Development of memory for pattern and path: Further evidence for the fractionation of visuo-spatial memory

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Evidence from a number of sources now suggests that the visuo-spatial sketchpad (VSSP) of working memory may be composed of two subsystems: one for maintaining visual information and the other for spatial information. In this paper we present three experiments that examine this fractionation using a developmental approach. In Experiment 1, 5-, 8-, and 10-year old children were presented with a visuo-spatial working memory task (the matrices task) with two presentation formats (static and dynamic). A developmental dissociation in performance was found for the static and dynamic conditions of both tasks, suggesting that the activation of separable subsystems of the VSSP is dependent upon a static/dynamic distinction in information content rather than a visual/spatial one. A highly similar pattern of performance was found for a mazes task with static and dynamic formats. However, one strategic activity, the use of simple verbal recoding, may also have been responsible for the observed pattern of performance in the matrices task. In Experiments 2 and 3 this was investigated using concurrent articulatory suppression. No evidence to support this notion was found, and it is therefore proposed that static and dynamic visuo-spatial information is maintained in working memory by separable subcomponents of the VSSP.

Understanding the processes involved in the maintenance of information in memory for short periods of time owes much to the working memory model (Baddeley, 1986; Baddeley & Hitch, 1974). According to this model, visuo-spatial information is maintained in a slave system known as the visuo-spatial sketchpad. The activity of this and the other slave system, the phonological loop, is controlled by a further component, the central executive. Although many aspects of working memory relating to phonological loop function are now well understood, less is known about the workings of the visuo-spatial sketchpad. In particular, whereas the

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phonological loop is thought to be composed of two subcomponents: a phonological store and a subvocal rehearsal process, the visuo-spatial sketchpad has tended to be viewed as a unitary component dealing with both visual and spatial information.

Recent research has, however, challenged this view of the visuo-spatial sketchpad and highlighted the existence of at least two subcomponents for dealing with non-verbal information in working memory (see Baddeley & Logie, 1999, for a review). A number of studies now exist to suggest separable subsystems of visuo-spatial memory for dealing with spatial information (such as the location of an object) and visual information (such as appearance). Additionally, subcomponents for handling motor and kinaesthetic information have also been proposed (Smyth & Pendleton, 1990; Woodin & Heil, 1996). Evidence to challenge the notion of a unitary visuo-spatial sketchpad has come from a range of sources including psychological studies with adults, children, and neuropsychological patients, and neuroanatomical studies with animals and brain-damaged adults.

One approach to studying visuo-spatial working memory has involved the use of a selective interference paradigm in which primary tasks are paired with secondary tasks that are believed to utilize similar or differing cognitive structures. If the secondary tasks serve only to cause general disruption to performance no specific effects of pairing primary and secondary tasks of a similar kind would be expected. If, however, separable subcomponents were available for the processing of visual and spatial information, the activity of each component should not be affected by a secondary task of a different kind—only tasks that use the same resources. Using this methodology, Logie and Marchetti (1991) found that a visual interference task (the presentation of irrelevant pictures) and a spatial interference task (involving unseen arm movements) presented during a 10-s retention interval resulted in a significant decrement in performance only on a primary task of a similar kind. Comparable results were found by Tresch, Sinnamon, and Seamon (1993) in a study involving memory for dot locations and geometric shapes. Work by Quinn and colleagues (e.g., Quinn & McConnell, 1996) has identified a form of visual noise composed of a flickering dot pattern that has specific effects on memory for visual but not spatial information and a spatial tapping concurrent task has been found specifically to impair performance on spatially loaded primary tasks (Smyth & Pendleton, 1989). More recently, Della Sala, Gray, Baddeley, Allamano, and Wilson (1999) have found that a visual interference task composed of viewing abstract paintings produced a much greater decrement in performance on a visual task (the visual patterns task) than did an interference task involving spatial tapping. The opposite pattern was found for a spatial primary task (the Corsi blocks task)—see Milner, 1971.

A different, but complementary, approach to the study of visual and spatial memory involves the examination of patterns of relationships between performance on tasks of a visual or spatial nature. A study of patients with senile dementia (Wilson, Brodie, Reinink, Wiedman, & Brooks, 1988) found that performance on a visual pattern recall task was not related to performance on a task involving the recall of paths between blocks (similar to the Corsi blocks task). Similar results were found with children in a study by Logie and Pearson (1997).

Studies involving neuropsychological patients provide opportunities to identify areas of specific cognitive deficit and, in particular, double dissociations of cognitive function. In one such study Della Sala and colleagues (1999) were able to identify two individuals from their sample of brain-damaged adults who were found to be highly impaired in their performance
on a spatial task (the Corsi blocks task), but to be performing at above median level on a visual patterns task. A third patient showed the opposite pattern.

Additional evidence of specific visual and spatial memory deficits comes from case studies such as Farah and colleagues’ observations of LH (Farah, Hammond, Levine, & Calvanio, 1988). Following a car accident and subsequent surgery, LH was found to have a selective impairment of his visual memory in the presence of spared memory for spatial information. The converse pattern was found by Luzzatti, Vecchi, Agazzi, Cesa-Bianchi, and Vergani (1998) in patient EP, whose performance on spatial imagery tasks was severely impaired, although visual imagery and visual and spatial perceptual processing were normal. Taken together these two case studies provide a double dissociation of visual and spatial memory processes. Hanley, Young, and Pearson’s (1991) patient ELD also showed some dissociation of memory function following a cerebral artery aneurysm. She was found to perform poorly on many visuo-spatial tasks (e.g., the Brooks matrix task—Brooks, 1967), but was still able to retrieve visual information from long-term memory that had been learned before her illness.

Experimental and neuropsychological evidence therefore suggests that two different subcomponents of the visuo-spatial sketchpad are responsible for the maintenance of visual and spatial information. Neuroanatomical evidence further supports this dissociation of function. For example, De Renzi (1982) found that patients with parietal occipital lesions could not point to specified locations, suggesting that damage to this area of the brain results in impairments in spatial processing. Conversely, patients with inferior temporal lesions were found to have difficulties with identifying items—a deficit in visual processing. This neuroanatomical distinction is supported by work with monkeys (Ungerleider & Mishkin, 1982) in which two anatomically distinct pathways were located in the monkey brain—one for dealing with the identity of objects and the other with their position.

If two cognitive functions are carried out by separable subcomponents it is possible that the two functions do not mature at the same rate. This principle is known as developmental fractionation (Hitch, 1990) and can be observed by comparing performance on the cognitive functions of interest in children of increasing age. Logie and Pearson (1997) investigated the separability of visual and spatial working memory in children of 5–6, 8–9, and 11–12 years of age by administering a visual patterns task and a Corsi blocks type task and observing the rate of age-related increase in performance for each task. They found that although performance increased with age for both tasks, there was a much steeper age-related increase for the visual patterns task, suggesting that the visual subcomponent of the visuo-spatial sketchpad is distinct from the spatial subcomponent and develops faster in children.

