Visuo-spatial Working Memory

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CHAPTER FOUR

Working Memory

In the United Kingdom, the study of short-term memory function over the last 20 years has been influenced to a great extent by the notion of working memory. Working memory refers to the temporary storage and manipulation of information. It is involved in information processing during the performance of a wide range of everyday tasks, as well as in laboratory studies of short-term storage. As I discussed in Chapter 1, working memory grew out of a dissatisfaction in the early 1970s with the idea of a single short-term storage and processing system, characterised most notably in the Atkinson and Shiffrin (1968) model. This led Baddeley and Hitch (1974) to propose a working memory which comprised a number of components. One component, the central executive, was proposed as the system responsible for reasoning, decision making, and coordinating the operation of subsidiary specialised "slave" systems. Two slave systems were proposed initially, namely the visuo-spatial sketch-pad, or VSSP, and the articulatory loop. The visuo-spatial sketch-pad was considered to be responsible for the temporary storage and manipulation of visuo-spatial material, while the articulatory loop provided a similar function for verbal material.

This scheme has remained broadly intact (Baddeley, 1986), although the characterisation of the components of working memory has become somewhat clearer, and the articulatory loop is now often referred to as the phonological loop. The component about which least is known is also the most complex, namely the central executive, although I discussed in

TEE, SORE, THRIVE" and so on. The general disruptive effect of irrelevant speech has also been referred to as the unattended speech effect (Salamé & Baddeley, 1982).

Word Length Effect

A further phenomenon in verbal serial recall is that sequences of long words such as "University, Aluminium, Hippopotamus, Mississippi, Refrigerator" can be recalled rather less well than sequences of short words such as "Pen, Book, Chair, Greece, Nail". This word length effect seems to apply to the length of time required to pronounce the words rather than the number of syllables or letters they contain. Thus sequences of words that can be pronounced fairly rapidly for example "Cricket, Bishop, Parrot" can be retained in sequence rather more readily than can words that take a relatively longer time to pronounce such as "Friday, Typhoon", (Baddeley, Thomson, & Buchanan, 1975).

Articulatory Suppression

Finally, retaining a verbal sequence is dramatically impaired when subjects are simultaneously required to repeat aloud an irrelevant speech sound such as "the, the, the" or "hiya, hiya, hiya" (Levy, 1971, 1975; Murray, 1965, 1968). This technique, known as articulatory suppression, also removes the effect of word length for visual and auditory presentation, and removes the phonological similarity effect but only when the list for recall is presented visually (Baddeley, Lewis, & Vallar, 1984).

Interpreting the Phenomena

This set of findings has been interpreted in terms of a model of the phonological loop comprising two components; a passive phonological store and an articulatory rehearsal process. A diagram of the model in its current form is shown in Fig. 4.1.

According to this model, information that the subject hears goes directly into the phonological store and is maintained in the store by means of subvocal, articulatory-based rehearsal. Information that the subject reads is transferred into the phonological store via articulatory rehearsal.

The model accounts for the effects of articulatory suppression by suggesting that the technique blocks the use of articulatory rehearsal, thereby undermining an important facility for retention. The phonological similarity effect arises because items contained within the phonological store will become confused when they are phonologically similar to one another. As verbal sequences are held in this store whether they are heard

Chapter 1 some of the evidence that this system plays a role in coordinating dual-task performance (Baddeley, Bressi, Delia Sala, Logie, & Spinnler, 1991; Baddeley, Logie, Bressi, Delia Sala, & Spinnler, 1986). However, much remains to be explored.

In contrast, the concept of the phonological loop has become significantly more sophisticated (Baddeley & Logie, 1992; Salamé & Baddeley, 1982, 1989). In this chapter, I shall explore the possibilities of drawing analogies between the characteristics of the phonological loop, and those of the visuo-spatial sketch-pad. Therefore, before going on to describe the literature on the VSSP, it would be useful at this stage to describe the basic findings and phenomena associated with the phonological loop model, and how these findings led to its theoretical development. These phenomena are often thought of *as* the rudiments of verbal short-term memory, and collectively they provide converging evidence for the characteristics of the phonological loop.

THE PHONOLOGICAL LOOP

The Phonological Similarity Effect

This is probably one of the best known phenomena associated with verbal short-term memory, and it was discussed briefly in Chapter 1 as one source of evidence for a distinction between short-term and long-term memory. Specifically it refers to the fact that recall of a series of words or letters is more difficult when the words or letters for recall sound alike. Thus a series such as "Mat, Cat, Fat, Rat, Hat, Chat" is rather more difficult to recall in its original order than is a sequence such as "Bus, Clock, Spoon, Fish, Grate, Men". This effect, known as the phonological similarity effect or as the acoustic similarity effect, has been widely replicated with different sets of materials (e.g. Baddeley, 1966a; Conrad, 1964), and appears for verbal materials that the subject is asked to read as well as for materials that are heard. That is, when subjects are asked to read and remember a verbal sequence they appear to translate the visually presented material into a phonologically based code for temporary storage. When a word is heard it appears to be directly encoded phonologically.

