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Interference in immediate spatial memory

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It has been suggested that maintenance in visuospatial immediate memory involves implicit motor processes that are analogous to the articulatory loop in verbal memory. An alternative account, which is explored here, is that maintenance is based on shifts of spatial attention. In four experiments, subjects recalled spatial memory span items after an interval, and in a fifth experiment, digit span was recalled after an interval. The tasks carried out during the interval included touching visual targets, repeating heard words, listening to tones from spatially separated locations, pointing to these tones, pointing to visual targets, and categorizing spatial targets as being from the left or right. Spatial span recall was impaired if subjects saw visual targets or heard tones, and this impairment was increased if either a motor response or a categorical response was made. Repeating words heard in different spatial locations did not impair recall, but reading visually presented words did interfere. For digit span only, the tasks involving a verbal response impaired recall. The results are interpreted within a framework in which active spatial attention is involved in maintaining spatial items in order in memory, and is interfered with by any task (visual, auditory, perceptual, motor) that also makes demands on spatial attention.

The maintenance of information in immediate memory has been widely studied, particularly with verbal items such as words and digits. For nonverbal material, much less is known about the ways in which information is maintained over short periods of time, although there is evidence that visual and visuospatial information is not maintained by verbal recoding (Allen, Marcell, & Anderson, 1978). Baddeley (1986) has suggested that visuospatial and verbal material may be held in two separate, passive, perceptual stores with rapid decay in each store prevented by an active control process based on a response system. According to this view, maintenance rehearsal refreshes a trace in immediate memory that decays over time (Baddeley, 1986; Schwieckert & Boruff, 1986). According to Baddeley's (1986) account, if the rate of rehearsal for the complete sequence is less than the rate of decay for any item, then a sequence can be maintained. With verbal materials, this view has been supported by a variety of findings that indicate that the length of time it takes to speak words affects the number of items that can be held in immediate memory. The length of the words to be remembered affects memory span, as does the rate at which subjects can articulate (Baddeley, Thomson, & Buchanan, 1975; Ellis & Hennelly, 1980; Hulme, Thomson, Muir, & Lawrence, 1984; Naveh-Benjamin & Ayres, 1986). The time taken to articulate is thought to affect memory span because the response system that supports maintenance is carried out at the same rate as actual articulation (Baddeley & Wilson, 1985).

In this paper, we are concerned with the maintenance of items in visuospatial immediate memory, particularly with the role of spatial attention. Baddeley (1986) suggested that covert visual attention is involved in maintenance, but this was put forward only as an alternative to his preferred view—that maintenance is based on implicit motor activity. Having argued that the rehearsal of verbal material is based on taking information out of a phonological store and feeding it back by a process similar to articulation, Baddeley argued that rehearsal of visuospatial material is based on taking information out of a passive visual perceptual store and feeding it back by a process similar to eye movements. Evidence from a range of studies using dual-task methodologies supports this view, but does not test it directly. Baddeley and Lieberman (1980) found that pointing at an unseen pendulum that emitted a tone interfered with performance of the Brooks matrix task, and Idzikowski, Dimbleby, Park, and Baddeley (unpublished, cited in Baddeley, 1986) found that concurrent eye movements to visual targets also interfered with matrix memory. Farmer, Berman, and Fletcher (1986) found that tapping in a clockwise direction around a set of four spatial targets interfered with spatial reasoning, and Smyth and Pendleton (1989), using a similar spatial tapping task, found that performance on a spatial memory span task was decreased if subjects carried out spatial tapping during the presentation of the items to be remembered. Hand or eye movements to spatial targets do appear to interfere with other spatial tasks if the two activities are concurrent. These findings are consistent with the view that visuospatial memory is maintained by a system that

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uses motor processes shared by actual movements and that the eye and hand movements used as secondary tasks may prevent the maintenance system from operating.

Three points of interest arise from these studies. One is that if motor processes are involved in maintenance, and memory performance is limited by the rate at which these are carried out, then there may be a strong analogy to be drawn between memory span for verbal items and memory span for spatial items. The second is that secondary tasks in dual-task methodologies (such as articulatory suppression or moving to spatial targets) tend to require explicit responses and therefore make response-based accounts of processes more plausible without actually testing them. The third point is that visuospatial memory does not involve only visually presented material or interference from eye movements; auditory stimuli and hand movements both interfere with memory for visually presented material. This suggests that the interference is indeed spatial, and not visual, and reflects some of the concerns in imagery research as well those in immediate memory. These three points form the basis for the experiments reported in this paper, and we will deal with each of them in turn.

The possibility of a strong analogy between verbal and spatial immediate memory has been investigated by using sequential memory span tasks in both domains (Smyth & Scholey, 1992, in press). Memory span for spatial locations (also known as Corsi block span, or block span) is widely used in neuropsychological contexts as an immediate spatial memory task similar to digit span (Milner, 1971). A set of nine blocks is used, and on each trial a subset of blocks is touched, one at a time, by the experimenter. The subject's task is to repeat the sequence by touching the same blocks in the order in which they were presented. If there is a strong analogy to be drawn between rehearsal of verbal material involving articulation and rehearsal of spatial material involving movements to spatial locations, then the similarity between the verbal and spatial span tasks should allow that analogy to be expressed. In particular, if memory for spatial items is limited by the rate at which rehearsal can take place, then spatial span should be predicted by external measures of movement time, just as verbal span is predicted by external measures of articulation rate. We investigated this by varying the size and distance between spatial targets, so that movement time by hand or eye would increase (Smyth & Scholey, in press), and by measuring the time taken by subjects to make hand and eye movements to spatial targets and correlating this with their spatial span performance (Smyth & Scholey, 1992). We were unable to show an effect of response-based timing increases on span performance. This does not, of course, mean that response-based rehearsal is not used, but simply that we were unable to find an overt measure of it that allowed us to predict span. There is, however, no other direct evidence that motor processes are involved in rehearsal of spatial information.

The evidence that motor processes are involved in spatial immediate memory is indirect, because the secondary spatial tasks that have been used have involved the subject moving from one location to another (Farmer et al., 1986; Moar, 1978; Smyth & Pendleton, 1989). It is helpful for experimenters if secondary tasks can be monitored, and this tends to involve actual responses. However, moving the hand to a target in space does not only require movement, but also a shift of attention in space before, and possibly during, the execution of the movement. Localization by attentional mechanisms is preliminary to accurate motor control (Stein, 1991). It is impossible to discriminate between attention-based and movement-based interference by using movement tasks. In addition, many of these secondary spatial tasks also carry a memory load and have a sequencing component, and they may interfere with spatial memory because general-purpose resources are involved rather than a purely spatial system (Logie & Baddeley, 1990). Dual-task paradigms, therefore, may not be most appropriate in the spatial domain.