To date, the most significant attempt to extend the working memory model to accommodate the findings outlined here has come from Logie and colleagues (e.g., Logie, 1995; Reisberg & Logie, 1993; Salway & Logie, 1995). They suggest that the two subcomponents of the visuo-spatial sketchpad can be thought of as a “visual cache” and an “inner scribe” working in partnership. The visual cache is thought to deal with information that is visual in nature, such as form and colour, and to be closely linked to the activities of the visual perceptual system. The inner scribe, in contrast, is proposed to handle information about movement sequences and, in a manner somewhat analogous to the subvocal rehearsal process of the phonological loop, to refresh the contents of the visual cache.

Study of the visuo-spatial sketchpad has been largely dominated in recent years by the use of tasks of two specific kinds. One type of task, the Corsi blocks task, involves the presentation
of a visuo–spatial sequence by tapping a randomly placed set of nine blocks, which are fixed to a board. Each block is tapped one at a time and can only be identified on the basis of its spatial location. The to-be-recalled sequences can be increased in length to provide a span measure of performance, which has been found to increase during childhood to an average of five and a half items at age 15 (Issacs & Vargha–Khadem, 1989). In recalling the sequences, it appears that participants are retrieving a series of paths or vectors between the different blocks in the sequence. The view that this task is more spatially than visually loaded has come from studies in which another task believed to use spatial resources—the spatial tapping task—significantly interferes with recall of visuo–spatial sequences (Smyth & Pendleton, 1989). In contrast, visual memory has often been measured using pattern recall type tasks, such as the visual pattern task (Della Sala et al., 1999; Della Sala, Gray, Baddeley, & Wilson, 1997; Wilson, Scott, & Power, 1987). Tasks of this type have typically involved matrices of squares, which are filled or contain a dot (Ichikawa, 1982; Phillips & Christie, 1977), and participants are required to recall the abstract pattern that is created by the filled squares in the matrix.

It is important to note, however, that Corsi blocks type tasks and visual pattern tasks do not differ only in their relative visual and spatial components. They also differ in the extent to which the information to be recalled is presented in a dynamic format (as in the case of Corsi blocks type tasks) or a static format (as with the visual patterns tasks). In directly comparing performance on these two visuo–spatial measures two different types of cognitive function are being sampled: visual and spatial processing, and static and dynamic processing. A problem in the interpretation of findings from studies using these tasks is that it is not possible to say which of these two kinds of process is directly responsible for the different patterns of performance that have been found. The two hypothesized subcomponents of visuo–spatial working memory may actually be operating on information that is either static or dynamic in nature, rather than visual or spatial.

In this article we present three experiments that attempt to specify more precisely the nature of the hypothesized subcomponents of the visuo–spatial sketchpad by presenting tasks that hold the visuo–spatial information presented constant, but vary presentation format as either static or dynamic. To this end a task was designed (the matrices task) using the black and white matrix patterns of the visual patterns test, with a facility for presenting information to be recalled as either static patterns or dynamic paths. The matrices task therefore captured the key aspects of both the visual patterns task and the Corsi blocks task, which have been used in previous research in this area. However, rather than tapping three-dimensional blocks on a wooden board as in the Corsi blocks task, children were required to point to the same type of black squares in a matrix as are found in the visual patterns task. In line with the developmental fractionation approach, tasks were presented to children of different ages in order to examine differences in developmental trajectories for different kinds of cognitive processing.

In Experiment 1, the matrices task was presented to children of 5, 8, and 10 years of age. Two predictions were possible. First, if the developmental fractionation observed by Logie and Pearson (1997) is actually due to the static and dynamic nature of the two tasks used in their study rather than to their visual and spatial content, particular developmental patterns should be observable for the matrices task. Specifically, performance on the static and dynamic versions of the task should show distinct developmental trajectories to one another. If, however, it is the visuo–spatial content of the visual pattern and Corsi blocks tasks and not their static and dynamic format that is important in determining performance, no significant
differences in the developmental increases between the static and dynamic version of the task should be found.

Even if a difference in developmental trajectories in the matrices task is found, it is still possible that this might merely be a feature of tasks that closely resemble the visual patterns and Corsi blocks tests, and not of visuo-spatial tasks in general. In order to investigate whether other types of visuo-spatial information presented in static and dynamic format produce similar patterns of findings, a second task was included in Experiment 1. The mazes task required children to recall two-dimensional routes through printed mazes either as static patterns or dynamic paths. Inclusion of this second task allows us to investigate whether this pattern of differing developmental increase in performance is generalizable to other visuo-spatial memory tasks.

EXPERIMENT 1

Method

Participants

Fifty-six children from three different years (Years 1, 4, and 6) of one local primary school took part in the experiment. The youngest group (n = 20) had a mean age of 5.9 years (SD = 2.56 months, range = 5.5–6.2 years), the middle group (n = 20) were aged 8.8 years (SD = 3.37 months, range = 8.3–9.1 years), and the oldest group (n = 16) had a mean age of 10.9 years (SD = 3.47 months, range = 10.5–11.2 years). No child was known to have any sensory or educational difficulty.

Measures and procedure

Each child was tested individually in a quiet room of the school and completed the tests during a number of sessions over a 3-week period. All conditions of the matrices test were given one after another, but for the mazes test, the two conditions were presented with an interval of at least 3 days between them.

Matrices task. Three conditions of this test were actually presented to children, however, scores from only two conditions were used in this experiment (scores from an order-only version were collected but not used for analysis here1). The task was presented to children using a Macintosh C3500 Powerbook

1 To overcome a possible confound between the presentation format of the matrices task and the amount of information to be recalled, a third “order-only” condition was also included in Experiment 1. In this condition, participants were required to attribute order of presentation to a pattern of black squares in a matrix that remained on the computer screen (with each square flashing one at a time, as in the dynamic version). Performance of the three age groups was examined separately across the static, dynamic, and order-only presentation formats using a series of one-way analyses of variance (ANOVAs) with Student–Newman–Keuls post hoc analysis. For all three age groups performance in the order-only condition was found not to differ significantly from that in the dynamic condition, although it did differ significantly from performance in the static condition.

For the 5-year-old group, mean performance in the order-only condition was 6.20 trials compared to 5.85 in the dynamic condition. These two conditions did not differ significantly from one another, but did differ from the static condition at the p < .01 level. For the 8-year-olds a similar pattern was found, with mean performance in the order-only condition being 10.80 trials compared to 9.40 trials in the dynamic condition. Post hoc analyses produced identical results to those for the 5-year-olds. Finally, 10-year-olds scored an average of 13.94 trials correct in the order-only condition compared to 13.19 in the dynamic condition, producing the same pattern of post hoc results as for the two younger age groups. These findings are interpreted as suggesting that recall of a dynamic sequence is not significantly more difficult when both items and order are required than when only the order of the sequence is required.
and consisted of stimuli of the kind illustrated in Figure 1. One condition involved static visual patterns for recall (matrices static), and the other condition presented sequences of flashing squares within a matrix (matrices dynamic), for which the child was asked to recall the location and sequence of the items. Three different sets of patterns were used and were systematically allocated to the three test conditions to avoid confounding presentation condition with pattern set. Order of presentation was counterbalanced across participants as was the assignment of pattern set to presentation type. Two practice trials were given at the beginning of the whole test, and each condition was not begun until the experimenter was confident that the child understood the instructions for the task. The static and dynamic conditions of the matrices task are described as follows.

