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SYMMETRY AND BINDING IN VISUO-SPATIAL WORKING MEMORY

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Abstract—Three experiments study the impact of symmetry on a sequential block tapping immediate memory task in human subjects. Experiment 1 shows an advantage from vertical symmetry over non-symmetrical sequences, while finding no effect of horizontal or diagonal symmetry. Experiment 2 tests the possible role of verbal labeling by means of a secondary task that prevents this by articulatory suppression. No evidence of verbalization was observed. A third study examines the effects of a concurrent executive load, finding an overall impairment, that did not differ between symmetrical and asymmetric patterns, suggesting that the effect of symmetry reflects automatic rather than executive processes. Implications for the episodic buffer component of working memory are discussed. © 2005 Published by Elsevier Ltd on behalf of IBRO.

Key words: immediate memory, sequential block tapping, interference, automaticity, executive processes, episodic buffer.

Our approach to studying the recall of spatial patterns is based on the model of working memory proposed by Baddeley and Hitch (1974; Baddeley, 1986, 2000), and further specified with respect to Logie's (1995) approach to visual–spatial processing. According to this model, the working memory system consists of a central executive (CE) and at least two additional subsystem, specifically the "phonological loop" (PL) and the "visuo-spatial sketchpad" (VSSP). The central executive is responsible for controlling ongoing processing (Baddeley, 1996); the phonological loop maintains acoustically based information temporarily (Gathercole and Baddeley, 1993; Gathercole and Hitch, 1993), and the visuo-spatial sketchpad maintains visual and spatial information, either directly perceived or internally generated by mental imagery, for brief periods of time.

Neuropsychological studies have indicated the need to distinguish between visual and spatial memory. Logie (1995) has proposed a fractionation of the sketchpad that is analogous to that of the loop. He distinguishes between a visual storage component, the visual cache, and a more dynamic retrieval and rehearsal process which he terms the inner scribe. He argues that the sketchpad is not a perceptually-based store, but visual information enters the store after it has been processed in LTM. Support for this view comes from two types of patient, both showing visuo-spatial neglect after right hemisphere damage (Della Sala and Logie, 2002). Logie's account of visuo-spatial working memory (VSWM) was further revised by Pearson (2001) by including a functionally separate visual buffer in VSWM which is the medium in which conscious visual images are represented. This model was put forward so as to avoid assigning the storage of conscious mental images and sequential visual patterns to a single representational medium. A further important feature of Pearson's model is that representations in the buffer can be generated not only from information stored in long-term memory but also loaded directly from the perceptual systems, suggesting that access to working memory can be through either perception or long-term memory.

With regard to the capacity of visuo-spatial storage, the data suggest that it is limited by pattern complexity (Wilson et al., 1987; Logie et al., 1990). In these studies complexity was defined in terms of the number of pattern elements in a matrix, which thus constituted a quantitative measure of the concept. However, complexity could also pertain to the degree of internal coherence contained within a stimulus. For example, research within the framework of information theory (Attneave, 1955; Schnore and Partington, 1967) found recall of dot-in-matrix patterns to be a linear function of the degree of symmetry manifest in the patterns. Research on complexity judgments of matrix patterns has in fact shown that the concept of complexity is determined by both a quantitative and a structural factor (Chipman, 1977; Ichikawa, 1985). Quantitative complexity includes aspects such as the number of elements in a stimulus and the size of a stimulus. Structural complexity is related to the redundancy of a stimulus. A stimulus is redundant if parts of it can be predicted from other parts. Gestalt factors including symmetry, good continuation, and other forms of regularity constitute redundancy. Recent works (Kemps, 2001; Zoelch and Schumann-Hengsteler, 1999) reported effects of both quantitative and structural measures of complexity on visuo-spatial memory. They showed that the structural complexity of the to-be-remembered path imposed a limit on the serial recall of block sequences. This finding suggests that the representation of a redundant path is more compact, and thus takes up less storage capacity of the visuo-spatial slave system than that of a complex path. Therefore, when the path contains some form of redundancy, more items can be held in the short-term visuo-spatial store than when the path is complex. This observation is consistent with Kemps' (1999) report that the presence of structure has a facilitating effect on the temporary retention of visuo-spatial material, confirming pre-

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Abbreviations: M, mean; S.D., standard deviation; VSWM, visuo-spatial working memory.

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vious findings showing that the capacity of VSWM is limited by complexity (Logie et al., 1990; Wilson et al., 1987).

