The role of the executive system in visuo-spatial memory functioning

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Abstract

Participants were presented with a spatial sequence in which between 4 and 10 cells were highlighted. On each trial list length was unknown to the participant who was required to serially recall the last four cells. Processing of longer lists is assumed to call upon the executive system, which is thought to be involved in updating the contents of the short-term visuo-spatial store. Study 1 revealed that loading the executive system with concurrent random letter generation impaired performance on the spatial task especially recall of the early serial positions. However, contrary to expectation the degree of impairment was no greater on the longer lists, where it had been assumed that updating would be occurring. Study 2 confirmed this finding and demonstrated that relative to sequences of known length, under conditions of uncertainty when the list length was unknown, spatial recall was impaired even on short sequences. The present results support the growing consensus, which is suggestive of closer links between visuo-spatial and executive processes. However, it remains unclear whether or not updating is actually occurring on the longer sequences, and if it is, what specific executive processes are involved.
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1. Introduction

The purpose of the present paper is to investigate the role of executive processes in visuo-spatial working memory. Existing research evidence concerning the mechanisms underpinning aspects of visuo-spatial processing will be outlined and the possible role of the executive system in the visuo-spatial domain will be discussed. A running memory task will be administered and the role of the executive system in processing spatial sequences of various lengths will be explored through the use of various dual tasks including random letter generation (a task known to tap aspects of executive functioning).

Research into visuo-spatial working memory dates back to an early study by Brooks (1967), who investigated individuals' ability to store a spatial movement sequence. Brooks' task uses a four by four matrix of blank cells, one of which is defined as the starting square. The participant constructs a mental image through this matrix by following a set of instructions provided by the experimenter, e.g., in the starting square put a 1, in the next square up put a 2, in the next square to the right put a 3, etc. This creates a movement sequence through the matrix. Instructions can be presented so that participants employ a spatial strategy (utilising the words up, down, left, and right as above) or they can be presented as a verbal sequence with non-spatial non-sense words, e.g., in the next square to the good put a 2, in the next square to the weak put a 3, in the next square to the bad put a 4, etc., presumably causing participants to use a verbal processing strategy.

Brooks' suggestion that the two versions of the task use different processing systems was supported by Baddeley, Grant, Wight, and Thompson (1975) who found that while concurrent visual tracking disrupts the visual version of the task, it has minimal effect on the verbal version. Consistent with this early research, and also using the dual task methodology, Logie, Zucco, and Baddeley (1990) showed that spatial processing was disrupted by the spatial version of Brooks (1967) task, while the non-spatial version produced significantly less

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disruption. The opposite effect was observed in relation to a letter span task with the non-spatial Brooks task producing more disruption relative to the spatial version. Similar results were observed by Quinn (1994), who found that a secondary task involving active movement disrupted performance on the Brooks spatial task, with incompatible movements and random movements having the most disruptive effects. The same results were obtained with passive incompatible movements, where the experimenter moved the participant's hand. It appears that although involuntary, the incompatible sequence manages to access and disrupt the visuo-spatial system in the same way that unattended speech has automatic access to the phonological system. More recently, similar results were obtained by Lawrence, Myerson, Oonk, and Abrams (2001), who found that limb movements and eye movements disrupted spatial working memory to a greater extent than verbal working memory.

There is some evidence that the mechanisms responsible for processing static visual stimuli may be distinct from those responsible for sequential spatial processing. Logie and Marchetti (1991) showed that delayed recall of visual information (recalling the colour of previously presented squares) was impaired by a secondary visual task during the retention interval but not by a secondary movement task, while the opposite was true for delayed recall of a spatial sequence. Using a similar methodology, Tresch, Sinnamon, and Seamon (1993) also report evidence for the functional separation of visual and spatial systems in working memory.

In recent years there has been considerable speculation concerning the role of the executive system in visuospatial processing. Early research using the dual task methodology was influenced by Baddeley's (1986) model of working memory, in which the central executive was viewed as a unitary construct. For example, Morris (1987) found that disrupting executive processes impaired the performance of a spatial task but only during the encoding phase of the task and not during rehearsal. Logie and Marchetti (1991) also suggest that executive functions may be involved in encoding spatial movement sequences. A similar argument has been proposed by Quinn (1994), who maintains that once encoded, spatial sequences may be stored in a static visual format, subsequently being reconverted into a spatial form during retrieval. Consistent with this assertion, Quinn (1991) found that the spatial version of the Brooks task was disrupted by concurrent passive movement during the encoding phase but passive movement during the maintenance phase had no effect on performance. Quinn argues that executive processes may be implicated in processing spatial sequences during encoding and possibly retrieval but not during the maintenance phase.

Klauer and Stegmaier (1997) have also postulated that executive processes might be called upon in the performance of spatial tasks. They found that listening to tones emanating from different spatial locations impaired performance on a primary spatial task. However, discrimination of pitch also impaired performance even when the tones originated in the same spatial location. Klauer and Stegmaier interpreted their pattern of results as suggestive of more than simple spatial interference. Rather they argue that the disruption of the main spatial task was due to increased demands for general purpose resources, emerging as a consequence of the pitch discrimination task, i.e., an increased executive load. This being the case, they argue that executive processes must be involved in the rehearsal process in serial spatial memory and that this is at least in part responsible for the observed impairments in the main task. This contrasts with Morris's (1987) and Quinn's (1991) results where there was an absence of an interference effect during rehearsal.

Contrary to early conceptualisations that viewed the executive as a unitary construct, in recent years a consensus has emerged in which the executive is conceived of as a fractionated system. Representative of this viewpoint is an important study by Miyake et al. (2000), which demonstrates that executive functions can be subdivided into three separate types of operation: updating, shifting, and inhibition. Updating involves evaluating incoming information and revising the existing contents of working memory as necessary by deleting what is no longer relevant and incorporating more recent salient information. Shifting is concerned with the individual's ability to shift attention between different sub-tasks or different elements of the same task. Inhibition is concerned with the individual's ability to withhold dominant, automatic or pre-potent responses when they are inappropriate. While these three operations share some common element, Miyake et al. showed that they are separable with different executive tasks such as the Tower of Hanoi and the Wisconsin Card Sort Test loading heavily on just one or two specific operations. Miyake and co-workers have also examined the extent to which various aspects of executive functioning are involved in spatial processing. In a recent study using structural equation modelling (SEM) and factor analysis, Miyake, Friedman, Rettinger, Shah, and Hegarty (2001) found that in the visuo-spatial domain, complex working memory tasks (which require concurrent processing and storage) as well as more basic storage tasks both involve aspects of executive functioning and are not clearly distinguishable in terms of the extent to which they call on executive resources. Thus in contrast to the situation with verbal working memory, where clear distinctions have been made between executive and non-executive processes, in relation to spatial processing, Miyake et al.'s (2001) results suggest that executive processes are implicated in a wide range of spatial tasks, including relatively basic ones.