Matrices static. This condition is very similar to the visual patterns test reported elsewhere (Della Sala et al., 1997, 1999; Wilson et al., 1987) with computer presentation allowing more careful control of presentation time and interval before recall. The task began by presenting a $2 \times 2$ matrix in which two of the square cells were filled black and two were unfilled (see Figure 1 for an example). The child was instructed to look carefully at the pattern and try to remember where the black squares were. The matrix was presented on the screen and there was a half-second delay before presentation of an empty matrix of the same size for recall. The mode of recall was full free recall, with the child pointing to the location of the target squares, and the experimenter clicking on the chosen squares with the computer mouse (which acted to change cells from unfilled to filled). The child was asked to confirm that they were happy with the final selected pattern, and the next trial was initiated. Level of difficulty was increased by adding two squares to the matrix (one filled, one unfilled) every four trials. Testing was stopped when a child was unable to recall two or more patterns correctly at a particular difficulty level. The total number of correct trials before discontinuation of the task was noted as each child’s score.

Matrices dynamic. In contrast to the static condition, the dynamic condition was designed to measure recall of the location and order of a series of black squares presented one at a time. In this way, task requirements were very similar to those for the Corsi blocks task. The task began with the presentation of an empty $2 \times 2$ matrix, in which two of the squares flashed black, one after the other, each for half a second (with a half-second interstimulus interval). The child, having been instructed to watch the presentation of the sequence carefully, was then asked to indicate the location of the black squares in the order that they appeared in the matrix. The experimenter recorded the child’s responses by clicking the computer mouse on the selected cells. As in the static condition, difficulty level increased every four trials, and

![Fig 1](image.png)  
**Figure 1.** Examples of stimuli from the matrices task.
testing stopped when two out of four trials at a particular level were incorrectly recalled. Performance was noted as the total number of correct trials before testing was discontinued.

**Mazes task.** This task tapped children’s immediate memory for two-dimensional routes through a maze. Mazes were constructed using a series of walls (rectangles) each having two possible “entrances” in different sections of each rectangle. The most basic type of maze is illustrated by the smaller figure in Figure 2, consisting of a “person” to be reached, situated inside two walls. Four mazes similar to the basic-level maze were presented at the first level of difficulty. Subsequent levels of difficulty were achieved by adding an additional wall to the outside of the maze. The larger example in Figure 2 illustrates a more difficult maze from the penultimate level of the test. Both conditions of the mazes task were presented using paper and pencil format using a test booklet and a booklet containing empty mazes for the child’s responses.

Two different conditions of the task were presented (mazes static and mazes dynamic), with the order of presentation counterbalanced across participants. The static version was designed to tap children’s memory for a static route already present on the maze, whereas the dynamic version measured children’s memory for a movement-based path traced through the maze, with no enduring features. Comparable sets of routes were designed, and one set was allocated to each of the different conditions. Procedures for administration are described as follows.

**Mazes static.** The child was given a response booklet which contained the series of empty mazes in which he or she would recall the routes presented. The experimenter instructed the child to look carefully as she opened the mazes static test booklet at the first item, for a period of 3 s. Each of the mazes in the test booklet contained a route for recall already present as a clear red line from the outside of the maze to the person in the centre. Once the maze had been removed from sight, the child was asked to draw the route into the appropriate empty maze in the response booklet. The difficulty level of the mazes

![Figure 2. Examples of stimuli from the mazes task.](image-url)
increased every four trials, and testing was discontinued when a child incorrectly recalled two out of four of the mazes at a particular difficulty level. Performance was taken as the total number of correct trials completed by the child before testing was stopped.

*Mazes dynamic.* The child was again given a booklet for responses containing empty mazes. However, in this condition of the test the experimenter demonstrated the route to the child by tracing it with her finger, into the maze in the response booklet. As soon as this was done, the child was asked to draw the route into the empty maze. Testing continued in this way until the child was unable to correctly recall two mazes at a particular difficulty level. The total number of correct trials before testing was discontinued was noted.

**Results**

Mean performance of the three groups of children on the matrices and mazes tasks is shown in Figure 3. Scores from each task were analysed separately using two-way analyses of variance (ANOVAs) with factors: group (5, 8, and 10 years) and task format (static/dynamic). For the matrices task a significant main effect of age was found, \(F(2, 53) = 62.798, p < .001\). There was also a significant main effect of task format, \(F(1, 53) = 168.077, p < .001\), reflecting better scores for the static version of the task. A significant group by task format interaction was also found, \(F(2, 53) = 9.061, p < .001\), indicating a differential pattern between the task formats across age groups. Post hoc tests were carried out in order to investigate differences in performance across age groups and task conditions. In this and all subsequent post hoc analyses the selected test was the Sheffe test. All three age groups were found to perform significantly better in the static version of the matrices task: for the 5-year-olds, \(p < .01\), and for the 8- and 10-year-olds, \(p < .001\). Comparisons between the different age groups in the static and

![Figure 3](image)

*Figure 3.* Mean performance on the matrices and mazes tasks as a function of age group and task presentation format.
dynamic versions of the task were also examined. In the static matrices task all three age groups were found to perform significantly differently from one another: the 8-year-old group outperformed the 5-year-old group, \( p < .001 \), and the 10-year old group outperformed the 8-year-old group, \( p < .01 \). In the dynamic matrices tasks, however, only the 5- and 10-year-old children performed significantly differently from one another, \( p < .001 \). There was no significant difference between 5- and 8-year-olds’ performances, and between the 8- and 10-year olds performances, in this task condition, \( p > .05 \).

Similar results were found for the mazes task. Two-way ANOVAs yielded significant main effects of group, \( F(2, 53) = 85.192, p < .001 \), and task format, \( F(1, 53) = 8.722, p < .01 \), with static performance exceeding that of dynamic in two out of the three groups. The steeper increase in performance for the static mazes task format was supported by a significant Group × Task format interaction, \( F(2, 53) = 15.046, p < .001 \). Post hoc comparison of performance indicated that the 8- and 10-year old groups performed significantly better in the static version of the mazes task than in the dynamic version: for the 8-year-olds, \( p < .05 \), and for the 10-year-olds, \( p < .01 \). For the 5-year-old group, however, whose mean performance showed the converse pattern (dynamic better than static), no significant differences between mazes conditions were found (\( p > .05 \)). Comparisons between the different age groups in each version of the task were also examined. In the static mazes task all three age groups were found to perform significantly differently from one another: The 8-year-old group outperformed the 5-year-old group, \( p < .001 \), and the 10-year-old group outperformed the 8-year-old group, \( p < .01 \). The same was true for the dynamic version of the mazes task where 8-year-olds significantly outperformed 5-year-olds, \( p < .01 \), and the 10-year-old group significantly outperformed the 8-year-olds, \( p < .05 \). The general advantage for the static version of both the visuo-spatial tasks and the interactions between age and task format can be seen in the graph in Figure 3.