Irrelevant Speech

Verbal serial recall also is disrupted by the concurrent presentation of irrelevant speech. This disruptive effect is even greater when the irrelevant speech comprises words that are phonologically similar to the words for recall. Thus recall of a list of visually presented digits is most impaired by irrelevant speech comprising words that sound like digits "TUN, WOO,

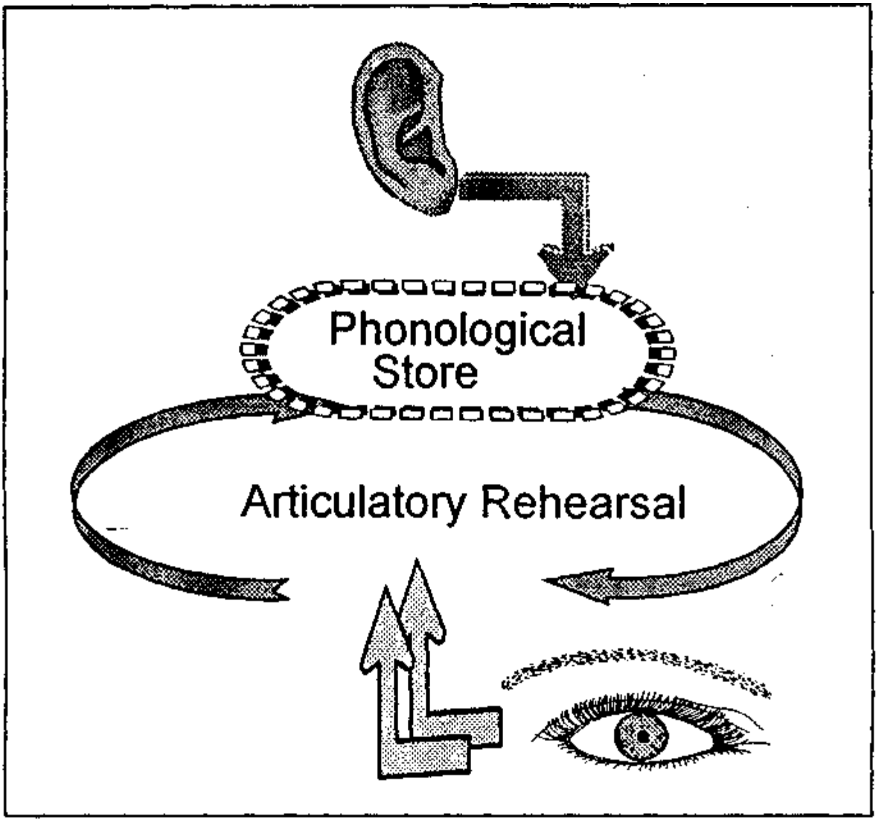

FIG. 4.1. A diagram of phonological loop derived from Baddeley (1986).

or read, the phonological similarity effect appears for both visually presented and auditorily presented material. With articulatory suppression, visually presented material cannot be transferred into the phonological store and the phonological similarity effect disappears. As auditory presentation results in direct input into the phonological store, the potential for phonological confusion remains even with articulatory suppression.

The effect of irrelevant speech arises from the fact that heard speech directly accesses the phonological store, thereby disrupting its current contents.

The word length effect is interpreted as reflecting the operation of subvocal rehearsal. Words that take a longer time to say are more difficult to rehearse, and therefore will be less well retained. Words are rehearsed weather they are heard or read, and therefore the word length effect appears for both visual and auditory presentation. Because articulatory suppression blocks the operation of this function it removes the potential for rehearsing words of different length, and the word length effect disappears. Moreover, the number of items that subjects can retain appears to depend on their speaking rate. For example Hulme, Thomson, Muir, and Lawrence (1984) measured speech rate and verbal memory span in children of different ages. They discovered that the speed at which children can speak increases with their age, and that this increase in speech rate was closely related to an increase with age in short-term verbal memory span.

The strength of the phonological loop model is that with a very simple organisation and few assumptions, it can cope with a number of diverse laboratory findings. In addition, the utility of the model is not restricted to accounting for these specific laboratory phenomena. For example the mean digit span for normal adults using different languages depends on the length of time it takes to pronounce the words for digits in those languages. Thus digit span in Welsh *is* lower than is digit span in English because the Welsh digit words take longer to say than do the English equivalents (Ellis & Hennelley, 1980). The converse is true for a comparison between Chinese and English (Hoosain & Salili, 1988; Stigler, Lee, & Stevenson, 1986). That is, for several dialects of Chinese the words for digits take less time to say than do the English words for digits, and digit span in Chinese is higher as a result. Similar correlations between pronunciation time and digit span have been reported in comparisons of English with Italian, Arabic, Hebrew, and a number of other languages (see e.g. Delia Sala & Logie, 1993; Naveh-Benjamin & Ayres, 1986). The phonological loop also appears to be involved in normal counting (Logie & Baddeley, 1987), in mental arithmetic (Logie, Gilhooly & Wynn, 1994; Dehaene, 1992), in aspects of reading (Baddeley & Lewis, 1981), language comprehension (McCarthy & Warrington, 1987; Shallice, 1988, p.63; Vallar & Baddeley, 1984, 1987), in children's acquisition of language (Gathercole & Baddeley, 1989; 1990), and in adult acquisition of foreign language vocabulary (Baddeley, Papagno, & Vallar, 1988). For more detailed reviews of literature on the phonological loop, see Baddeley (1986) or Baddeley and Logie (1992).

