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Brain and Cognition 52 (2003) 144–154
Brain and Cognition
www.elsevier.com/locate/b&c

The Nine Box Maze Test: A measure of spatial memory development in children

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Accepted 21 April 2003

Abstract

This study investigates the development of visuo-spatial memory in school-aged children, as measured by the Nine Box Maze Test Child Version (NBMT-CV). This task, originally developed for adults by Abrahams, Pickering, Polkey, and Morris (1997), utilises an allocentric framework to assess the complexities of spatial memory. Sixty children participated in this study (aged 5–12 years), which also involved administration of traditional 'non-verbal' memory tests. Results indicate that visuo-spatial memory develops across childhood and that the NBMT-CV taps distinct skills compared to other 'non-verbal' memory tasks. The theoretical, assessment and developmental issues raised by these findings are discussed.

Keywords: Allocentric; Hippocampus; Cognitive map

1. Introduction

Non-verbal memory is a process that relates to the encoding and retrieval of spatial representations. As such, spatial memory includes storage of information about objects and their location. The capacity to store information in spatial "maps" allows for novel environments to become familiar, and thus represents an important skill at all stages of the lifespan. This familiarity in turn supports independent navigation, which is central to social behavior. Although much research has been directed towards investigating the development of non-verbal memory, theoretical and methodological issues have led to confusion around the nature and development of these functionally significant skills.

Although neuropsychological tasks provide a sensitive means of assessing verbal memory processes, non-verbal memory measures are often criticized as not tapping relevant cognitive processes (Barr, 1997). Traditional non-verbal memory tests, such as the Spatial Learning Test (SLT) (adapted form L'hermitte & Signoret, 1972) and Complex Figure of Rey (CFR) (Rey, 1941) have been administered to healthy children and yielded contradictory results (Anderson & Lajoie, 1996). The disparity in the development of non-verbal memory suggested by these two tasks may reflect a range of factors, including variable task difficulty and the absence of a rationale to link these measures to theories of spatial function. In addition, Luciana and Nelson (1998) emphasize that current non-verbal memory tests are multi-factorial, which clouds the interpretation of end-point scores. Whilst the studies that have applied traditional non-verbal memory tasks to healthy children are useful in guiding interpretation of test scores, it is difficult to draw conclusions about cognitive development.

Animal lesion studies provide a theoretical basis to guide expectations about the nature and development of non-verbal memory. Specifically, these studies suggest that there are two dissociable although interconnected visual processing systems (Ungerleider & Mishkin, 1982). The ventral pathway, often referred to as the "what" system (Barr, 1997), is responsible for encoding and storing object properties, such as shape and color.

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0278-2626/03/$ - see front matter © 2003 Elsevier Science (USA). All rights reserved.
doi:10.1016/S0278-2626(03)00079-4

The second is a dorsal or "where" system (Barr, 1997), which processes spatial properties such as location and size. On these grounds, non-verbal memory is more precisely defined in terms of a synthesis of visual and spatial (visuo-spatial) information.

One major limitation of conceptualizing visuo-spatial processing in terms of ventral and dorsal streams is that this separation does not allow for the integration of such information, which is presumably fundamental to place learning. There are a variety of reference systems, by which objects and locations can be associated, which include egocentric, proximal and distal associations (Jagaroo, 1999). Distal association is the most adaptive level of encoding as it is independent of personal perspective (egocentric) and juxtaposed environmental cues (proximal). Distal or allocentric associations utilize remote cues or landmarks to form a coordinate reference system to create a map that allows the location of objects to be identified from any given starting point. It is this level of association that is thought to be mediated by the hippocampus (Jarrard, 1993; Morris, Garrud, Rawlins, & O'Keefe, 1982; Nadel & MacDonald, 1980; Olton & Papas, 1979; Rudy, Stadler-Morris, & Albert, 1987).

In humans there is emerging evidence that the right hippocampus supports allocentric memory (Abrahams et al., 1999; Abrahams et al., 1997; Maguire, Frackowiak, & Frith, 1996; Maguire, Frackowiak, & Frith, 1997). Whereas Maguire et al. (1996, 1997) demonstrated this relationship in healthy subjects using functional imaging techniques, Abrahams and respective colleagues (1999, 1997) studied a clinical population using a task, the Nine Box Maze Test (NBMT), which could easily be incorporated into standard neuropsychological assessment. This task is strongly grounded in O'Keefe and Nadel's (1978) cognitive mapping theory and includes separate measures of object-based and location (spatial) function. In accordance with Olton, Becker, and Handelmann (1979), their design also distinguished between information that was held constant across trials (reference memory) and that which varied (working memory). Results indicated that the location or spatial memory measures were the most sensitive indicator of right hippocampal damage. Reference and working measures generally did not differ across groups. Although innovative, the design did not consider the role of strategy, which Luciana and Nelson (1998) identified as a central consideration in interpreting overall task performance. In addition, subjects were not asked to associate object and location measures, which may have further extended the ceiling of the NBMT.

Abrahams et al.'s (1997) study raises the possibility that the same task could be modified for children and potentially used to address questions of visuo-spatial memory development. Although a number of studies have applied experimental allocentric tasks to healthy children, there is no consensus in terms of the age at which children are expected to develop the capacity to form distal or allocentric associations. Estimates range from infancy (Huttenlocher, Newcombe, & Sandberg, 1994) through mid childhood (Overman, Pate, Moore, & Peuster, 1996) to maturity at age 9 (Lehnung et al., 1998; Piaget & Inhelder, 1967). Of note, none of these studies found significant gender differences in the development of these abilities.

The significant disparity around the age at which a child develops the capacity to utilize distal cues, may be partially attributed to clouding of stages of development. That is, a lack of clarity around whether a skill is emerging, developing or mature (Dennis, 1989). In addition, most studies report the mean age at which milestones are attained. Whilst this dependent variable provides an approximate indicator of developmental stage, significant individual variability is often overlooked. One possible synthesis of the current literature is that rudimentary skills may emerge in infancy, continue to develop in early-mid childhood and mature around age 9.

The primary aim of this study was to modify the NBMT developed by Abrahams et al. (1997) and investigate performance in a sample of healthy children aged 5–12. The NBMT shows promise as a useful measure of visuo-spatial memory development, given Abrahams et al.'s (1997) finding that this task was sensitive to lesions in the right hippocampus (a part of the brain thought to be central to visuo-spatial memory), in adults. The basic design of Abrahams et al. (1997) was extended to include an associative component, whereby children were asked to explicitly associate object and location. Inclusion of this more difficult component extended the ceiling of the measure and improved the likelihood that the task would be sensitive to protracted development. In addition, the role of strategic behavior was investigated.

Specifically, it was hypothesized that young children would demonstrate basic allocentric abilities, in-keeping with Huttenlocher et al. (1994). It was expected that these abilities would develop rapidly throughout early childhood and mature by the age of 9, consistent with the conservative estimate of Lehnung et al. (1998). It was expected that the object/location associative condition would be the slowest to mature, given the more difficult nature of this measure. No gender differences were anticipated. In terms of reference and working memory, it was hypothesized that there would be a significant correlation between reference memory and strategy. In the absence of awareness that the two objects and locations are held constant across trails, performance on reference and working memory measures was not expected to differ. Finally, it was expected that performance measures obtained from the Nine Box Maze Test—Child Version (NBMT-CV)