An alternative approach is to use interference during a retention interval to investigate maintenance. Researchers who have done this have also tended to use actual movement to a target during the interval, and have produced inconsistent evidence of interference. Smyth and Pendleton (1990) found that subjects' recall of six spatial items in order was decreased when they watched someone else move to spatial targets during an interval. Logie and Marchetti (1991) have shown that moving the hand to spatial targets disrupts recall performance in spatial span, as have Smyth and Pelky (1992) with subspan sets of spatial items. However, Morris (1987) has shown that a secondary spatial task affected recall of five spatial locations if it was carried out during encoding, but no further decrement was shown if it was also present during maintenance, which suggests that maintenance rehearsal does not affect the recall of spatial locations. There are considerable differences between Morris's task and those used in other studies. Subjects had to recall the exact location of each target in Morris's task, not the presence of items of known locations. Recalling the exact location of a target in an array with no identifiable structure may not require rehearsal, or the encoding task may be so difficult that the small number of items encoded can be maintained, even with other tasks. In addition, Morris imposed no order requirement in recall. In other studies, the tasks that do show interference have easily identifiable stimuli, of which five or six can be recalled, and do involve order. However, as discussed above, the reason for that interference is not clear. The secondary tasks involve spatial attention shifts, movement to spatial targets, memory for sequences, and serial output, and any or all of these could be responsible for the decrement in performance.

Interference between presentation and recall of visual material has also been used to separate visual and spatial components of immediate memory. Logie and Marchetti (1991) have indicated that maintenance of spatial sequences is interfered with by hand movements to spatial targets, whereas maintenance of sequences of colors is interfered with by watching irrelevant pictures, suggesting that visual and spatial aspects of nonverbal stimuli can be maintained separately. This supports the distinction made within the imagery literature. Farah, Hammond, Levine, and Calvanio (1988) have suggested that specifically spatial characteristics of imagery can be dissociated from specifically visual components, with both normal subjects and neuropsychological patients. If hand movements interfere with visuospatial memory, and if auditory spatial stimuli interfere with maintenance of visual information, as the earlier experiments indicate, then maintenance by shifts of attention may be characterized as shifts of spatial attention rather than shifts of visual attention.

In the experiments reported here, we used interference between presentation and recall of a sequence of spatial locations to investigate how such sequences are maintained. The first experiment sets out to confirm that interference with memory for a clearly identified set of spatial locations can occur when movements to a spatial target are made during an interval, and that this is not due to accessing long-term memory or to producing sequences of output. In the subsequent experiments, we used a range of interference tasks involving the presentation of spatial and verbal material during the maintenance interval, with the subjects making simple pointing or vocal responses or no response at all. This allowed separation of visual and spatial components of stimuli (items can be heard or seen) as well as comparison of conditions in which no response was required with conditions in which the subject produced movement to a spatial target. In addition, auditory stimuli were used to distinguish between conditions in which covert orienting to separate spatial stimuli occurred, and those in which spatial separation did not lead to shifts in spatial orientation. If maintenance of a sequence of spatial locations involves attention shifts rather than implicit movements, then interference should be found whether the subjects actually move or not. However, as movement to targets imposes extra attentional demands, such movement should lead to further interference.

EXPERIMENT 1

In previous work (Smyth & Scholey, 1992, in press), we have been unable to find any evidence for a response-based rehearsal process that could be linked to hand- and eye-movement time in the same way that subvocal rehearsal can be linked to articulation rate. Because of this, and Morris's (1987) finding that adding a secondary spatial task during an interval did not lead to interference, we have taken a negative view of the possibility of rehearsal in the interval after presentation of a set of spatial locations that are to be remembered in order. The memory task used was a spatial span task, in which subjects are asked to remember a set of spatial targets presented in order. After an interval, they are asked to recall by touching the same targets in the order in which they were presented. The spatial interference task used in this experiment is very close to the spatial span task itself. It involved input that was visual and spatial and required responses that were movements to spatial targets. The interference task consisted of the subject's reaching out to touch visual targets as they were presented, one at a time, during the maintenance interval. Both hand and eye movements were involved, but the task was a simple one, requiring no memory load and no serial ordering other than that required for the motor system to achieve the goal. The subjects did not have to remember the targets in order to produce the responses. If any kind of a response-based control process is involved in maintaining a sequence, this task should prevent that process from being used, although interference by this task can also be explained in terms of shifts of attention. However, if this task does not interfere with the number of spatial locations that can be recalled in order, then any suggestion that such a rehearsal process is involved in the recall of items from a set of nine can be dismissed.

It is, of course, possible that any task will interfere with rehearsal, so we also asked the subjects to recall spatial span items after an interval in which they repeated words that they had heard. This task did not have a spatial or visual component, nor did it involve sequencing or memory, although it was selected to be of approximately the same difficulty as the spatial interference task. The task could, however, be expected to interfere if any verbal recoding was involved in spatial span performance, or if there was nonspecific interference.

Method

Subjects. The subjects were 24 undergraduate volunteers, who were paid for participating.

Materials. The stimuli for the span tasks were presented, and the responses recorded, by a Macintosh IICX computer fitted with a 21-in. Aydin Ranger monitor and a Micro Touch touch screen.

An array of nine squares was used to present the spatial spans, which was based on the Corsi blocks task used by De Renzi and Nichelli (1975). The layout of the nine squares can be seen in Figure 1. On the computer screen the squares were white, outlined in black. They were 4.4 cm square; the maximum distance between the centers of any two blocks was 28 cm, and the minimum distance was 6 cm. When a set of items was presented, each of the squares in the set turned black, one at a time; they also turned black when touched by the subject during recall.

Two interference tasks were carried out between span presentation and recall. In the spatial task, the subjects were asked to touch six targets as they appeared one at a time on the blank computer screen. The targets were squares rounded at the corners and shadowed on the right and along the bottom. They did not occupy the same positions as the items in the span array. The targets were 4×3.8 cm. They were presented one at a time for 2 sec each. In the verbal task there were 20 three-syllable nouns, such as *company* and *hospital*, with a frequency of between 453 (*company*) and 130 (*hospital*) in Francis and Kučera's (1982) word-frequency count. They were recorded in a male voice using Macrecorder; each word was adjusted to take 750 msec to present. Presentation was followed by a 1,250-msec interval. Six words were presented in each trial.

Design and Procedure. The subjects took part in three span conditions: recall after an unfilled interval, recall after an interval with the spatial interference task, and recall after an interval with the verbal task. Order of presentation was counterbalanced. Each subject performed six trials at Set Sizes 3, 4, 5, 6, and 7, in each of the three conditions.