There is also evidence for the phonological loop derived from studies of neuropsychological patients. A number of patients with severe short-term verbal memory deficits have been described who exhibit patterns of deficit and sparing in the phenomena described earlier (for reviews see Caplan & Waters, 1990; Delia Sala & Logie, 1993). On the whole their patterns of deficit are consistent with damage to the phonological storage component of the loop. For example patient P.V. (Basso et al, 1982; Vallar & Baddeley, 1984) has an auditory digit span of just two items, and she fails to show visual presentation for normal adults was reported by Hanley, Young, and Pearson (1991). This is an intriguing debate, but I shall avoid the temptation to discuss it in detail here (see e.g. Logie et al, submitted; Logie, in press). Nevertheless, the notion that some aspects of working memory might be involved in planning response output is a theme that I shall return to later in the book.

VISUO-SPATIAL WORKING MEMORY

Clearly extensive research effort has been directed towards the study of phonological and articulatory components of working memory. The visuo-spatial component of working memory has received much less attention, although there has been considerably more than a flurry of activity in this area over the last few years.

In the working memory literature, visuo-spatial working memory was originally referred to as the visuo-spatial sketch pad. As I mentioned in Chapter 1, this term was later changed to the visuo-spatial scratch pad. This modified term was thought to convey less of an impression of a system that dealt only with pictorial material, and more of a system that could deal with all visuo-spatial material, for example word shape and letter shape (Baddeley, 1986). In practice, the two names are used interchangeably in the literature, or the ambiguity is avoided by using the abbreviation VSSP. As I have hinted already, the concept of a single visuo-spatial working memory system may be rather simplistic in the face of the data collated thus far, and I shall continue to use the more generic term visuo-spatial working memory and the abbreviation VSWM when referring to those functions of working memory that store and process visual and spatial information.

Basic Requirements for Visuo-spatial Working Memory

The model for the phonological loop was based on the accumulation of evidence from a variety of sources. Such a model provided a framework within which to ask theoretically derived questions that could be explored experimentally both with normal subjects and with neurological patients. Until recently, the lack of a substantive body of research on VSWM has been accompanied by a lack of an explicit model or framework for studying visuo-spatial working memory. In other words we need some basis from which to generate and test hypotheses, as well as to provide accounts for patterns of data. In the main, exploration has been largely data driven. A separate, specialised visuo-spatial working memory system has been assumed, and experiments have been designed to explore what might be

With auditory presentation she does show a phonological similarity effect, but does not show a word length effect. These data are interpreted by suggesting that P.V. has damage to the phonological loop. However with heard material, access to this store is direct, and she has no choice but to rely on the damaged system. Although the normal pattern of findings does not appear spontaneously, memory span for visually presented items is rather higher than it is for auditory presentation. One suggestion with these kinds of patients is that for the visually presented material they are relying on some form of visual store, and in the next section of this chapter I shall discuss the evidence from studies of normal subjects for the use of such a store in the retention of visually presented verbal material.

The phonological loop is not without its critics, and a number of complications have arisen. Thus for example, Longoni, Richardson, and Aiello (1993) have shown that retention of verbal sequences in a phonological form is not necessarily dependent on articulatory rehearsal. Specifically, they found that in normal subjects, the phonological similarity effect with auditory presentation survived a delay of 10 seconds between presentation and recall even when this delay was filled with articulatory suppression. Moreover Bishop and Robson (1989) reported that children who have been unable to speak from birth (congenitalanarthrics) nevertheless show word length effects in serial verbal recall tasks. This kind of evidence points to the idea that rehearsal can be phonologically based and that word length effects can arise from the use of phonological coding. For these kinds of reasons, the original term "articulatory loop" is sometimes replaced by the term "phonological loop" (Baddeley & Logie, 1992). Waters, Rochon, and Caplan (1992) have also suggested that some of the phenomena associated with serial verbal recall might arise from the mechanisms responsible for planning speech prior to production of articulation.

An interesting aspect of this evidence for the role of phonological coding is that it does not undermine the conclusion that word length effects can result from the use of subvocal articulation even if it is not the only source of the effect (Martin, 1987; see also Monsell, 1987). As mooted in Chapter 2, subjects can be strategic in their approach to experimental tasks and some normal subjects spontaneously fail to show word length and phonological similarity effects (Delia Sala et al, 1991; Logie et al, submitted). This is accounted for largely by whether or not they have attempted to use subvocal rehearsal when retaining the word list for recall. For example one subject in the Delia Sala et al. study who failed to show the standard effects had a word span of nine items and reported spontaneously using semantic associates and imagery mnemonics to perform the task. When specifically instructed to use subvocal rehearsal the effects of phonological similarity and word length appeared in his data pattern. A similar failure to show the phonological similarity effect with its characteristics. However, some of the basic assumptions underlying these studies tend not to be made explicit.

To tackle these issues I should like to consider a number of basic functions that would be required of any temporary memory system, and will then go on to see how the available data on VSWM fit with these basic requirements.

Any temporary memory system ought to have some means by which information gets into such a memory system from the senses or from longer-term storage. Further, given that information is held on a temporary basis, the system must be subject to a process by which information may be lost over time, either through decay of the memory trace or by interference from new material displacing what is already in the system. Such a system should also have some means to extend the period of retention should this be necessary. Finally, given that it is a system that purports to store or manipulate visual and/or spatial material, the memory codes involved should have some relationship with the characteristics of the visual and spatial material with which the system has to deal.