How might these effects be explained within the multicomponent working model? One possibility is through the process of chunking, a concept introduced by Miller (1956), which assumes that short-term memory (STM) is limited in terms of number of chunks rather than items. For that reason we can remember far more letters when they comprise meaningful words than if they occur in random order since a word may constitute one chunk, but several letters. This issue has recently been reactivated by Cowan (2000) who has presented strong arguments for a capacity for around four chunks, rather than the seven initially proposed by Miller (1956). This is turn raises the question of how the chunks are formed, whether they rely on relatively automatic processes, or are dependent on active manipulation within working memory. It seems likely that both methods of chunking exist. Immediate recall of briefly presented chess positions is substantially greater in expert than in novice players (de Groot, 1965), presumably because the expert can chunk more effectively. However, when given a demanding executive, or visual spatial concurrent task, both experts and novices show impaired performance (Robbins et al., 1996) suggesting that attention and visuo-spatial processing are necessary for this type of chunking. It seems possible however that other more low-level visual components of chunking may be automatic rather than executive. One obvious candidate for this might be symmetry. The experiments that follow explore this possibility, first attempting to detect effects of symmetry on a visual spatial recall task then going on to investigate the possible roles of phonological loop and the central executive.

Experiment 1

The aim of the first experiment was to verify the role of symmetry in the superior recall of structured paths.

EXPERIMENTAL PROCEDURES

Subjects

Twenty-five students of the Faculty of Psychology participated. Age ranged from 20 to 29 years (mean [M]=23.4; standard deviation [S.D.]=2.47).

Materials

Twenty-five black blocks (4×4×4 cm) were positioned on a black wooden board (40×40 cm) in a regular 5×5 matrix, this was an adapted version of the Corsi blocks task (Kemps, 1999, 2001). The blocks were numbered from 1 to 25; these numbers could be seen by the experimenter, but not by the subject.

Stimuli

Paths could be symmetrical or non-symmetrical. The symmetrical paths were divided in vertical, horizontal and diagonal symmetry. Examples of the paths are shown in Fig. 1.

Procedure

Subjects were tested individually in a quiet room. They were given instructions about the task and two practice trials with patterns

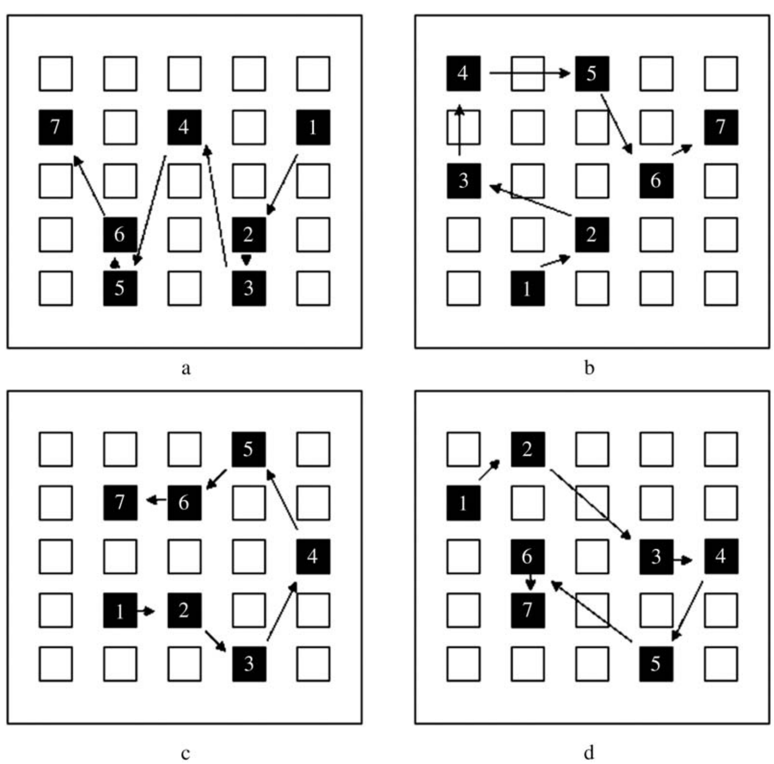

Fig. 1. Examples of trajectory sequences which subjects had to correctly recall in experiment 1. Paths could be symmetrical along the vertical (a), diagonal (b), and horizontal axes (c), or non-symmetrical (d).