Each subject was tested individually. During span testing, the subjects were seated in front of the touch screen, which rested on

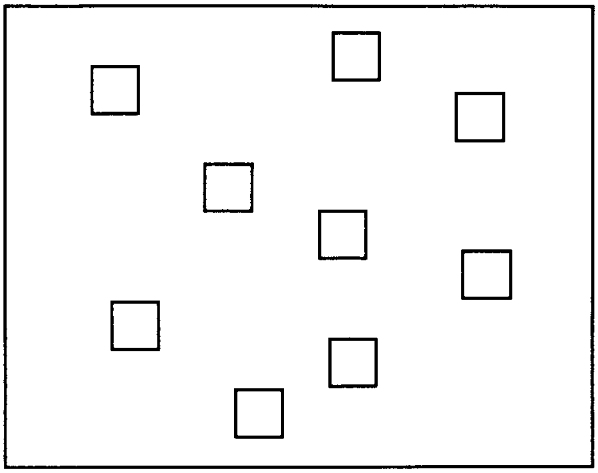

Figure 1. The nine squares presented on the computer screen from which sets of items were selected for sequential presentation in the spatial span task.

a tabletop and was approximately 53 cm from the subjects' eye position. The testing session began with an introduction to the touch screen, in which the subjects discovered that when they touched a shape on the screen, it changed color if they had touched it correctly. Once they were able to touch a set of practice blocks correctly, they were introduced to the spatial span task. This was demonstrated with two items from the set of nine. Two squares turned black in sequence, and the subjects were told that they were to recall the items in the order presented by touching the appropriate blocks in the correct order. They then touched each square in the order in which it had appeared, and each square turned black as it was touched. The subjects had two attempts at recalling a set of two items before moving to the span task proper, in which they had six trials at each span length, from three to seven items in ascending order. The subjects were given no instructions concerning timing of responses, but were only told that the task was to recall the targets in the order in which they were presented. Memory items were presented throughout the session at a rate of one every 1.5 sec. After the end of the memory set, there was an interval of 12.5 sec in all conditions. At the end of the interval, a tone sounded as a cue for recall.

For the interference conditions, the subjects were instructed in the interference task and in the span task with two items before the tasks were combined. They were then asked to try to recall three spatial items after carrying out the interval task. At the beginning of each interval, there was a 500-msec delay followed by six items, each for a total of 2 sec, for a total of 12.5 sec. In the spatial interference task, six rounded targets were highlighted in turn for 2 sec each, and were touched by the subject. In the verbal interference task, the subjects heard a set of six words, each presented for 750 msec with a 1,250-msec interval between them, during which time they repeated each word aloud. The subjects were told that remembering the span sequences was the important part of the experiment and that the intervening items were not to be remembered. The intervening task was demonstrated before it was combined with the memory task, and performance on the intervening task was monitored throughout the experiment.

Results

A trial was scored as correct if all items were recalled in the correct order. The number of correct trials out of six was recorded for each subject at each of the five set sizes in the three interval conditions; the means are shown in Table 1. All analyses reported as significant in this and the subsequent experiments were significant at or beyond the .05 level. A 3×5 analysis of variance (ANOVA) with repeated measures on both factors showed that there was a significant main effect of interference [$F(2,46) = 63.754$, $MS_e = 1.510$], a main effect of set size [$F(4,92) = 129.719$, $MS_e = 1.42$], and a significant interaction [$F(8,184) = 3.199$, $MS_e = 1.031$]. Simple main effects analyses indicated that the interference conditions differed at all levels of set size, and the set sizes differed at all levels of interference task. However, inspection of the means in Table 1 indicates that the size of the difference between the condition in which the targets were touched and the other two conditions was smallest with Set Size 7. Tukey's *HSD* tests indicated that the overall mean for the target-touching condition was lower than that for the other two conditions, which did not differ.

Although a span cutoff procedure was not used in these tasks, it was possible to calculate a span equivalent score that was statistically equivalent to the total number of correct trials for a subject. A span equivalent score allows comparison between these data and those in the subsequent experiments, in which different numbers of trials were used. Span equivalent scores were calculated for each subject for each of the three conditions by counting the number of correctly recalled trials, dividing by 6 (number of trials at each set size), and adding 2, which was the set size above which testing began. So a subject who performed all trials correctly at Set Sizes 3, 4, and 5, but failed all trials at Set Sizes 6 and 7, would have a span equivalent score of 5. Each correct trial above this adds .167 to the span equivalent score. Mean spans for the three interference conditions can be found in Table 1.

Table 1
Mean Number of Correct Trials out of Six at Each Set Size and a Mean Spatial Span Score, After an Interval That was Unfilled or Filled by a Visual–Manual or Auditory–Verbal Interference Task

	Number of Items					Span Equivalent*	
	Three	Four	Five	Six	Seven	*M*	*SD*
Unfilled	5.833	5.250	4.083	3.083	1.333	5.264	.726
Auditory–verbal	5.583	5.000	4.083	2.750	1.167	5.097	.725
Visual–manual	3.708	3.375	2.125	1.375	.792	3.896	.801

*A spatial span score based on the number of correct trials over all set sizes.

Performance on the intervening tasks was error free. The results of the experiment indicate that maintenance is possible during an interval in which subjects repeat words, but is impaired when they are asked to touch spatial targets.

Discussion

This study was not intended to provide an exhaustive account of the causes of interference in spatial span performance. Instead, we attempted to show that the information could be maintained even when another task was carried out in the interval, but that such maintenance was interfered with by activity involving movement to spatial targets. The results indicate that maintenance is indeed interfered with by movement to spatial targets, even when such movement has no memory or sequencing component. The intervening task that interfered is very similar to the primary memory task, and interference may have been due to the similarity of the items, even though the interfering items did not have to be remembered. It is not possible with these data to distinguish between item similarity and rehearsal processes, but in the subsequent experiments the similarity between the two tasks is broken down in order to pinpoint the locus of interference.

EXPERIMENT 2

In the spatial interference task in the first experiment, we presented visuospatial information and required that responses be made to it. It is not possible to conclude that the responses are the only important feature, as it could be the visual nature of the stimuli, their spatial separation, attention to their spatial location, the response selection, or the nature of the response itself that contributes most to the effect. In the second experiment, we investigated this by having visual and auditory spatial targets to which subjects did or did not respond. When a response was required, it could be manual, pointing to a target, or verbal, saying "right" or "left." This allows us to investigate three aspects of maintenance. One concerns input modality and a second concerns the presence of unattended spatial input. These two are linked—if subjects employ an active visuospatial maintenance strategy linked to eye movements, it is unlikely that the presence of spatially distinct *sounds*, to which they do not have to respond, will have any effect on performance. Indeed, it is possible that visuospatial input that does not have to be attended to will also not interfere with active maintenance. However, if maintenance involves shifts of spatial attention, then visual and auditory stimuli may interfere. The third aspect of maintenance under investigation relates to the nature of the response. If maintenance is via a covert motor response, then pointing at spatial targets would be expected to cause most interference. However, there is no reason why motor-based visuospatial rehearsal should be disrupted by making verbal responses to auditory spatial targets. Interference should only occur in this condition if spatial memory is not modality specific and not based on motor processes similar to overt movements.