Given that most of these characteristics are basic requirements of any temporary memory system, it is not surprising that they are similar to some of the basic characteristics incorporated into the model of the phonological loop. Both in its original concept (Baddeley & Hitch, 1974) and in more recent discussions (Baddeley, 1986, 1990; Hanley et al., 1991; Logie, 1989, 1991; Morris, 1987) visuo-spatial working memory has been thought of as complementary to the phonological loop. This view has been supported by an increasing body of data. Thus my approach will be to explore the extent to which the model of the phonological loop might act as a framework for a model of visuo-spatial working memory.

A Possible Cognitive Architecture

One of the recurring themes in the study of the articulatory or phonological loop was that there appeared to be an overlap between the speech system (processing of speech and speech output) and verbal short-term storage, suggested for example by the effects of phonological similarity and of word length, along with the role of phonology and articulation. In the visuo-spatial domain a sensible question appears to be whether there is an overlap between the visual-perceptual system and visuo-spatial short-term storage. I shall discuss this question in three ways—first by exploring whether *visual* similarity among stimuli for retention results in confusions in memory. If the system under scrutiny relies on visual codes then we should expect to find evidence of visual confusions in memory for stimuli that are visually similar to one another. A second approach will be to study spatial information. Specifically, are visual information and spatial information dealt with in similar ways and by the same system, or do they involve two quite separate systems? Third and finally, there is the broader issue of the link between visual short-term storage and visual imagery. I have already discussed this to some extent in Chapters 2 and 3, but will return to the issue later in this chapter, specifically in the context of working memory.

Is There a Visual Similarity Effect?

Do confusions arise in memory for visually similar materials? There is certainly evidence that visual confusions occur when subjects attempt to remember visually presented letters or characters that are visually similar to one another. Hue and Ericsson (1988) reported visual similarity effects in immediate recall of unfamiliar Chinese characters. Wolford and Hollingsworth (1974) reported visual confusion errors in the recall of verbal stimuli that were presented visually, but very briefly.

In a review paper, Frick (1988) argued that images in visual short-term memory are both unparsed and uncategorised. So, for example, Frick reports that when visual confusion errors occur in retention of letters there appears to be independent degradation of parts of the letter. Thus the letter "P" might be mistakenly recalled as an "R". Also, when subjects are asked to retain visually presented numbers, the font in which the number is printed appears to be associated with the incidence of visual confusions rather than the number itself. For example, a square block character for the digit "9" is mistakenly recalled as an "8" more often than if the digit "9" is displayed as a continuous curve (See Fig. 4.2). Despite these confusions, subjects have no difficulty identifying the digits presented in different fonts. This supports the idea that the visual confusions arise because of the nature of the code stored in temporary visual memory, rather than because of difficulties in perceiving the presented digits.

Some as yet unpublished data of our own (Logie, Delia Sala, & Baddeley, in preparation) provide evidence for visual similarity effects in the recall of letter case. Letters were chosen where the upper and lower case versions were visually similar, for example Kk, Cc, Pp, Ss, or were visually different, for example Gg, Bb, Rr, Qq. Therefore, subjects might see a sequence such as "KC P s" or "g B r Q" and would then be asked to write down the sequence in the correct order, and with the correct case for each letter. When subjects had to perform this task and suppress articulation at the same time, they had more difficulty recalling the case of presentation of the letters drawn from the set where the upper and lower case versions of the letters were

This pattern of results led Baddeley and Lieberman to suggest that visuo-spatial working memory did indeed comprise a system that was involved in visuo-spatial retention, in visuo-spatial perception, and in motor control. They also concluded that the system was most likely to be a spatial system rather than a purely visual, or a visuo-spatial system. It was left unclear as to the nature of the system that would retain more visually based material.

In a series of studies of my own (Logie, 1986), I argued that the lack of disruption by a concurrent visual task may have arisen from the spatial nature of the Brooks matrix task and of the method of loci, rather than reflecting the characteristics of the functional system involved in performing the task. If subjects are required to perform a *visual* imagery rather than a *spatial* imagery task, then can performance be disrupted by a concurrent visual task?

The experiments involved subjects retaining a series of words, either by means of the one-bun pegword mnemonic or by means of verbal rote rehearsal. The pegword mnemonic is generally considered to rely on visual imagery for its success in enhancing verbal recall (e.g. Paivio, 1971), and the visual nature of this task was assumed by Baddeley and Lieberman.

These two forms of the memory task (pegword or rote rehearsal) were combined with presentation of irrelevant visual patterns. You may recall from the discussion of the phonological loop that irrelevant speech seemed to have direct access to the phonological short-term store, causing disruption of its contents, and this was the basis for choosing irrelevant visual patterns. I have argued earlier that one of the basic requirements of a visual short-term memory system is that visually presented stimuli should have ready access to such a system. If visual imagery and visual perception involve overlapping cognitive functions, then visual input of irrelevant material should have some disruptive effect on tasks that rely on the use of visual imagery. When presented with the irrelevant visual patterns, subjects were asked to try to ignore the patterns as far as possible, but without closing their eyes or looking away, and to concentrate on remembering the list of words.

The results were clear. When subjects were asked to use the visual mnemonic, concurrent irrelevant patterns disrupted recall. Concurrent pictures had no effect on recall following rote rehearsal. It is possible that the lack of an effect on rote rehearsal was due to the relatively low level of recall with this strategy even without the presence of irrelevant material. This possible alternative interpretation was tested by replacing the irrelevant visual patterns with irrelevant speech. If the initial set of results was due to a floor effect in the rote rehearsal condition, then irrelevant speech should not cause performance to drop any lower than that achieved without the irrelevant material. However when the mem combined with irrelevant speech, rote rehearsal was significantly disrupted while use of the visual imagery mnemonic was largely unimpaired. This then rules out an interpretation based on a possible floor effect. This cross-over interaction is illustrated in Fig. 4.3.

