comprehensive theory of declarative memory development must (1) account for the effect of experience on flexibility, (2) be empirically separable from more parsimonious explanations, and (3) propose a mechanism by which the transition takes place. We will argue that a converging-methods approach is necessary to understand not only when and what develops in declarative memory, but also how developmental change occurs. Copyright © 2006 John Wiley & Sons, Ltd.**

*Key words:* imitation; declarative memory; flexibility

To date, much of the research investigating infant memory has focused on determining when declarative memory develops. Some researchers argue that declarative memory does not come online until the end of the first year of life (e.g. Nelson, 1995; Bauer, 2004), while others dispute the claim that there is a qualitative shift in the nature of infants' memory across this period (e.g. Rovee-Collier, 1997; Hayne, 2004). Studies using the deferred imitation task, which is considered by many to be a non-verbal measure of declarative memory, have been relied on heavily in this debate.

Evidence from deferred imitation studies has shown that declarative memory abilities are evident in infants as young as 6-months of age, as they are able to recall individual actions over a 24-hour delay (Hayne, 2004). It is not until 9-months of age, however, that infants are able to remember the temporal order of actions over long delays (Bauer, 2004). Although 6- and 9-month-old infants exhibit rudimentary declarative memory abilities, considerable age-related changes in deferred imitation performance occur across infancy and into early

*Correspondence to: Jenny Richmond, Childrens Hospital Boston, Harvard Medical School, USA. E-mail: jenny.richmond@childrens.harvard.edu

childhood. As such, the focus of empirical research has now shifted from identifying when declarative memory develops to characterizing what develops.

Age-related changes in representational flexibility are a characteristic feature of declarative memory development (Hayne, 2004). With age, infants are increasingly able to retrieve memories for imitation events despite changes in the event cue and/or context. The authors suggest that a qualitative shift in the nature of infants' memory representations accounts for this increasing memory flexibility. Younger infants bind components of the event together into a unitary representation, such that retrieval is precluded if any aspect of the event is changed between the demonstration and the test. Older infants, on the other hand, are able to relationally organize components of the event and weight them in a hierarchical manner, so that the cue and actions are given greater priority than details of the context.

## DOES EXPERIENCE MATTER?

The authors' suggest that maturational changes are responsible for a shift from unitary to hierarchical representations with age. The theory does not account for the way in which experiential factors interact with age to affect infants' memory flexibility. Both experience that is provided by the experimental situation, such as verbal cues and practice (for review, see Hayne, 2004), and experience that the infant brings to the imitation task, such as locomotor ability (e.g. Herbert *et al*., 2003), have been shown to facilitate infants' memory flexibility. In the case of verbal cues and practice at least, the authors' theory would suggest that these variables call infants' attention to the focal aspects of the event, facilitating the formation of a hierarchical representation. It is equally plausible, however, that infants' exhibit enhanced flexibility under these conditions because verbal cues and practice allow them to encode a richer representation of the event. In the case of locomotor development, the mechanism by which this global, non-task-specific experience brings about a change in the way infants' memory representations are organized is not specified. A comprehensive theory of development needs to account for not only maturation, but also for how maturation and experience interact to contribute to age-related changes in declarative memory.

## HOW CAN THE THEORY BE EMPIRICALLY TESTED?

A useful theory must be empirically testable and potentially falsifiable. In the case of the present theory, it needs to be made clear how a shift from unitary to hierarchical representations could be empirically distinguished from alternative possibilities, such as the one mentioned above (i.e. that changes in the richness of the representational content account for age-related changes in flexibility).

Given the methods available for use with human infants, how could we test the hypothesis that younger and older infants differ in the nature of the representations that they form of imitation events? We would likely need not only a measure of the overt behaviour but also an index of the underlying processes, be they attentional, cognitive, or neural that are associated with the behaviour. For example, continuous electroencephalogram (EEG) recordings may give some insight into age-related differences in the synchronous brain activity that is associated with item/context binding. Studies with adults have shown

 

that the coherence of theta-band activity (4–8 Hz) between frontal and posterior leads during encoding predicts the subsequent recall of item/context associations (Summerfield & Mangel, 2004). By measuring continuous EEG from infants during the demonstration phase of an imitation event, it may be possible to distinguish patterns of brain activity that are associated with item/context binding in infants. Age-related changes in the coherence of this activity may be indicative of differences in the nature of infants' representations, and may point to a mechanism by which the nature of memory representations changes with age.