Method

Subjects. The subjects were 24 undergraduates of the University of Lancaster who volunteered their services and were paid to participate.

Materials. The span task was presented on the same equipment that was used in Experiment 1. In the visual intervening task, we used two targets similar to those in the interference task in the first experiment. These were 5 × 3.5 cm, with midpoints 34 cm apart on the computer screen. The visual angle between them was approximately 40°. For the auditory task, the targets were two tones presented on speakers positioned 160 cm apart (80 cm to the right and left of the subject's midline) and on a line that was 88 cm from the subject at the body's midline. They were therefore to the right and left of the touch screen and 35 cm behind it.

Design and Procedure. Two groups of subjects were used: one performed a visual interference task and the other performed an auditory interference task during the retention interval. Within each group, all the subjects took part in four conditions, with order of presentation randomly selected from a set of all possible orders for each subject. In the four conditions, the task carried out during the retention interval varied. They were an unfilled interval, an interval in which spatial stimuli were presented but not responded to, an interval in which the stimuli were responded to by pointing, and an interval in which the response was to say "left" or "right."

The items to be remembered were presented as in the first experiment, except that the six trials at Set Size 3 were removed and practice was given on two trials with three items, before continuing with six trials at Set Sizes 4, 5, 6, and 7. This was done to reduce the demands made on the subjects who took part in four conditions in this study rather than the three conditions in the first study. In all the conditions there was a 12.5-sec delay before recall. In the no-response conditions, the subjects heard a sequence of six tones, one every 2 sec, or saw six presentations of one of the two visual stimuli, one every 2 sec. The order of right and left presentations was randomized. In the pointing condition, the subjects were asked to point in the direction of the tone or visual target. They did not touch the screen, but sat with their pointing hand in front of them and extended the index finger to indicate the approximate direction of the target. The finger was flexed between stimuli. For the verbal response, the subjects said "right" or "left" in response to each stimulus. They were given practice on the interference tasks before they were combined with the span tasks (five points at tones from the right and left, and five categorizations of tones from each direction). The experimenter monitored performance on the pointing and verbal tasks, which were error free throughout the experiment.

Results

The number of correct trials out of six for each condition and set size were calculated for each subject. The means for the two modality conditions are shown in Table 2. Span equivalent scores (which are statistically equivalent to the overall number of trials correct over the four conditions) were calculated in the same way as in Experiment 1, except that the total divided by 6 was added to 3, as this was the level above which span testing began. The means can also be found in Table 2. A 2×4×4 ANOVA of the number of correct trials with repeated measures on the last two factors showed that there was no significant difference between visual and auditory input ($F < 1$), a significant main effect of interference task [$F(3,66) = 35.761$, $MS_e = 1.580$], and a significant main

Table 2
Mean Number of Correct Trials out of Six at Each Set Size and a Mean Spatial Span Score, With Visual and Auditory Input and Four Response Conditions During the Interval Before Recall

Condition	Number of Items: Four	Five	Six	Seven	Span Equivalent*: *M*	*SD*
			Visual Input			
Unfilled	5.083	4.083	2.750	1.167	5.180	.601
No response	4.250	3.583	1.667	.833	4.722	.730
Verbal response	3.833	1.833	1.000	.167	4.139	.797
Manual response	2.167	2.250	1.000	.750	4.027	.762
			Auditory Input			
Unfilled	5.083	3.750	3.333	1.667	5.305	.699
No response	4.167	2.917	1.833	1.083	4.708	.667
Verbal response	3.833	2.333	.833	.667	4.278	.686
Manual response	3.417	2.000	1.500	.667	4.264	.650

*A spatial span score based on the number of correct trials over all set sizes.

effect of set size [$F(3,66) = 150.449$, $MS_e = 1.180$]. Tukey's *HSD* tests on the main effect of interference task indicated that all differences between means were significant, except for that between the verbal response condition and the pointing response condition. There were no significant two-way interactions with input modality [modality and task, $F < 1$, modality and set size, $F(3,66) = 1.262$], and although inspection of the means suggests that the pointing response with Set Size 4 led to more errors with visual than with auditory input, the three-way interaction was not significant [$F(9,198) = 1.103$, $MS_e = 1.276$]. There was, however, a small but significant interaction between set size and interference task [$F(9,189) = 2.660$, $MS_e = 1.276$]. Simple main effects analyses were of no help in explaining this interaction, but inspection of the means suggested that, overall, the pointing task led to poorer performance at Set Size 4 than did the other three tasks. This was confirmed by removing the pointing condition and repeating the analysis, which removed the significant interaction [$F(6,132) = 1.574$, $MS_e = 1.243$].

Recall performance was poorer after an interval filled with visual and auditory unattended input, and still poorer when either type of input had to be responded to. But response type did not affect overall performance, although it had a small effect when only four items were presented.

Discussion

Spatial span performance is affected by the presentation of spatial input during an unfilled interval, even when no response is required, whether input is auditory or visual. This is in contrast to the finding in the first experiment, in which auditory presentation of nonspatial material that did require a response did not lead to interference. In addition, there is increased interference if a response is required, but it does not matter if the response is verbal or manual. Thus, for the spatial span task, presentation of auditory spatial stimuli that have to be categorized as "left" or "right" leads to considerable interference, and its overall effects cannot be distinguished from those of making manual responses to visually presented spatial stimuli. The interference is therefore spatial, not visual, and it is not purely based on the selection of different spatial targets for manual responses. It is not possible to argue that no internal selection of spatial responses precedes the spoken response, but at least we know that a manual response is not necessary for interference to increase above that found with unattended spatial input. This spatial interpretation of the results of the vocal categorization task is supported by the finding that spatial stimulus-response compatibility effects occur with both left-right vocal responses and left-right manual responses (Weeks & Proctor, 1990).

In both the manual and verbal conditions in this study, there was a spatial target that was responded to. It has been suggested in the literature (e.g., Hitch, 1984) that sequential spatial tasks may have memory characteristics that are different from those that involve the simultaneous presentation of patterns (e.g., Phillips & Christie, 1977), because sequential spatial tasks involve manual motor processes in recall and pattern memory does not. This view may be mistaken. If spatial targets are presented and responded to, there is interference whether responses are manual or not. Interference with the spatial span task in this experiment was from both visual and auditory input and with both manual and verbal responses. These findings suggest that interference is spatial, not visual, and that it is related to covert spatial attention rather than to overt manual responses. These issues are explored further in the following experiments.