**Discussion**

Overall, performance in the static version of the matrices task was found to be superior to that in the dynamic version and to increase more steeply with age. This significant interaction between age and task format (static or dynamic) provides further evidence of a developmental fractionation of visuo-spatial short-term memory. However, rather than this being based purely on the visuo-spatial characteristics of the information to be recalled, it seems to depend upon whether that information has a static or dynamic presentation format. It appears, therefore, that the separable subsystems in visuo-spatial memory may be sensitive to the static and dynamic features of the visuo-spatial stimulus.

Moreover, this pattern of performance is not only found in tasks that closely resemble the visual patterns and Corsi blocks tasks. Performance in the static version of a task involving recall of maze routes was also superior for 8- and 10-year-old children, and a significant interaction between age and task format suggests that developmental increases in one condition of the task (static) occur faster than those in the other condition (dynamic). Interestingly, the performance of the youngest children in the mazes task showed the reverse pattern to that of their older counterparts.

The results of Experiment 1 replicate the developmental fractionation of visuo-spatial memory performance found by Logie and Pearson (1997) using a task in which the visuo-spatial content is held constant and information to be recalled is varied as either static or dynamic.
More importantly, this pattern of findings has also been seen with a visuo-spatial task quite unlike the visual pattern and Corsi blocks tests used in previous research, suggesting that generalizations can be made to other tests of visuo-spatial memory.

There are, however, other possible explanations for the static and dynamic developmental functions observed in Experiment 1, which do not depend on the presence of dissociable memory systems. A possible account of the steeper developmental increase in static over dynamic visuo-spatial recall is that the former task provides a greater opportunity for strategic recoding of stimuli. The use of such a strategic recoding strategy may in turn increase with age, for a number of reasons (e.g., knowledge of a strategy, ability to carry it out). One possible strategy that might be available to older but not younger children is the use of simple verbal recoding of visuo-spatial stimuli. It might be the case that opportunities for, and the resulting usefulness of, simple verbal recoding of stimuli may be greater for the static versions of the mazes and matrices tasks presented in Experiment 1, resulting in better scores for older children. Indeed, observation of children during Experiment 1 revealed a number of instances in which the older children attributed verbal labels to quite abstract visual patterns, often comparing stimuli to objects or nameable patterns (e.g., “a cross”, or a “letter C”).

Previous research provides some evidence to suggest that verbal recoding may be used in visuo-spatial memory tasks. For example, Miles, Morgan, Milne, and Morris (1996) found that when a visual patterns task was paired with articulatory suppression, the performance of 7-year-old children and adults was significantly reduced, suggesting that a verbal strategy may have benefited memory for the visual patterns. The performance of younger children was not, however, significantly affected. Additionally, Hitch and colleagues (e.g., Hitch, Halliday, Dodd, & Littler, 1989; Hitch, Halliday, Schaafstal, & Schraggen, 1988; Hitch, Woodin, & Baker, 1989) found that children older than 7 years of age tend to recode pictures into a phonological form.

The above studies and observation of test behaviour in Experiment 1 suggest that older children may spontaneously recode visuo-spatial images into verbal labels, which may in turn assist with the encoding, maintenance, or recall of the images. For example, when static patterns are presented, children may be able to describe the stimuli using verbal labels, which may make reconstruction of the pattern during recall easier. With dynamic presentation, however, children would be required to attempt to verbally recode the paths or vectors that they see. The formulation of a verbal description of a dynamic path may be more complex and lengthy and less likely to assist in its reconstruction. In short, our long-term stored knowledge of recognizable patterns and their verbal labels may be more easily applied to static images than to moving paths.

Experiment 2 therefore directly investigated the possibility that the increasing static advantage with age found in Experiment 1 was due to a greater use of or benefit from simple verbal recoding by the older children. As the observed pattern of findings for the mazes task was highly similar to that for the matrices task in Experiment 1, investigations of concurrent task performance focused only on the matrices task.

In this experiment two groups of children—a younger group, considered unlikely to be using spontaneous verbal recoding of visuo-spatial stimuli and an older group, likely to be familiar with verbal recoding strategies—were presented with the static and dynamic versions of the matrices task. Performance on the matrices tasks when carried out alone was compared to performance when children were carrying out articulatory suppression during encoding
and retention. It was predicted that if the static advantage found in Experiment 1 were simply due to the use of verbal recoding strategies, performance in this version of the task should be impaired relative to when it is carried out alone. However, performance on the dynamic version of the task should be relatively unimpaired by the addition of articulatory suppression. If verbal recoding is not being utilized by the children, performance on the static matrices task should not be affected by the addition of articulatory suppression.

It should be noted, however, that the design just outlined leads to a comparison of performance in a single-task condition with that in a dual-task condition. Consequently, decrements in performance cannot be directly attributed to the prevention of verbal recoding by articulatory suppression. To overcome this, an additional condition was included in the experiment in which the matrices tasks were paired with a spatial tapping task. Such tasks are thought to interfere with spatial processing in particular (Farmer, Berman, & Fletcher, 1986; Smyth & Pendleton, 1989), and inclusion of this condition allows for a secondary prediction to be made regarding the outcome of Experiment 2. That is, if the dynamic version of the matrices task has a greater spatial content than the static version (in line with the similarity of the task requirements to the Corsi blocks task), this task should be more affected by the spatial tapping than the static matrices task.

**EXPERIMENT 2**

**Method**

**Participants**

Two groups of 16 primary school children took part in the experiment. Children were selected from two school years: The younger group (Year 2) had a mean age of 6 years and 10 months (SD = 3.07 months, range = 6.6–7.3 years), and the older group (Year 6) had a mean age of 10 years and 9 months (SD = 3.79 months, range = 10.1–11.5 years). No child was known to have any sensory or educational difficulty.

**Measures and procedure**

Each child was tested individually in a quiet room of the school and completed the tests during two sessions over a 2-week period. Two conditions of the matrices task (matrices static and matrices dynamic) were presented three times to each child: once alone, once combined with articulatory suppression, and once with spatial tapping, giving six test conditions in all. Although for each participant the single task “alone” test condition was always given before the two secondary task conditions, order of presentation of combined test conditions was systematically counterbalanced to prevent order effects.

The matrices tasks were presented to participants as described in Experiment 1. In one session, the three conditions of one of the matrices tasks (either static or dynamic) were presented. The three pattern sets were then allocated to each of the three different conditions of each of the matrices tasks in order to prevent the child from remembering patterns from earlier presented conditions. Details of administration of the “alone”, with articulatory suppression, and with spatial tapping conditions are described as follows. In all six conditions of the experiment, performance was taken as the total number of correct trials on the matrices task before testing was discontinued.