There was one major difficulty with the irrelevant pictures effect, namely that by using pictures it is possible that some form of semantic activation is the basis for the interference. That is, the use of mnemonics involves the semantic features of the material being remembered in order to create a coherent visual image as an aid to later recall. A series of pictures of common objects may also activate the semantic system. Rote rehearsal is less likely to involve semantic coding and this could account for its insensitivity to disruption from irrelevant, but meaningful, visual stimuli.

With respect to the problem of possible semantic intereference, further experiments in the Logie (1986) paper showed similar selective interference effects with square matrix patterns and with coloured squares rather than pictures. The effect for matrix patterns was equivalent to that found for the irrelevant pictures. The selective disruption by coloured squares was present but slight. Both findings undermine an account of the interference effects in terms of semantic interference.

In some very recent studies, Quinn and McConnell (1994) have demonstrated a selective irrelevant visual input effect using a continuously

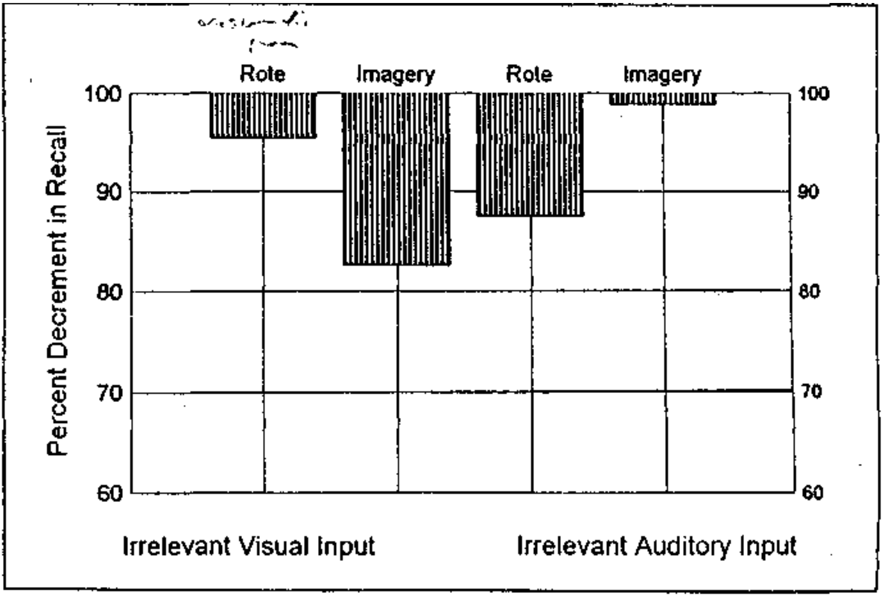

FIG. 4.3. Results from the Logie (1986) studies.

ostensibly spatial tasks. Therefore data from this technique alone are not sufficient, and we have to look for other sources of evidence that might help settle the putative visual versus spatial distinction.

Nevertheless, taken together the studies described earlier and experiments previously discussed are consistent with a temporary storage system for spatial information that also appears to be involved in movement tasks such as tracking. Moreover, there seems to be support for a system that is involved in generating and/or retaining visual images, and which has some role in retaining and in processing visual input. However, the unresolved issue is whether there is a single system that deals with both visual and spatial information, or whether some further fractionation of the system is required. Clearly any theory based on the notion of a single system would have to account for the role of movement and for the link with visual input as well as for the temporary storage functions. This seems an apposite point at which to tackle the issue more directly.

A Case for Fractionation

The neuropsychological evidence discussed in Chapter 1, for a dissociation between short-term and long-term memory, gained considerable momentum from the use of the double dissociation technique (contrasting but complementary patterns of deficits in patients). Similar neuropsychological dissociations have been used in developing and fractionating the phonological loop (Vallar & Baddeley, 1984). The data from Brooks (1967; 1968), Logie (1986), and Baddeley and his colleagues (e.g. Baddeley et al., 1975b; Baddeley & Lieberman, 1980) illustrate the use of an experimental (rather than a neuropsychological) double dissociation. In this case the dissociation is between verbal short-term memory and visuo-spatial short-term memory, respectively comprising two parishes of the diocese of working memory. Data from neuropsychological patients can also be used to dissociate verbal and visuo-spatial short-term memory. This comes from reports of patients with verbal short-term memory deficits, and contrasting patients who appear to have visual and/or spatial short-term memory deficits (De Renzi & Nichelli, 1975; Farah, Hammond, Levine, & Calvanio, 1988; Hanley et al., 1991). A fuller discussion of the neuropsychological data will be given in Chapter 5.

Returning to the data on healthy adults, the studies by Baddeley et al. (1975), Baddeley and Lieberman (1980), by Johnson (1982) and by Smyth and colleagues (1988; 1989) supported the idea that perceptuo-motor performance did seem to require overlapping resources with retention of spatial information. However the nature of the spatial information and the way in which it differs from visual information is really rather vague in the published literature. One way in which to think of the term "spatial" changing dot pattern as the irrelevant visual stimulus. As in the Logie (1986) studies, Quinn and McConnell asked subjects to use a visual imagery mnemonic or rote rehearsal. The irrelevant visual input comprised a display of numerous small squares which randomly turned black or white continuously. They found a very clear disruptive effect of this material on use of the mnemonic, but no dual task impairment of rote rehearsal. Like the matrix patterns in my own studies the material was abstract, and the interference effect is unlikely to be due to semantic interference.