EXPERIMENT 3

In Experiment 1, the task of repeating heard words did not interfere with recall of spatial span after an interval, but in Experiment 2, simply listening to tones from one of two locations did interfere. The comparison between these two conditions is not direct, because the auditorily presented words in the first experiment all came from the same location. In Experiment 3, the subjects were asked to attend to and repeat words that came from either the right or the left; recall after this task was compared with recall after repetition of words that were heard as coming from straight ahead. In this situation, the spatial location of the words was secondary to their identity and had no consequences for action. If any kind of unattended spatial input has an effect on spatial attention, then repeating words from different locations might be expected to have effects similar to those found when tones are presented but no response is required. If, however, the level of spatial attention that is involved in maintaining spatial material is at the level of relevance for action, then separating the locations from which words are heard may have no interfering effect. If this is so, then we can conclude that it is not the spatial origin of input that interferes, but the origin in the context of the processing task as a whole. The results for the auditory materials in the present study will be compared with those in Experiment 2, as well as with visual presentation.

Visual presentation of words allows the investigation of the relationship between the spatial location in which a stimulus occurs and its identity. If words are presented auditorily, then eye movements to spatial targets are not required in order to repeat those words. However, if words are presented visually, eye movements will occur. Repeating seen and heard words could, therefore, be expected to have different effects on the maintenance of spatial span because the spatial demands of reading are different from those of listening.

Method

Subjects. The subjects were 36 graduate and undergraduate students of the University of Lancaster, who took part as paid volunteers.

Materials. The span task was presented in the same way as in the previous experiments. The words used in the interference task were 12 of those used in Experiment 1, from which 6 were selected at random on each trial for visual or auditory presentation. Auditory presentation was computer controlled via a pair of speakers arranged in the same way as in Experiment 1. The speakers were used separately in the spatially separated conditions; for the central condition, both speakers were used. In the visual interference condition, words from 5.5 to 7.5 cm long were presented in the center of 13.5 × 2 cm boxes. For the central presentation, one box was shown midway up the computer screen, and for the separated presentation, two boxes were shown at the same height on the screen with a gap of 26 cm between their midpoints.

Design and Procedure. The subjects were run with either visual or auditory presentation of the interference stimuli. Each subject took part in three interference conditions—unfilled, central presentation, and spatially separated presentation. These were balanced for order over groups of 6 subjects.

The presentation of span material was as in the previous experiments. Intervening material was presented 500 msec after the end of span presentation. Each intervening word was presented for 750 msec, with a 1,250-msec interval for the subject to repeat it. Six words were presented, giving a 12.5-sec interval in all. The end of span presentation and the end of the interval were signaled by a tone. The subjects were told that the main task was to remember the spatial items in the order in which they were presented. The intervening word-repetition task was demonstrated before testing, in which the subjects were asked to repeat a set of six words. There were no errors in word repetition during the experiment.

Results

The number of correct trials for each subject was calculated as in the earlier experiments. The mean for each condition can be found in Table 3. Span equivalent scores were also calculated to allow comparison with previous experiments. Separate analyses of the number of correct trials for the auditory and visual intervening task conditions were carried out, so that the auditory condition could be compared with those in the earlier experiments. The results of a 3 × 4 repeated measures ANOVA on the scores for the group performing the auditory intervening task indicated that there was no significant difference between the interval conditions [$F(2,34) = 2.315$, $MS_e = .088$, $p > .10$], a significant main effect of set size [$F(3,51) = 78.35$, $MS_e = 1.763$], and no interaction ($F < 1$). The difference between unfilled recall and recall after separated auditory verbal input was extremely small. A direct comparison between these two conditions and the unfilled interval and unattended tones condition in Experiment 1 produced a significant interaction [$F(1,28) = 5.156$, $MS_e = .883$]. This indicates that the difference between the unfilled and filled conditions was greater when the filled condition involved making no response to tones, compared with when words from different spatial locations were repeated.

Table 3
Mean Number of Correct Trials out of Six at Each Set Size and a Mean Spatial Span Score for Interval Conditions in Which Subjects Repeated Auditorily and Visually Presented Words From Either Spatially Separate Locations or a Central Location

	Number of Items				Span Equivalent*	
Condition	Four	Five	Six	Seven	*M*	*SD*
			Visual Words			
Unfilled interval	5.222	4.611	3.278	2.056	5.528	.728
Central presentation	4.500	3.389	1.944	1.111	4.824	.873
Separated presentation	3.611	2.167	1.389	.722	4.315	.930
			Auditory Words			
Unfilled interval	5.611	4.667	2.667	2.111	5.509	.764
Central presentation	5.333	4.333	3.000	1.778	5.407	.719
Separated presentation	5.278	4.111	2.889	1.500	5.296	.797

*A spatial span score based on the number of correct trials over all set sizes.

The results of a 3 × 4 repeated measures ANOVA on the visual intervening task indicated that there was a significant difference between the conditions [$F(2,34) = 25.391$, $MS_e = 2.367$], and Tukey's analyses indicated that all the conditions differed from each other ($p < .05$). Reading words displayed in a central location interferes with recall of spatial locations, and reading words that appear in different locations adds further interference. Set sizes also differed [$F(3,51) = 94.78$, $MS_e = 1.076$], but did not interact with interval activity [$F(6,102) = 1.224$, $MS_e = 1.073$].

As would be expected from these analyses, the interaction between visual and auditory intervening tasks over the three interval conditions was significant [$F(2,68) = 12.991$, $MS_e = 1.580$]. Simple main effects analyses indicated that the input groups did not differ on the unfilled interval, but did differ on both central and separated presentation. Reading words presented centrally or in different locations interferes with spatial span recall, whereas repeating heard words does not.

Discussion

Repeating words heard from separate locations does not interfere with the recall of spatial items after a short interval. Reading words does interfere, whether the words are presented centrally or in one of two separated locations. Repeating heard words has less effect on recall performance than simply experiencing tones from two separated locations.

The difference between reading and repeating heard words can be explained if we argue that the location of a word in space has to be attended to by active looking in order for it to be read, but that this is not necessary if a heard word is to be repeated. Although speech sounds come from different locations with respect to the perceiver, perceiving them as speech allows spatial information to be ignored. The task used here emphasized the content of the speech signal—not its direction. If speech is perceived as speech in modular fashion, as Fodor (1983) has argued, and this modular system is precognitive, then in this task the output of the speech perception module is attended to and no (or few) spatial effects follow at the memory level. It has been argued that speech is not an auditory signal like all other auditory signals, but has specific speech characteristics (Liberman & Mattingly, 1985). Mattingly and Liberman (1991) have argued that the speech perception module is independent of the module for scene analysis (which deals with the direction of sounds), and comes before it in the architecture of audition. In this account, speech perception makes no use of the representations of the qualities of particular sources of input, and judgments of directionality are based on the output of a precognitive scene analysis module that operates on the nonspeech aspects of the signal. While all of these modules are precognitive, and it is their output that is available to cognition, the special nature of speech as both a directional auditory signal and as input to phonetic processing may have consequences for the way in which spatial orientation to speech sounds is achieved.