*Matrices task alone (static and dynamic).* In this condition, each of the matrices tasks were given exactly as outlined in Experiment 1.
Matrices task (static and dynamic) with articulatory suppression. Before combining the primary and secondary tasks in this condition, it was ensured that the child had some practice in each of the tasks separately. As children had effectively practised the matrices task during the alone condition carried out directly beforehand, only practice in the articulatory suppression task was given. Children were asked to suppress articulation by repeating the word “table” over and over, as fast as they could. Once the experimenter was happy that the child was performing the secondary task adequately, it was combined with the matrices task.

The child was instructed to begin saying “table”. Once this was happening, the experimenter presented the matrices stimulus on the computer screen, and the child was told to stop articulating when the stimulus disappeared. Recall of the pattern or sequence began immediately after this. Every attempt was made to ensure that children maintained a constant fast pace in their articulation.

Matrices task (static and dynamic) with spatial tapping. Spatial tapping was carried out using a wooden board (18.5 × 18.5 cm) with a peg placed at each corner. Each peg was 2.5 cm in diameter, and there was a gap of 10.5 cm between each of the pegs. For the youngest age group, children were instructed to tap between two pegs only in a horizontal plane. In order to equate difficulty level for the two groups, the older group was asked to tap each of four pegs in turn, moving the hand in a clockwise direction around the board. Before combining the primary and secondary tasks in this condition, it was ensured that the child had some practice in each of the tasks separately. With the tapping board placed to one side, out of view, children were asked to tap between the appropriate pegs as fast as they could. Once the experimenter was happy that the child was performing the secondary task adequately, it was combined with the matrices task.

The child was instructed to begin tapping. Once this was happening, the experimenter presented the matrices stimulus on the computer screen, and the child was told to stop tapping when the stimulus disappeared. Recall of the pattern or sequence began immediately after this. Every effort was made to ensure that children maintained a constant fast pace in their tapping.

Results

The mean number of trials correctly recalled by the 6- and 10-year-old children in the matrices tasks, with and without the addition of the two secondary tasks, is illustrated in Figure 4. Scores were analysed using three-way ANOVAs with factors: age group (6 and 10 years), matrices task format (static and dynamic), and secondary task condition (alone, articulatory suppression, and spatial tapping). This analysis yielded a significant main effect of age group, $F(1, 30) = 50.584, p < .001$, and a significant main effect of task format, $F(1, 30) = 395.657, p < .001$. As in Experiment 1, these main effects were modified by an age group by task format interaction, $F(1, 30) = 12.919, p < .001$. Post hoc tests were carried out in order to investigate differences in performance across the two age groups in the matrices task conditions. Both the 6- and 10-year-old groups performed significantly better in the static condition of the matrices task than in the dynamic condition ($p < .001$). Additionally it was found that in both task formats, the older group significantly outperformed the younger group: for the static, $p < .001$, and for the dynamic, $p < .01$.

The main effect of secondary task was found to be significant, $F(2, 60) = 3.907, p < .05$, and post hoc analysis revealed that while the spatial tapping task significantly reduced matrices performance compared to that in the alone condition ($p < .05$), there were no significant differences between performances in the alone and articulatory suppression conditions. In addition, the effect of articulatory suppression and spatial tapping secondary tasks were not
significantly different from one another. From Figure 4 it can be seen that in all cases performance on the matrices task is lowest when it is paired with spatial tapping.

No significant interaction between matrices task format and secondary task was found ($F < 1$), indicating that neither articulatory suppression nor spatial tapping affected the two matrices task formats differently. Interactions between age group and secondary task were also not found to be significant ($F < 1$), suggesting that there was no difference between the two groups in the degree of interference caused by the secondary tasks to their primary task performance. Finally, the three-way interaction between age group, matrices task format, and secondary task was not found to be significant ($F < 1$).

**Discussion**

Several interesting findings emerge from Experiment 2. First, a significant interaction between age group and the presentation format of the visuo-spatial task was found. As in Experiment 1, performance was better in the static condition and increased more steeply with age in this condition. Second, no significant decline in matrices task performance was observed when children were asked to concurrently articulate when encoding the task stimuli. This was true for both the static and the dynamic versions of the matrices task, suggesting that articulatory suppression did not have a specific detrimental effect on static performance. Recent research has suggested that articulatory suppression may actually improve performance in some visuo-spatial tasks (Pelizzon, Brandimonte, & Favretto, 1999). However, although in the present experiment there is some slight improvement in static matrices performance in the articulatory suppression condition, performance is not significantly better than

![Figure 4](image_url). Mean performance on the matrices task as a function of age group, task presentation format, and secondary task (Experiment 2).
when static matrices is carried out alone. Third, performance on both the static and the dynamic formats of the matrices task was significantly impaired by the addition of concurrent spatial tapping, and the lack of interaction between the matrices task formats and secondary tasks found in this experiment does not lend support to the idea that the dynamic task condition was more severely affected by the concurrent tapping task.

The more dramatic age-related increase in static matrices performance seen in both Experiments 1 and 2 does not appear to be due to the increasing use of simple verbal recoding by the older children. Blocking children’s opportunities to generate verbal labels during encoding of the visuo-spatial stimuli does not significantly impair performance compared to when the matrices task is presented alone. Requiring the children to complete a spatial tapping task during encoding, on the other hand, does significantly impair performance. This is true for the dynamic version of the matrices task, which shares task demands with the Corsi blocks task but, perhaps more surprisingly, is also true for the static matrices task, which is similar to the more visually loaded visual patterns task.

One possible limitation of Experiment 2 concerns the fact that although introduction of a secondary task might be expected to have detrimental effects on the primary task of interest, a trade-off between primary and secondary task performance may occur. In other words, children may have maintained their performance on the matrices task by allowing a decline in secondary task performance, which was not directly measured. Consequently, a third experiment was carried out to verify the findings of Experiment 2. In this experiment matrices task performance was measured in three secondary task conditions: alone, articulatory suppression, and spatial tapping. In addition, articulatory suppression and spatial tapping performance was also measured in three different conditions: Alone, with matrices static, and with matrices dynamic. If simple verbal recoding of visuo-spatial stimuli does have a positive effect on matrices static performance, this will be detectable by decreases in this task condition when paired with articulatory suppression or, similarly, by decreases in articulatory suppression performance when combined with the matrices static task. However, if no decrement in static matrices performance or articulatory suppression is seen when the two tasks are combined, the findings of Experiment 2 are supported, and verbal recoding cannot be considered as the cause of the steeper increase in matrices task performance with age.

One further aspect of the design of Experiment 3 was the addition of an adult group as well as younger and older children, and the addition of a digit recall task for the adult group only. As Experiments 1 and 2 had focused on the performance of children with a maximum age of 11 years, adult participants were included in Experiment 3 to investigate whether the developmental changes in performance on the static and dynamic visuo-spatial tasks were generalizable to adults.