Matthews (1983) reported analogous interference effects in subjects' retention of high- and low-imagery word lists. Mixed lists (high- and low-imagery) of words were presented auditorily while subjects were either asked to perform a shape-matching task or to perform a counting task. After presentation, subjects were asked to recall the word lists. The usual memory advantage for high-imagery words was found in the counting condition, but not in the shape-matching condition. Matthews interpreted this differential disruption of memory for the high-imagery words as reflecting the communal use of a visual imagery based system for dealing both with visually presented shapes and with retention of high-imagery words.

Interference effects have also been found in the spatial domain. Johnson (1982) investigated the effects of a visual interference task on memory for movements. In his experiments subjects were asked to make an arm movement to a stop on a linear track. During a retention interval subjects were asked to make a movement of a different length, or to imagine a movement of a different length, and then to recall the original movement. With both real and imagined interpolated movements subjects' recall was impaired. However in one condition, during the retention interval subjects were asked to watch a visual display showing two asymmetric oscillating wave forms, and at the same time were to imagine a movement. Under these conditions, the biasing effect of the imagined movement was removed, suggesting that watching the moving wave forms disrupted the subjects' ability to imagine a movement.

Smyth and Pendleton (1989; Smyth, Pearson, & Pendleton, 1988) provided further support by demonstrating that when subjects are asked to retain a sequence of presented body movements, then a requirement to simply watch other movements being made during a retention interval interferes with recall of the original sequence. I shall return to the work of Smyth and her colleagues later in the chapter.

In sum, some form of irrelevant visual input appears to offer a tractable technique for studying the nature of visuo-spatial working memory. However whether the observed selective interference effects are primarily visual or primarily spatial remains an open question as interference with variants of this technique has been shown for both ostensibly visual and is as a reference to the location of items in space and the geometric relationships between those items. Visual information might then refer to properties of those items such as their shape, colour, and brightness. Another way in which to use the term "spatial" might be to refer to movement through space, for example scanning or moving from one item to another. A visual representation in working memory might involve retention of static visual arrays which incorporate geometric properties of the layout of objects or the relationship of the parts of a single object to one another. In this sense, to retain a purely visual representation of a scene there need be no distinction between an array of several objects and a visual display of a single object which has a number of components, in a form close to Marr's 2½-D sketch (Marr, 1982). The distinction is only required when we wish to identify objects in the scene in addition to retaining their visual form and their location in space relative to other objects in the scene.

Other interpretations of the term "spatial" may be possible in addition to these, and in the working memory literature at least, the assumed interpretation tends not to be made explicit. This ambiguity in the use of the term "spatial" tends to undermine its utility. One could be very pragmatic and define spatial as referring to a particular meaning of the word, or one could ignore the term altogether and use a less ambiguous vocabulary. In practice it is difficult to avoid the use of the term given its widespread, if equivocal, use in the literature and I lean towards the pragmatic approach. Of course this opens another can of worms, because it is extremely difficult to come up with a concise definition. My own inclination when using the term spatial is to refer to a representation that involves movement in its broad sense, to incorporate imagined movement as well as physical movement. This movement could be in the form of scanning a visual array (via perception or scanning a mental image), or movement to a target in the array (with or without visual input), or movement of objects in an array. It could also involve building up a representation of the geometric relationships between objects by scanning from one to another or moving from one to another. This is a loose description rather than a definition, and it may be that there are better ways of describing the concept behind this description. However this particular use of the term "spatial" is by no means idiosyncratic, as it does map onto at least some of the assumptions that are implicit in much of the working memory literature. The debate becomes more salient if one dips more than a toe into the literature on representation of space or on the neuropsychology of spatial representation. I shall discuss some of the relevant neuropsychological literature in Chapter 5. Some of the literature on normal spatial processing and representation I discuss in this chapter.

One key element of a spatial representation on which most people would agree is that it need not involve any form of visual perceptual inpu for example, the relative physical location of objects can be determined by hearing, by touch, or by arm movement, as well as vision, and few people would dispute that the blind can have spatial representations (e.g. Cornoldi, Cortesi, & Preti, 1991; Kerr, 1983; Millar, 1990). In each of these cases, movement is of course required to build up representations of the relative locations of objects in space. Whether some form of covert movement or imagined movement is required to maintain the representation of those locations, and to process the locational information is a topic that will be a major focus for the last chapter in this book.

In the meantime, when discussing the topic, I shall try to make clear the concepts and the assumptions adopted by the differing researchers cited. However some of the reasons for preferring to incorporate movement into the concept of a "spatial representation" should become clear in the following discussion of temporary memory for movements.