If repeating heard words does not necessitate a covert shift of spatial attention to the location from which the words are produced, then auditory spatial input need not interfere with spatial memory. Listening to tones does interfere, which suggests that covert orientation to the location of these nonspeech sounds does occur. For reading, spatial orientation is not covert. The eyes must be directed to a location in space, and if this is under exogenous control, as it is when stimuli appear in one of two locations at random, then further spatial localization is required. While the gaze is actively directed to a location in space, maintenance of spatial items in memory is impaired, although this impairment is not as great as that found when spatial responses are also required.

EXPERIMENT 4

Listening to tones that come from one of two different directions interferes with the ability to recall spatial targets. Making responses to these tones adds further interference, but repeating words from different targets does not. It may be the case that listening to tones and pointing to tones will interfere with any immediate memory task, not only with a spatial one. Tones could, for example, interfere with the ability to engage any rehearsal system, whatever the nature of the material to be rehearsed. To complete the argument that shifts of spatial attention interfere with spatial immediate memory, we need to show that these tasks do not interfere with verbal material. In Experiment 4, subjects were asked to carry out a digit span task with an interval between presentation and recall and during the recall interval they were asked to do nothing, to listen to tones, or to respond to tones either by pointing to the right or left or by saying "right" or "left" appropriately. The conditions were directly comparable to the auditory interference conditions in Experiment 2. If the interference is specific to the spatial memory task used in Experiment 2, then little effect of listening to tones or pointing to tones should be found. However, if the words *right* and *left* have to be selected and produced, this should have a deleterious effect on digit recall because they prevent rehearsal of the set of digits. Thus, interference would be expected only when the intervening task involved the production of a verbal response, and not otherwise.

Method

Subjects. The subjects were 16 undergraduate and postgraduate students of the University of Lancaster, who took part as volunteers and were paid for their services.

Materials. The memory task was a digit span task in which sets of digits were presented in a male voice. The digits were recorded using Macrecorder and adjusted so that each digit was 750 msec long. Sixteen sets of digit strings were generated by random selection, without replacement from the digits 1-9, inclusive. These did not contain obvious patterns of digits. Four sets were assigned at random to each of the experimental conditions for each subject. A 13 × 4 cm white rectangle was used to signal the end of the interval and to cue recall. The interference tasks were the same as in the auditory interference condition in Experiment 2.

Design and Procedure. The subject's task was to recall auditorily presented digits in each of four experimental conditions. In one condition, the interval between presentation and recall was unfilled, and in the remaining three it was filled by six tones presented from speakers to the right and left. In one of the interference conditions, the subjects did not respond to the tones, in the second they pointed to the appropriate direction after the tone was presented, and in the third they said "right" or "left" appropriately after the tone was presented. Each subject took part in all four conditions with order of presentation randomized.

The subjects sat in front of the computer screen used in the previous experiments and were tested individually. The digits were presented at a rate of one every 1.5 sec. At the end of a set of items, there was an interval of 12.5 sec in total, and at the end of that interval a white rectangle on the computer screen appeared to signal recall. Recall was spoken and was scored by the experimenter as it was produced. After recall, the subject touched the rectangle on the screen to signal readiness for the next trial. Following four practice trials with three items, the subjects were given four trials at each set size, starting with four items and increasing by one item until there were eight items in the set. The four interference tasks were presented in the same way as the auditory tasks in Experiment 2. The subjects were given practice on the interference tasks and the memory task before they were combined. Performance on the interference tasks was monitored and was error free throughout the experiment.

Results

The mean number of correct trials at each set size and the span equivalent scores were calculated for each subject over the four conditions. The results can be found in Table 4. The span equivalent scores indicate that performance tended to be higher on the digit span task than on the spatial span task used in the other experiments. A two-factor repeated measures ANOVA on the number of correct scores indicated that there was a significant effect of set size [$F(4,60) = 83.161$, $MS_e = 1.275$], a significant effect of condition [$F(3,45) = 20.399$, $MS_e = .898$], and an interaction between the two [$F(12,180 = 2.460)$, $MS_e = .502$]. Simple main effects analyses indicated that there was no difference between the conditions at Set Size 4 [$F(3,45) = 1.438$, $MS_e = 0.127$, $p > .20$], but that they did differ significantly at all other set sizes. Tukey's tests on the main effect of condition indicated that the interfering task that involved a verbal response led to performance that was poorer than any other condition and that the three remaining conditions did not differ significantly.

Discussion

Listening to tones and pointing to tones does not significantly decrease subjects' ability to maintain a set of digits over an interval. When the tones have to be categorized as coming from the right or left, and the words *right* and *left* have to be produced, the number of digits that can be maintained over the interval decreases significantly. This is presumably because the production of these words interferes with the ability to rehearse the digits. In combination with the results of Experiment 2, we can conclude that hearing and responding to spatial targets does not interfere with verbal memory provided that the response does not involve words, but that interference is found with a spatial memory load, whether words are produced or not. This indicates that the interference effect of spatial stimuli and responses in Experiment 2 is specific to spatial processing.

EXPERIMENT 5

In reporting these experiments, we have presented the data over different sizes of memory sets rather than presenting an overall score for each condition. This is because in the spatial memory task there are indications that interference affects performance, even when comparatively small set sizes are used. Set size either does not interact with the interference task, suggesting that interference has effects even when small numbers of items are presented, or does interact because interference effects are comparatively large with small numbers of items to be remembered. In Experiment 2, we presented three items in order during practice, and began testing with four items in order. It was thought that this would allow the subjects to perform adequately with four items in the set, on the basis of earlier work, of pilot studies with interference tasks, and of the finding that subjects can recall five items in order even when they carry out a spatial suppression task during presentation. However, the data in Experiment 2 indicated that when subjects are required to point at auditory and visual targets, there may be impairments in recall for very short sets, although this effect was small and the three-way interaction between set size, interference task, and input modality was not significant.

Table 4
Mean Number of Correct Trials out of Four at Each of Five Set Sizes and a Mean Digit Span Equivalent Score

	Number of Items					Span Equivalent*	
Condition	Four	Five	Six	Seven	Eight	*M*	*SD*
Unfilled interval	3.937	3.812	3.375	2.000	.875	6.500	.917
No response	4.000	3.687	2.937	1.812	1.250	6.422	.888
Manual response	3.875	3.625	2.750	1.500	1.000	6.188	.824
Verbal response	3.750	2.625	1.562	.687	.187	5.188	.973

*A digit span score based on the number of correct trials over all set sizes.