The digit recall task was presented to the adults in three conditions: alone, with articulatory suppression, and with spatial tapping. Two important issues addressed by the addition of the digit recall task were, first, ensuring that the articulatory suppression task used in this and Experiment 2 actually cause disruption to the activity of the phonological loop and, second, that spatial tapping does not cause decrements in performance simply because it is a more difficult task. If the articulatory suppression task chosen in these studies does indeed interfere with verbal coding in working memory, it should significantly impair performance on the digit recall task. The addition of spatial tapping to the digit recall task should not, however, impair performance.
EXPERIMENT 3

**Method**

**Participants**

Two groups of 12 primary school children and one group of 12 adults took part in Experiment 3. Children were selected from two school years: the younger group (Year 2) had a mean age of 6 years and 11 months ($SD = 4.34$ months, range = 6.5–7.5 years), and the older group (Year 6) had a mean age of 10 years and 8 months ($SD = 1.98$ months, range = 10.6–11.1 years). No child was known to have any sensory or educational difficulty. The adult group comprised largely postgraduate students from the Department of Psychology who were paid a small fee for taking part. Participants in this group included 3 males and 9 females, and their mean age was 26.5 years ($SD = 37.82$ months, range = 22.6–31.0 years).

**Measures and procedure**

The different conditions of Experiment 3 were administered to all participants during three sessions over a 2-week period. The 6- and 10-year-old groups completed nine different conditions: matrices static alone, matrices dynamic alone, articulatory suppression alone, articulatory suppression with matrices static, articulatory suppression with matrices dynamic, spatial tapping alone, spatial tapping with matrices static, and spatial tapping with matrices dynamic. The order of presentation was again counterbalanced to avoid order effects, and the three pattern sets were allocated to the different conditions of the matrices task in order to avoid learning of patterns over closely repeated presentations. For the adult group a further three conditions, each involving a digit recall task, were added to the nine conditions outlined previously. Specific details of administration of the different task conditions are outlined as follows.

*Matrices tasks (static and dynamic) alone.* In these two conditions, each of the matrices tasks was administered as described in Experiment 1.

*Matrices tasks (static and dynamic) with articulatory suppression.* Participants were instructed to say the word “table” in order to suppress articulation. In this experiment, all sessions involving articulatory suppression were audiotaped for later analysis. An additional feature was added to the computer program that presented the matrices task, to assist with the scoring of articulation rate—a tone sounded 2 s before the presentation of each matrices stimulus and again as the stimulus disappeared from the screen. As all matrices static stimuli were presented for 2 s, the period of articulation was set at 4 seconds. In the dynamic condition, duration of stimulus was dictated by the number of items in the trial—a two-item trial being present on screen for 2 s, and a five-item trial for 5 s. For this version of the matrices task, therefore, the period of articulation was the number of items plus 2 s for each trial. Recall of the matrices began immediately. During the matrices with articulatory suppression conditions participants were instructed to begin saying the word “table” as fast as they could, as soon as they heard the first tone, and to stop on hearing the second tone. Practice was given in this before the test proper began. The matrices tasks then proceeded as described in Experiment 1 until participants incorrectly recalled two or more trials at a particular difficulty level. For each participant matrices task performance was taken as the total number of correct trials before testing was stopped. Later analysis of articulatory suppression performance from the audiotape was carried out by counting the number of repetitions of the word “table” during each time period, from which a repetitions-per-second measure was calculated.

*Matrices tasks (static and dynamic) with spatial tapping.* In this condition, the matrices tasks were presented with a tone (as outlined previously) to signal to participants to begin and stop tapping. The
materials used for tapping in Experiment 3 were slightly different from those used in Experiment 2, with the main difference being the inclusion of four buttons in the place of the wooden pegs. The purpose of this modification was to allow the use of a tapping counter, which registered the number of times that each of the buttons was pressed. The new tapping box consisted of a metal box with a cylindrical-shaped button at each corner. The box was 14 × 14 cm in size, and each button was located 6.5 cm from the next around the outside of the box. Participants were instructed to tap each button in turn, moving around the box in a clockwise direction, and practice was given to allow fluent and speeded tapping. During the session proper, the tapping box was placed to one side of the participant and was obscured from view by a screen. Consequently, participants were required to keep in mind an image of the tapping box in order to accurately tap around each of the corners.

During the dual–task conditions, the tapping task was paired with the two matrices tasks in the same way as that described for articulatory suppression. Participants began tapping at the sound of the tone (2 s before the stimulus was shown) and stopped at the second tone (when the stimulus disappeared from the screen). Recall began immediately. At the end of each matrices trial, the experimenter recorded the number of taps completed from the counter attached to the tapping box. Matrices task performance was taken as the total number of correct trials before testing was stopped, and spatial tapping performance was recorded as the number of taps per second.

**Articulatory suppression alone.** Participants were instructed to say the word “table” as outlined earlier, and all responses during this condition were audiotaped for later analysis. A total of 10 trials were given, and in order to control for practice effects, 5 of these were administered at the beginning of the articulatory suppression condition (before the dual–task conditions), and 5 were given at the end of the session. To ensure that articulation duration was standardized, the computer-generated tone described earlier signalled the beginning and end of a 5-s period. Later analysis of articulatory suppression performance from the audiotape was carried out as outlined earlier, giving a repetitions-per-second measure of performance.

**Spatial tapping alone.** Using the spatial tapping box and the computer tone described previously, 10 trials of spatial tapping alone were given to each participant. As in the case of the articulatory suppression alone condition, 5 of the trials were given before spatial tapping was paired with matrices, and 5 were given after the matrices tasks, in order to control for practice effects. For each trial the experimenter recorded the total number of taps made during each 5-s period, and a taps-per-second rate was calculated.

**Digit recall—alone, with articulatory suppression, and with spatial tapping.** Digit recall was administered to the adult group only, using an Apple Macintosh C5300 Powerbook. Participants were presented with randomly ordered spoken lists of the numbers 1 to 9, for immediate spoken recall. The task began with four trials of two-item lists, and difficulty level increased every four trials as the list length was extended by one item. Testing continued until two or more errors at a particular list length were made, and performance was taken as the total number of correct trials before testing was discontinued. When paired with the two secondary tasks (articulatory suppression and spatial tapping), the tone described earlier signalled to the participant to begin the secondary task, 2 seconds before the presentation of the digit list. A second tone signalled the end of the list and for the participant to stop articulating/tapping. Articulation and tapping rates were recorded as outlined previously, using the audiotape and tapping counter, and a rate-per-second measure was calculated for both.
Results

Figure 5 indicates mean performance of the three groups on the matrices tasks, in the three secondary task conditions. Scores from the matrices tasks were analysed using three-way ANOVAs to examine the effects of age group, matrices task format (static or dynamic), and secondary task (alone, articulatory suppression, or spatial tapping). Results were very similar to those found for Experiment 2. Both a significant main effect of age group, $F(2, 33) = 34.905, p < .001$, and a significant main effect of matrices presentation format, $F(1, 33) = 499.360, p < .001$, were found. In addition, a significant interaction between age group and matrices task format was again found, $F(2, 33) = 5.625, p < .01$. Post hoc tests indicated that all three age groups performed significantly better in the static condition of the matrices task than in the dynamic condition ($p < .001$). In the static version of the task all three groups performed significantly differently from one another: The 10-year-olds outperformed the 6-year-olds ($p < .01$), and the adults outperformed the 6- and 10-year-olds ($p < .001$ in both cases). However, only the performance of the 6-year-olds and the adults was found to differ significantly in the dynamic version of matrices ($p < .001$).