The Role of Movement

Temporary memory for movements has been examined systematically in a series of studies by Mary Smyth and her colleagues. In one set of studies, Smyth, Pearson, and Pendleton (1988) asked subjects to watch an experimenter perform a sequence of simple movements such as a forward bend of the head followed by the left arm raised above the head, a step forward onto the right leg, and so on. After presentation of the movement sequence, subjects were required to reproduce the movements in the order of presentation. Smyth et al. reported that subjects could recall a mean of 4.33 movements in sequential order. This was compared with mean verbal spans of 5.12 for these same subjects. Subjects were then asked to perform the movement span and verbal span tasks concurrently with articulatory suppression, or hand tapping to four switches arranged on a square board, or repeated arm movements. The arm movements involved touching the top of the head with both hands, followed by touching the shoulders, followed by touching the hips, and then returning to the head and repeating the sequence. Smyth et al. reported that the repeated arm movement during presentation impaired recall of the movement sequence but not of the verbal sequence. Articulatory suppression appeared to disrupt memory for the movement sequence as well as for the verbal sequence. Tapping four switches in a square had no effect on recall of the movement sequence.

However in Experiments 3 and 5 Smyth et al. asked subjects to retain a sequence of locations. This involved a task often referred to as "Corsi blocks" (De Renzi & Nichelli, 1975) where the experimenter points to a sequence of blocks chosen from a set of nine blocks arranged randomly on a board. The subjects' task is to recall the sequence of blocks indicated. Performance on the Corsi blocks task was not disrupted by "arm movement brightness judgements had any effect at all is in contrast to the complete lack of an effect reported by Baddeley and Lieberman (1980).

Movement and brightness judgement also had equally disruptive, but small effects on recall of the Brooks verbal material. Moreover, Quinn (1988; 1991) also demonstrated that the disruptive effects on either of the Brooks tasks appeared only if the secondary tasks were performed during encoding of the material. No disruption occurred in dual task performance during a retention interval.

In combination, these results are pointing to some general processing load involved in combining these kinds of tasks. They also suggest that any disruption, whether it is due to specifically spatial interference or due to a more general cognitive load, occurs during encoding and not during temporary retention. This is a crucial point, because the data from the dual task studies involving the Brooks material (verbal or spatial) could be interpreted in terms of some general processing function; a function that deals with visuo-spatial temporary storage only as part of its cognitive remit.

The Role of General-purpose Resources

Some further insight into the problem just discussed might be gained by looking more closely at the assumptions underlying the adopted tasks. One of the assumptions is that the Brooks matrix task relies primarily on visuo-spatial processing and visuo-spatial resources, whereas the verbal version of the task relies primarily on verbal resources. The single and double dissociations reported in the literature (Baddeley & Lieberman, 1980; Brooks, 1968; Logie, Zucco, & Baddeley, 1990; Quinn, 1988, 1991; Quinn & Ralston, 1986) go some considerable way towards supporting the use of different cognitive resources for each of the Brooks tasks. What is missing is any direct test of the general processing load associated with performance of these tasks.

In practice, researchers equate the levels of recall performance on the verbal and matrix versions of the Brooks tasks by adjusting the number of sentences presented on each trial. For example, in the Logie et al. (1990) study, the matrix task involved six sentences, while the verbal task involved only four thereby resulting in control levels of performance of 92% and 88% respectively. In pilot studies where the number of sentences in each task is the same, recall performance for the verbal task is generally poorer than it is for the matrix task. The *explicit* assumption has been that the verbal task is on the whole the more difficult of the two, and hence uses more general-purpose resources in addition to its load on specifically verbal resources (Brooks, 1968). By equating levels of performance, one *implicit* assumption is that this also equates cognitive load.

suppression", but was disrupted by tapping a square pattern of four switches. These data point to a distinction between body movements and movements to specified target locations. The distinction was reinforced by later studies which contrasted Corsi block span with memory for series of hand configurations (Smyth & Pendleton, 1989). These results, together with the evidence discussed earlier, lend added sustenance to the idea that a spatial/movement component of working memory is linked to the planning and control of movement to targets in space.

The role of movement has also been studied by Gerry Quinn in a series of experiments, combining unseen arm movements with the Brooks (1968) matrix task. In the Quinn and Ralston (1986) experiments, subjects had to move their arms around a square matrix taped to the table. The matrix on the table and the subject's arm were covered, and movements had to be completed without the subject being able to see their arm. This ensured that the concurrent movement task did not involve any visual processing. Quinn and Ralston compared the effects of unseen arm movements that were either compatible with the matrix pattern, or were incompatible. For example, say that the Brooks task involved a series of instructions such as "In the starting square put a 1, in the next square to the right put a 2, in the next square down put a 3" and so on. Compatible concurrent movement would comprise an arm movement to the right, followed by an arm movement down. Incompatible arm movement involved tracing out a boustrepedal pattern, where the arm moved to the right along the top row of the matrix, then down to the next row, moving to the left along that row and so on.

Quinn and Ralston found that incompatible movement disrupted recall of the Brooks matrix material, whereas compatible movement did not. They followed up this experiment with a "passive movement" condition where the experimenter held the subject's arm and moved it for them. Even under these conditions, there was a disruptive effect of passive incompatible movement. This finding suggested that the disruption was not due to a general attentional deficit. However, it was unfortunate that Quinn and Ralston did not include a verbal control condition involving the Brooks verbal material. It would have been nice to have demonstrated that retention of the verbal material was insensitive to disruption by movement, as even with passive movement subjects may covertly monitor the movement of their hands.