In a Brown-Peterson paradigm, Vallar and Baddeley (1982) found that articulatory suppression during a recall interval did not affect the recall of three digits. They argued that three digits were within the residual that remains when verbal span is suppressed by the addition of articulatory suppression and therefore were maintained outside the articulatory rehearsal loop. In the present Experiment 4, the verbal interference task did not affect the recall of four items, which supports the view that small amounts of verbal material can be maintained, even when other verbal processing is carried out. Spatial span is reduced from six to approximately five items by the addition of a sequential tapping task during presentation (Smyth & Pendleton, 1989), but recall of three spatial items in order is further affected by tapping a sequence of spatial targets during a 15-sec interval (Smyth & Pelky, 1992). That is, the same task affects both span and subspan sets. There could be two explanations for this difference between verbal and spatial domains. One is that tapping at spatial targets is not analogous to articulatory suppression and uses some resources that are also involved in maintaining the residual spatial span. The other is that maintenance is very different for verbal and spatial material. For verbal material, there are many contributors to immediate memory performance; some of these are susceptible to articulatory suppression whereas others are not. For spatial material of the type used the present studies, the difference between maintaining a small n ˙mber of items and a large number of items is primarily a question of the demands on a single visuospatial maintenance system.

In Experiment 5, subjects were asked to remember two, three, and four items in order. They were asked to recall them after an interval in which they saw or heard stimuli to which they did not have to respond, and after an interval in which they had to point at these stimuli. In the previous experiment, the subjects were very accurate on four items after an interval in which they did not respond to stimuli, so the present investigation concerns the addition of a pointing response and its effects on the recall of very small numbers of spatial items.

Method

Subjects. The subjects were 20 undergraduate and postgraduate students at the University of Lancaster, who volunteered and were paid for their services.

Materials. The materials were the same as those used in Experiment 4.

Design and Procedure. Each trial involved the presentation of a short set of spatial items followed by a 12.5-sec delay, after which time the subject recalled the items by touching the appropriate ones in order. There were two modalities of presentation in the interval (visual and auditory) and two response categories (no response and pointing). Each subject took part in all four conditions and carried out six trials with two, three, and four items in ascending order. Half the subjects had auditory interference followed by visual interference, and half had visual followed by auditory interference. Within these orders, half had no response followed by pointing, and half had pointing followed by no response.

Each subject was introduced to the experiment in the same way as in the previous studies, and two practice trials with one memory item were provided before each condition to accustom the subjects to carrying out the secondary task during the interval. Testing began on two items.

Results

For each subject, the number of correct trials at each level was recorded. The mean numbers correct at each level are shown Table 5. A 2×2×3 ANOVA with repeated measures on all factors indicated that there was a significant main effect of response type, with pointing producing more errors than no response [$F(1,19) = 25.968$, $MS_e = 1.329$], no significant difference between seeing and hearing the stimuli in the interval [$F(1,19) = 2.906$, $MS_e = 1.206$], but a significant interaction between these two factors [$F(1,19) = 4.674$, $MS_e = .750$]. Simple main effects analyses indicated that no response was better than pointing for both visual [$F(1,19) = 25.147$, $MS_e = 25.147$] and auditory stimuli [$F(1,19) = 9.044$, $MS_e = .886$], that there was no difference between auditory and visual stimuli when no response was required ($F < 1$), but that when a pointing response was made, visual stimuli led to more errors than auditory stimuli [$F(1,19) = 4.367$, $MS_e = 1.605$, $p = .050$]. There was also a significant main effect of set size [$F(2,38) = 21.299$, $MS_e = .750$], but no interactions with set size were significant [response × set size, $F(2,38) = 1.889$, $MS_e = .730$; modality × set size, $F < 1$, and response × modality × set size, $F < 1$].

Because set size did not interact with the other variables, it seems highly likely that there were differences between the conditions when only two items had to be recalled, even though the mean in each condition is higher

Table 5
Mean Number of Correct Trials out of Six for Sets Containing Two, Three, and Four Items Following an Interval in Which Subjects Saw or Heard Spatial Stimuli and Either Did Not Respond or Pointed in the Appropriate Direction

Condition	Number of Items: Two	Three	Four	Mean Number Correct Trials
	Visual Input			
No response	5.700	5.600	5.200	5.500
Manual response	5.100	4.600	3.800	4.500
	Auditory Input			
No response	5.700	5.650	5.150	5.500
Manual response	5.300	5.150	4.500	4.983

than 5 out of 6. Separate analyses indicated that the difference between no response and pointing at a target was significant at each set size, including Set Size 2 [$F(1,19) = 9.50$, $MS_e = .526$].

Discussion

Recall of very small sets of spatial items is affected by intervening activity during a recall interval. This activity is not a sequencing task initiated by the subject, as was the tapping task used by Smyth and Pelky (1992), and therefore does not require initiation of a remembered sequence of movements to targets. Rather, the task is simply to respond by pointing in the direction of visual or auditory targets, and it is responding to the targets rather than simply ignoring them that leads to the decrement in recall performance. As in the earlier pointing study, responding to auditory targets led to interference, although it led to less interference than that found when the subjects pointed at visual targets. Although the drop in recall accuracy is very small with only two items in the memory set, it is a reliable decrement.

If a span procedure were being used in these studies, the subjects would often be allowed to proceed to a new level of difficulty if they had succeeded on 50% (i.e., one of two) or 67% (two of three) of the trials at a given level. Such a procedure would not show that interference occurred at two items in the set, on the basis of the data presented here. Given that Smyth and Pelky (1992) have found that movement to spatial targets continues to interfere with recall of three items, even though approximately five items can be recalled in a span paradigm with simultaneous spatial suppression, it may be that there is no residual component of spatial span that can be handled by other immediate memory systems, but rather that specific spatial interference can be seen at all set sizes.

GENERAL DISCUSSION

The results of the present experiments suggest that there is a complex relationship between visual, auditory, spatial, and motor processes in maintaining a sequence of spatial locations in order, but that these may all be integrated within a framework of spatial attention. In this framework, looking has greater demands than listening, and repeating heard words does not make spatial demands. Reading a word presented centrally interferes, but repeating a word heard centrally does not. Reading a word involves actively looking at a location in space, but listening to a word does not involve such a directional element. Repeating heard words interferes less than just listening to tones, which suggests that with the tones there is a shift in spatial awareness. Subjects may not be able to disregard these tones as imperatives to attend to that part of space. However, when a verbal repetition task is involved, it is possible to ignore the directionality of heard words, which is irrelevant to the task.