The main effect of secondary task was found to be significant, $F(2, 66) = 13.994, p < .001$. Post hoc analysis revealed that although the articulatory suppression condition did not produce significantly different matrices performance from that of the alone condition, the spatial tapping condition caused a significant decrement in performance ($p < .001$). In addition, the spatial tapping and articulatory suppression conditions resulted in significantly different matrices performance ($p < .001$). From Figure 5 it can be seen that generally matrices performance is best in the alone condition and worst in the spatial tapping condition.

No significant interaction between matrices task format and secondary task was found ($F < 1$), however, indicating that the static and dynamic formats were not differentially affected by the different secondary tasks. The three-way interaction between group, matrices format and secondary task was also non-significant ($F < 1$). In contrast to the findings of Experiment 2,
however, there was a significant interaction between group and secondary task, \( F(4, 66) = 3.547, p < .01 \). Post hoc analysis across age groups and secondary task conditions was carried out. This revealed that for the 6-year-old group, matrices performances in the spatial tapping alone, and articulatory suppression conditions differed significantly from one another (\( p < .01 \) and \( p < .05 \), respectively). For the 10-year-old and adult groups, however, matrices performance did not differ significantly as a consequence of secondary task condition. There were also some differences between groups in each of the secondary task conditions. In the alone condition, the matrices performance for the 6-year-olds differed from that for the adults (\( p < .001 \)), however, other group comparisons in this condition were not significant. In the articulatory suppression condition, the pattern of findings was the same, with only the 6-year-olds and adults differing significantly in their performance (\( p < .001 \)). In contrast, all three groups differed significantly from one another in their matrices performance when it was paired with spatial tapping. The 10-year-olds outperformed the 6-year-olds (\( p < .01 \)), and the adults outperformed both groups of children (\( p < .001 \) in both cases). Figure 5 illustrates the greater differences in performance as a function of age in this secondary task condition.

In the digit recall task it was found that the adults mean performance was very much lower in the articulatory suppression condition (15.58 trials correct, \( SD = 4.70 \)) than in the alone (23.33, \( SD = 4.83 \)) or spatial tapping (22.08, \( SD = 5.57 \)) conditions. Analysis of variance performed on the digit recall scores yielded a significant main effect of secondary task, \( F(2, 22) = 24.683, p < .001 \). Post hoc analysis indicated that digit recall performance was significantly worse in the articulatory suppression condition than in either the alone condition and the spatial tapping condition (\( p < .001 \) in both cases).

Performance of the three groups on the two secondary tasks (articulatory suppression and spatial tapping) was analysed separately using two-way ANOVAs (Age Group x Matrices Task Format: alone, with matrices static, and with matrices dynamic). Mean performance (in terms of the number of articulations or taps per second) is shown for each task separately in the bar graphs in Figure 6. For articulatory suppression, the mean number of words spoken per second was found to increase significantly with age, \( F(2, 33) = 14.899, p < .001 \), and post hoc tests revealed that the 10-year old group and the adults had a significantly faster articulation rate than 6-year-olds (\( p < .01 \) and \( p < .001 \), respectively), whereas the 10-year-olds and adults did not differ significantly from one another (\( p > .05 \)). In addition, a significant effect of matrices task format was also found, \( F(2, 66) = 23.641, p < .001 \). Post hoc tests indicated that articulatory suppression performance differed significantly in all three matrices task conditions. The number of words spoken per second was greater in both the static and the dynamic matrices conditions than in the alone condition (\( p < .001 \) and \( p < .01 \), respectively), with the static matrices condition producing more articulations than the dynamic (\( p < .01 \)). No significant interaction between age group and the matrices task condition was found, \( F(4, 66) = 2.061, p > .05 \).

In order to examine the effect that digit recall had on the adults’ articulatory suppression performance, a one-way ANOVA was carried out including all four levels of primary task condition (alone, with matrices static, with matrices dynamic, and with digit recall). Mean articulatory suppression performance in the digit recall condition was very similar to that for adults in the other three conditions (see Figure 6) at 2.56 words per second (\( SD = 0.39 \)), and no significant difference in the adults’ articulatory suppression performance was found across any of the four conditions examined (\( F<1 \)).
Figure 6. Mean performance on the articulatory suppression task and the spatial tapping task, as a function of age group and matrices presentation format.
Analysis of scores from the spatial tapping task (number of taps per second) also yielded a significant main effect of age, $F(2, 33) = 20.840, p < .001$, and a significant main effect of matrices task condition, $F(2, 66) = 16.145, p < .001$. Post hoc Sheffé tests indicated that the spatial tapping performance of the 10-year-olds was better than that of the 6-year-olds ($p < .05$), with the adults performing better than both groups of children (for the 6-year-old group, $p < .001$, and for the 10-year-old group, $p < .01$). Similar analysis of the effect of matrices task condition revealed that although the alone and matrices dynamic conditions produced similar spatial tapping performance, the matrices static condition resulted in a significantly greater number of taps per second than did the alone or dynamic conditions ($p < .001$ in both cases).

A significant Group $\times$ Matrices task condition interaction was found, $F(2, 66) = 2.548, p < .05$. This was further investigated using post hoc tests. The effect of the three matrices task conditions on spatial tapping did not significantly differ in the groups of 6- and 10-year-old children. However, for the adults, there was a significant difference between the alone and the matrices static conditions ($p < .01$). Figure 6 indicates that the adults were faster in the matrices static condition than in the alone condition. The effect of group was significant in all three matrices task conditions. In the static and dynamic conditions all three groups differed from one another in their spatial tapping performance ($p < .001$ in all cases). In the alone condition, the same pattern was evident, with the 10-year-old group faster than the 6-year-old group ($p < .01$), and the adults faster than both groups of children (for the 6-year-olds, $p < .001$ and for the 10-year-olds, $p < .05$).

In a similar way to that for articulatory suppression, the effect of digit recall on adults’ spatial tapping was investigated using one-way ANOVA. No significant difference between each of the conditions in which spatial tapping was carried out was found, $F(3, 44) = 1.429, p > .05$, and the mean number of taps per second in the digit recall condition was found to be very similar to that in other conditions (3.02, $SD = 0.76$).

Discussion

The results from Experiment 3, in which both primary (matrices) and secondary (articulatory suppression and spatial tapping) task performances were measured, replicate those from the Experiment 2 in which only primary task performance was measured. A significant interaction between matrices task format and age group was again found, and examination of both matrices static performance and articulatory suppression performance suggests no significant decline in either when they were carried out simultaneously. Consequently, no evidence for the use of simple verbal recoding of stimuli in the matrices static condition emerges from this experiment. This pattern contrasts with that found when the matrices task is paired with spatial tapping. This secondary task causes a significant reduction in matrices performance in both the static and dynamic conditions of the task. Taken together, the results of Experiments 2 and 3 suggest no significant role for verbal recoding in the relatively steeper increase in static performance with age.