## WHAT IS THE MECHANISM OF CHANGE?

Although the target paper makes great strides in describing *what* develops in declarative memory, it is also important to consider *how* such change occurs. In other words, the theory must propose a mechanism by which the shift from unitary representations to hierarchical representations occurs with development. The paper draws on the suggestion that the hippocampus forms representations that are relational in nature, while the parahippocampal cortex fuses components of an event into a single representation (Eichenbaum & Bunsey, 1995). While most of the hippocampus is functionally mature very early in development, the dentate gyrus has a relatively protracted period of development. Although 70% of the cells that make up the dentate are in place at birth, cell migration continues until the 8th postnatal month, and synaptic connections are not mature until early childhood (Seress, 2001). This relatively protracted time course of development may at least in part explain age-related changes in memory flexibility. It is possible that in the absence of mature hippocampal function, younger infants rely more on parahippocampal cortex, forming representations in which aspects of the cue, actions, and context are fused. With continued development of the dentate gyrus, however, older infants are able to recruit hippocampal circuitry to form representations in which the cue, actions, and context are encoded separately but associated in a relational manner, thus allowing flexible retrieval.

The authors extend Eichenbaum's fused vs relational distinction to propose that flexible memory expression also requires that the components of a relational representation are weighted and organized hierarchically. At present it remains unclear how the authors' unitary vs hierarchical dichotomy better accounts for the developmental data than does Eichenbaum's fused vs relational dichotomy. If it is the case that there is a shift from unitary to hierarchical representations with age, the theory must propose a neural mechanism by which hierarchical representations are formed. Specifically, what is the brain system that is responsible for identifying the important components of an event and subsequently weighting components within a relational representation? Furthermore, how does this interact with the hippocampus and what is the developmental time course relative to parahippocampal and hippocampal circuits?

## OVERVIEW

The authors suggest that a shift from unitary to hierarchically organized memory representations accounts for age-related changes in infants' memory flexibility. We have argued that the theory must (1) account for the effect of experience on

 

flexibility, (2) be empirically separable from more parsimonious explanations (i.e. that the representations become more rich or simply relational) and (3) propose a mechanism by which this qualitative transition takes place. Researchers in the field must use converging methods and multiple levels of analysis in order to begin to understand not only when and what develops in declarative memory, but also how developmental change occurs.

## ACKNOWLEDGEMENTS

The preparation of this article was supported in part by a grant from the McDonnell Foundation to J. Richmond and a University of Minnesota dissertation fellowship to T. DeBoer. The authors would like to thank Dr Charles A. Nelson for his comments on a previous version of this manuscript.

## REFERENCES

Bauer P. 2004. Getting explicit memory off the ground: steps toward construction of a neuro-developmental account of changes in the first two years of life. *Developmental Review* **24**: 347–373.

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.

Hayne H. 2004. Infant memory development: implications for childhood amnesia. *Developmental Review* **24**: 33–73.

Herbert J, Gross J, Hayne H. 2003. *The Effect of Age and Experience of Deferred Imitation in Human Infants*. International Society for Developmental Psychobiology: New Orleans, LA.

Nelson C. 1995. The ontogeny of human memory: a cognitive neuroscience perspective. *Developmental Psychology* **31**: 723–738.

Rovee-Collier C. 1997. Dissociations in infant memory: rethinking the development of implicit and explicit memory. *Psychological Review* **104**: 467–498.

Seress L. 2001. Morphological changes of the human hippocampal formation from midgestation to early childhood. In *Handbook of Developmental Cognitive Neuroscience*, Nelson C, Luciana M (eds). MIT Press: Cambridge, MA.

Summerfield C, Mangels J. 2004. Coherent theta-band EEG activity predicts item-context binding during encoding. *Neuroimage* **24**: 692–703.

 