Increasing the spatial involvement by requiring a judgment of directionality increases interference, whether the response is made verbally or by pointing. This adds more to the visual than to the auditory input condition, indicating a cumulative effect of active looking, spatial input, and spatial output. There is some indication that pointing has an effect with small numbers of items to be remembered and that this adds more to the visual than to the auditory interference, suggesting that selecting and making a motor response directed to a target in space may also increase interference and that this can affect any size of spatial memory load. The Simon effect, in which the direction from which a stimulus appears facilitates responses in the same direction and interferes with responses in other directions, has been characterized by Simon (1990) as a tendency in humans to respond toward the source of stimulation. This suggests that pointing in the direction from which tones have been heard is a tightly coupled link between perception and action.

Interference with spatial immediate memory is therefore neither simply visuospatial nor spatial-motor, but accumulates over all sources of demands on spatial attention. Requiring movement to targets in space in secondary tapping tasks (Farmer et al., 1986; Smyth & Pendleton, 1989) affects spatial processing because action to targets in space is involved. Interference from active eye movements or from tracking of auditory input (Baddeley, 1986; Baddeley & Lieberman, 1980) would also occur, not because active movement was required, but because spatial attention shifts were involved in the planning of such movements. Interference occurs because of active engagement with spatial targets, whether in the external environment or in memory.

Many of the tasks used in other spatial interference paradigms are imagery rather than memory tasks. However, some of these involve the maintenance of spatial information once an image has been created. The Brooks matrix task, in which subjects enter digits into positions in an imagined matrix, is similar in many ways to the spatial task reported here. It involves maintaining an array, locations within it, and the order in which the locations are presented. Logie, Zucco, and Baddeley (1990) have shown that the matrix task does interfere with a matching span version of the spatial span task. What is not clear from this result, or from the studies reported here, is the extent to which temporal order in input is crucial for the interference results or whether maintenance of specific items involves shifts of spatial attention, even though temporal order is not involved. We are currently investigating this issue by using versions of the spatial span task that do not require order at output, and a visual span task (Wilson, Scott, & Power, 1987) that does not have order at input.

Short-term visuospatial memory requires the active maintenance of visuospatial information and is interfered with by tasks that require shifts of spatial attention. This suggests that the maintenance of the information is active, and is similar in some ways to active looking. Such a characterization suggests strong analogies between visuospatial memory and the maintenance of visual images, particularly in relation to the suggestion of Farah (1989), who proposed that visual imagery is like visual attention, and the proposal of Kosslyn, Flynn, Amsterdam, and Wang (1990), who suggested that maintaining a visual image requires effort. Such an analogy would be less successful for short-term verbal memory and auditory images and may have to be treated with caution in the visuospatial domain. In particular, the present task is closer to spatial imagery tasks than it is to visual imagery tasks (Farah et al., 1988) and may not be related to the maintenance of color and form.

The task of saying "right" and "left" to auditory and visual input involves categorical spatial relations, whereas in the pointing task, spatial targets are used to provide coordinates for pointing. These two types of spatial judgment have been implicated in different types of processing and, in particular, in differential activity of the cerebral hemispheres (Hellige & Michimata, 1989). Kosslyn et al. (1990) have suggested that coordinate and categorical spatial relations may have different roles in mental imagery formation and require different information to access. So, for example, knowledge about the position of a television may be categorical (by the window) or may be in coordinates related to movement through the space within the room. We cannot say that the categorical judgments in the present work are not secondary to a coordinate judgment, and that the level of detail required for both types of judgment was the same. However, categorical versus metric interference tasks may be a useful way to investigate spatial and visual memory in general.

In the account of mental imagery put forward by Kosslyn et al. (1990) and elaborated by Kosslyn (1991), maintaining an image created from memory is a special case of image generation, with the generation mechanisms being used repeatedly to refresh a pattem of activation in a visual buffer. It is unclear how such an account would explain performance on a matrix memory task, in which image generation is based on incoming verbal information, not purely on stored long-term representations. The relationship between imagery maintenance and maintenance of visuospatial input needs to be explored further. However, the issue here concerns spatial immediate memory rather than imagery generation as such.

Hanley, Young, and Pearson (1991) reported that spatial immediate memory was impaired in a subject who had difficulties remembering environmental spatial information as well as with spatial imagery tasks, suggesting that spatial immediate memory tasks do relate to processes involved in the construction of spatial memories. The construction of spatial experience and spatial memories may be dominated by visual input in the normally sighted, to the extent that the distinction between visual and spatial sometimes seems irrelevant. However, the blind are capable of carrying out spatial imagery tasks (Kerr, 1983; Marmor & Zaback, 1976), although there is evidence (Cornoldi, Cortesi, & Preti, 1991; Millar, 1975) that more complex spatial tasks in three dimensions are difficult for those who have never had visual experience and therefore must construe space in other ways.

Although sighted subjects are impaired in spatial memory if they have had spatial auditory input during a maintenance interval, which indicates that spatial memory is not purely visual, vision is the sense that is spatially most informative. Vision provides information about the body as well as the objects and events in the world, and the relationship between the body and objects and events in the world, whereas other sensory systems do not (Lee, 1978). Full visual input allows information about eyes, head, and body to be used to produce accurate coding of the location of extemal objects in an environment in which the body is also an object (Conti & Beaubaton, 1980). Other senses do not provide this rich spatial information. Audition cannot be used to discover the relative locations of objects in the environment that are not emitting sounds, and is comparatively poor at providing information about body position and the relationship between the body and the environment. Active touch and proprioception between them can provide information about the position of the body, but information about the relative spatial locations of objects is serial, and information about the relationship between the body and objects in the world is not directly available. Vision allows the space of objects and the space of action to be directly related in ways that are not possible without sight. When we say "spatial" as opposed to "visual," we may mean "visuospatial" for the sighted, because vision has provided the frameworks for space. Indeed, Cornoldi et al. (1991) used the term "visuospatial" for the blind as well as the sighted, which suggests that the tendency for sighted people to conceive of space as visual is very powerful.

If we consider perceptual representations of the locations of objects and events in the world, which are also spatial targets for action, with spatial attentive shifts involved in maintaining these in memory, then it becomes clear that the use of two-dimensional arrays and object-centered tasks may limit our understanding of how space is represented. Franklin and Tversky (1990) have used imagined three-dimensional environments, with subjects' having a location and direction within the environment, and have shown that in this situation mental transformation of location in space is not like that found in object-centered spatial imagery. The emphasis on two-dimensional arrays and on three-dimensional object-centered tasks may be restricting our understanding of spatial memory. The spatial attention shifts reported here may be a product of a strategic system that deals with two-dimensional or object-centered representations, and we do not as yet know whether the space of action can also be maintained in this way.

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