In Experiment 3 it has also been possible to demonstrate the absence of a decrement in matrices performance when it is carried out with concurrent articulatory suppression, but a significant decrement in performance when matrices performance is paired with spatial tapping. Moreover, this pattern of findings is not merely due to a failure of the articulatory suppression task to block the activity of the phonological loop, or to the spatial tapping task simply
being more difficult. Examination of the performance of adults on a digit recall task in these two secondary task conditions indicates that performance is significantly impaired by concurrent articulatory suppression, but not by spatial tapping—the opposite pattern to that found for the matrices tasks.

Recent research (Phillips, Wynn, Gilhooly, Della Sala, & Logie, 1999) has examined performance on secondary tasks by calculating the inter-response intervals between output in the secondary task. Using this method it is possible to investigate whether there is variation in secondary task speed in relation to variation in the processing demands of the primary task. Unfortunately examination of the secondary task data in Experiment 3 using this method was not possible due to the way that secondary task performance was measured. However, it is clear that inter-response intervals may well be an important factor to consider in concurrent task studies of working memory.

It is surprising to note that performance on the two secondary tasks is poorest when the tasks are carried out alone. If all 10 trials of the alone condition were administered at the beginning of the testing session, it might be possible to explain this finding in terms of a lack of practice compared to the conditions when the secondary tasks were paired with the matrices tasks. However, presentation of the three matrices task format conditions (alone, with matrices static, and with matrices dynamic) was arranged in such a way that each participant completed five of the alone trials at the beginning and the other five at the very end of the testing session (when most practice with the task had been obtained). Consequently, this poor performance cannot be explained solely in terms of practice and may be the result of overcompensation in performance by participants on the secondary tasks when these are carried out at the same time as an additional task. Most important, this finding does not pose problems for the view that simple verbal recoding is not the cause of the steeper increase in performance on the static visuo-spatial tasks found across the reported studies.

Additionally, it is also surprising to find that, unlike the younger children, the adults' matrices static performance was not detrimentally affected by the addition of spatial tapping. It is not obvious why these older participants were able to perform as well in this secondary task condition as when it was carried out alone. However, one interpretation of this finding is that adults were able to carry out either the primary or secondary task in a different way from the young children. For example, perhaps they were able to recall the static matrix patterns using a more visual strategy, with little reliance on spatial processing. Alternatively, it may be that adults are able to carry out spatial tapping without using visual memory to the same extent as the younger children: Perhaps they do not need to hold an image of the tapping board in mind in order to tap accurately. It could also be the case that carrying out spatial tapping is much more attentionally demanding for the young children, and that executive resources are being utilized by the need to tap the sequence of buttons. Overall it is clear that adults were able to maintain a very uniform level of secondary task performance regardless of whether another task was being carried out, or its nature. Further investigation of these findings seems worthwhile.

GENERAL DISCUSSION

Two key findings have emerged from the three studies in this paper. First, consistent evidence of a developmental dissociation in performance on static and dynamic versions of the matrices
task suggests that it may not be the visual and spatial properties of two tests used in the study of visuo-spatial memory (Corsi blocks and the visual pattern test) but the static and dynamic nature of the tasks that taps different subcomponents of this memory system. It is possible, therefore, that the visuo-spatial sketchpad may be made up of separable components for dealing with visuo-spatial information in the form of static patterns and paths of movement. Moreover, using a second visuo-spatial task in Experiment 1 (the mazes task) it was found that this static-dynamic developmental dissociation could be generalized to other tasks of visuo-spatial memory with static and dynamic components.

Second, no evidence was found to suggest that the pattern of results found in Experiment 1 (in which performance on the static task was superior to that for the dynamic task and increased more steeply with age) was due to the use of simple verbal recoding by children in one task but not the other. Although evidence from previous research suggests that verbal recoding of visuo-spatial information is a strategy that develops in children at around 7 to 8 years of age (Hitch, Halliday, et al., 1989; Hitch, et al., 1988; Hitch, Woodin, & Baker, 1989), concurrent articulatory suppression did not significantly impair performance on the static matrices task. Moreover, this was not due to the articulatory suppression task used in the studies failing to block the activity of the phonological loop, as with adults it was found to significantly impair performance on a digit recall task.

When the matrices tasks were paired with another secondary task, spatial tapping, a significant decrement in both static and dynamic task performance was observed. As the dynamic matrices task shares many task demands with the Corsi blocks task, which has been found to be impaired by the addition of concurrent spatial tapping, it was hypothesized that spatial tapping might cause greater disruption to the dynamic than to the static matrices task. However, although there is some suggestion that the dynamic matrices task shares cognitive resources with spatial tapping to a greater extent than does the static matrices task (spatial tapping performance is significantly lower in the dynamic matrices condition than in the static), it is clear that there is some overlap in processing between both matrices tasks and spatial tapping. This is perhaps surprising in the light of the conceptualization of spatial tapping as a task that utilizes spatial but not visual resources.

This finding clearly points to a need to establish exactly what processes are sampled in a spatial interference task such as tapping pegs on a board (Quinn, 1994; Smyth & Pendleton, 1989). Debate about the nature of this task may perhaps stem from the subtle differences in the way that it is carried out by participants in different studies. Variations in task procedure may result in a different balance of visuo-spatial processes being measured. For example, in the current studies the tapping board was shielded from view, a feature that may emphasize the visual component of the task more than in studies where the tapping board is not shielded from view. In our studies it may have been necessary for some of the participants to hold a visual image of the tapping board in mind in order to locate and tap the pegs, which may account for the extent to which performance on the matrices static task was disrupted by this concurrent activity.

The three studies reported provide further evidence to suggest that short-term memory tasks that involve the recall of either static visual patterns or vectors of movement between spatially and temporally distinct items are handled differently by the visuo-spatial sketchpad. These differences cannot be explained by the use of simple verbal recoding in the static patterns condition. There are, however, other possible strategic explanations for the steeper
developmental increase in matrices static performance than in dynamic performance. One such explanation is the greater potential for use of long-term knowledge regarding geometric structures, which children acquire with schooling (Wilson et al., 1987). Although not actually invoking the use of verbal labels, the recognition of sub-patterns within the abstract stimuli may reduce the need to individually encode every black square in the static matrices stimuli. This may also be true for the static mazes task reported in Experiment 1. It seems less likely that such knowledge would benefit the dynamic version of both of the tasks to the same extent as the static versions. This is clearly a subject for further investigation.

In conclusion, recent research into the structure of the visuo-spatial component of working memory has produced evidence from a number of sources to suggest that visual and spatial information may be maintained by separable subsystems of the visuo-spatial sketchpad. An alternative interpretation of much of this evidence is that it is actually the static and dynamic nature of the information being held in short-term memory that is critical to the activation of different subsystems, and such a notion is supported by evidence of a developmental dissociation for static and dynamic visuo-spatial information as found in all three of the present studies. However, further research is required to investigate the possibility that differences in performance for static and dynamic visuo-spatial tasks may be explained by strategic factors other than simple verbal recoding, such as the greater benefit of long-term knowledge in one task type more than another.

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