Memory and Early Brain Development

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Introduction

Memory is a fundamental capacity that plays a vital role in social, emotional and cognitive functioning. Our memories form the basis for our sense of self, guide our thoughts and decisions, influence our emotional reactions, and allow us to learn. As such, memory is central to *cognition* and cognitive development. Yet, historically, it was believed that children under three or four years were unable to form stable representations of events and thus, were unable to remember them. This belief came in part from findings that adults rarely recall personal events from before the age of 3½ years (a phenomenon known as *infantile or childhood amnesia*). However, research with infants and young children has made it clear that they can and do form memories of events. This research, coupled with studies from behavioural neuroscience (using animal models) and developmental neuroscience (using *electrophysiology* and *neuroimaging*), has given us insights into the ways in which memory, and the brain structures that support it, change with development.

Subject

There are many ways to divide the construct of memory. For example, we distinguish *working memory*, which allows maintenance of representations for seconds, and *long-term memory*, which allows us to remember events over a life-time. Long-term memory can be further divided into two types: non-declarative (or implicit) and declarative (or explicit). Non-declarative memories are inaccessible to conscious awareness and include skill learning (e.g., knowing how to ride a bike) and priming (i.e., facilitated processing of a stimulus as a function of prior experience with it). Non-declarative memory is apparent virtually from birth. For example, infants show more robust processing of faces they have seen before relative to novel faces. However, when most people think of memory or "remembering" they think of declarative memories. Declarative memory requires conscious recollection and includes the recognition and recall of names, objects, and events. This chapter is a review of what we know about declarative memory development in typically developing infants, and the relations between declarative memory and brain development.

Problems

Studying the development of declarative memory and the brain areas that support it are challenging for various reasons. The first problem researchers face is how to reliably measure declarative memory in *preverbal children*. Traditional tests of declarative memory rely on verbal report, and so are better suited for older children and adults. Second, it is challenging to link behaviour with the brain. Researchers must determine whether the timing of changes in behaviour corresponds with the timing of changes in the brain. Last, researchers must make tests that measure behaviour and brain function sensitive to potential deficits.

Research Context

Infants and young children experience rapid brain development. The weight of the brain increases from 25% of its ultimate adult weight at birth to 75% by the second year of life.[1] However, not all parts of the brain develop at the same time. This is especially true for the areas of the brain that are implicated in declarative memory. The cells that make up most of the *hippocampus*, a brain structure in the *medial temporal lobe* necessary for the formation of declarative memories, are formed by the end of the prenatal period. Yet the cells in the *dentate gyrus* of the hippocampus, an area that links the structure with *cortical regions* of the brain, do not appear adult-like until 12 to 15 months of age.[2] Another area of the brain implicated in memory function is the *prefrontal cortex*. The density of *synapses* in this area increases dramatically at eight months and peaks between 15 and 24 months.[3] Changes continue to occur after this period, until well into adolescence.[4] Thus, we see dramatic changes in the brain areas implicated in memory in the first two years of life.

Key Research Questions

1. How does long-term memory develop? What behavioural changes are seen in memory performance in infancy and early childhood?
2. How do changes in memory performance relate to postnatal changes in the brain?

Recent Research Results

Researchers have used *elicited imitation* to assess declarative memory in preverbal children. In elicited imitation, infants are presented with novel objects and are shown how to use them to create short “events,” such as making and ringing a bell. Immediately and/or after a delay, infants are given the opportunity to imitate the modeled actions. Memory is assessed by comparing the number of actions (individual actions and actions in correct temporal order) to the number of actions during baseline performance (before modeling).[5] Researchers have used this paradigm with infants as young as six months and have found that with age, infants remember for increasing lengths of time. For example, six-month-olds remember actions for 24 (but not 48) hours, nine-month-olds remember for one month (but not three months), and by 20 months of age, infants remember for as long as one year. In addition, with age the effect becomes increasingly reliable—a greater number of infants in each successive age group show evidence of recall (see [6] for review).

In general terms, the time course of improvements in memory with age (indexed behaviourally) is consistent with brain development. Late in the first year of life, the medial temporal lobe structures are functionally mature, and there are increases in the density of synapses in the prefrontal cortex. This corresponds to the improved recall abilities of infants near the end of the first year of life. Further improvements in the reliability of recall occur throughout the second year of life, corresponding to the continued increases in synapse formation in both the prefrontal cortex and dentate gyrus.[7]

Research Gaps

Although we have made a lot of progress in learning about memory and brain development in infancy, there is much we do not know. More information is needed on the time course of development of memory areas in the human brain. At the moment, a lot of information comes from animal models (rodents and nonhuman primates) and so it is unclear how precisely this time course would map onto human brain development. Further work in developmental neuroscience could help to fill this gap. Studies that relate behavioural measures of memory to brain activity are vital to a complete understanding of the development of declarative memory. An advance in this direction comes from research relating *event-related potentials* (ERPs, an electrophysiological technique that measures brain activity associated with specific stimuli) to the robustness of behavioural recall in infants.[8] Further work using this technique, spanning various ages, will be useful.

Conclusions

The ability to form memories and remember them is a vital part of human experience. Historically, people believed that infants lacked this ability. The use of a nonverbal task has allowed researchers to challenge and disprove this assumption. Declarative memory is apparent in the first year of life, as evidenced by behaviour or nonverbal, imitation-based tasks. It develops substantially throughout the first and second years of life. The timing of improvements in performance corresponds to the timing of changes in the developing brain. For example, the rise in synapse production in brain areas implicated in memory roughly maps onto the ages at which we see improvements in recall. Research combining measures of neural processing (assessed via ERPs) and behaviour (assessed via imitation) promises to bring greater resolution to the question of relations between developments in brain and in behaviour. Further work is needed to better understand the development of the human brain and relate it to memory performance in infancy and beyond.

Implications

This research has theoretical and practical implications. First, the work will inform the adult memory literature—one cannot fully understand the mature end-state of a function without understanding its beginning. Moreover this research adds to the literature on infantile amnesia. Infants are able to form memories, even if as adults, they are unable to recall them. The work also has practical implications. Once we understand the typical development of the brain areas associated with memory and the typical recall abilities of infants, we can apply this knowledge to special populations who are at risk. For example, infants born to mothers with blood sugar control problems during pregnancy are more likely to have *perinatal brain iron deficiency* which may have deleterious consequences for the normal development of the hippocampus. These infants show deficits in delayed recall compared to control infants of the same age.[9] Other groups that show deficits in *delayed recall* are infants adopted from international orphanages and healthy preterm infants.[10] As we increase our understanding of the relations between brain and behaviour, we will be able to develop interventions to help infants and children in these at-risk groups.

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