Quinn (1988) carried out the study just described, combining the Brooks matrix and Brooks verbal material with either arm movement or with brightness judgement. As before, concurrent movement interfered with the Brooks matrix task. However, the brightness judgement task also interfered with recall of the matrix patterns. The level of interference was not as substantial as that associated with arm movement, but the fact that

These assumptions are pragmatically useful for designing experiments, but may not be theoretically secure. Let us assume, for example, that the verbal version of the task places heavy demands on the phonological loop, and that the matrix task places heavy demands on a specialised visuo-spatial system. Given this scenario the different levels of performance achieved for verbal and for spatial processing may reflect cognitive loads on two quite different systems. An assumption that follows from this is that the performance indicators for the two different tasks are directly comparable, but it is a matter of debate as to whether a 50% level of recall performance on the verbal task is necessarily equivalent to a 50% level of recall on the matrix task. We can only be confident about comparability if a single cognitive system underlies the performance of both tasks, and if the performance indicators operate on the same linear scale. Given that the object of much of this enterprise is to try to establish the theoretical utility and the nature of a specialised visuo-spatial system, then at least one of the prerequisites (i.e. a single cognitive resource underlying performance) cannot apply. Thus, equating levels of performance does not guarantee equivalent cognitive processing load. It simply shows that two different tasks can produce equivalent levels on two indicators of performance, given appropriate task demands.

On the evidence discussed so far, there remains considerable uncertainty as to whether performance of the Brooks visuo-spatial task really does rely primarily on a specialised visuo-spatial system or on general-purpose resources. It is also a moot point as to which aspects of functional cognition would be involved in initial encoding of the material, in maintaining the material during a retention interval, and in retrieving the material. Given the suggestion from Quinn's data that a general processing load may be crucial, it would be useful to provide a more direct test of just how much of a general load is involved in the Brooks tasks, given their pivotal role in the theoretical development of visuo-spatial working memory.

One attempt at such a direct test was carried out by Alice Salway (Logie & Salway, 1990; Salway, 1991) who was interested in using a technique known as random generation as a possible indicator of central executive functioning, or of allocation of attention (e.g. Baddeley, 1966c; Evans, 1978; Hayes & Broadbent, 1988; Wagenaar, 1972). Random generation involves asking subjects to generate at random items from a well known and well defined set such as the alphabet or the numbers one to ten. In the latter case subjects might produce a sequence such as "3-7-1-8-4-6-4-8-9-2 … " and so on. A number of studies have shown that random generation appears to involve executive-like cognitive resources in that subjects have to keep track of the frequency with which they generate each item, and to inhibit well learned sequences such as "1-2-3-4-5" or items from outside the set for example "13". Random generation disrupts tasks normally associated with executive processing such as card sorting (Baddeley, 1966c).

Salway equated levels of control performance on the Brooks matrix and the Brooks verbal task, and then asked subjects to perform each version of the task concurrently with oral random generation of numbers at a one per second rate. She also looked at performance with concurrent articulatory suppression and with tapping four switches in a square pattern. Results in terms of the percentage correct on each of the Brooks tasks are shown in Fig. 4.4. What is clear from the figure is that articulatory suppression disrupted performance on the Brooks verbal task but not the Brooks spatial task, whereas tapping four switches had the converse effect. What is also clear is that random generation had a much larger disruptive effect on both Brooks tasks, and statistically, the effect was greater for the matrix task. That is, even though performance on the verbal and matrix tasks were equated before the experiment, verbal random generation disrupted an ostensibly visuo-spatial memory task more than it disrupted a verbal memory task. This raises the strong suspicion that the Brooks tasks place substantial demands on general-purpose resources, with the visuo-spatial version demanding the larger share of such resources.

Another way to approach the problems with interpreting interference effects on the Brooks tasks is to look at performance levels on the same

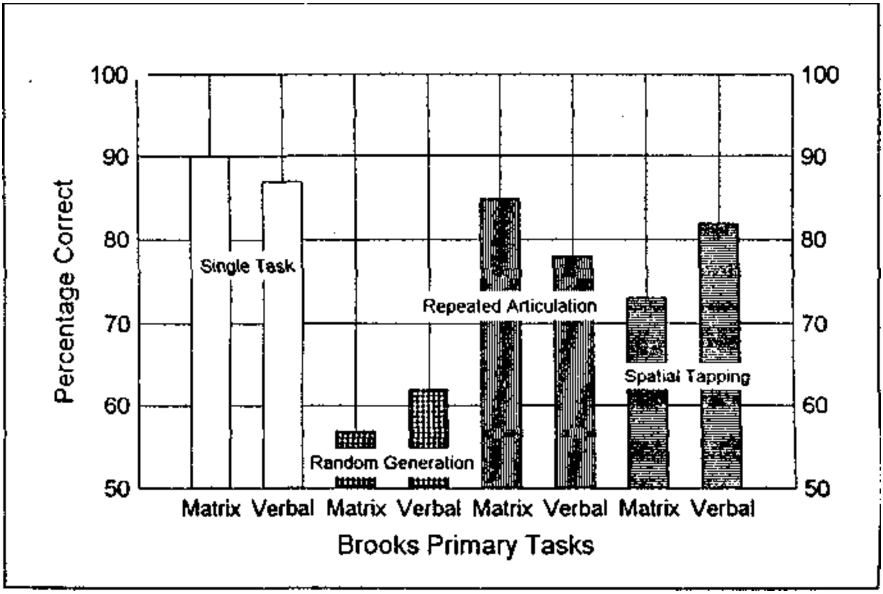

FIG. 4.4. Performance of the Brooks matrix and verbal tasks performed alone and

cannot be taken as clear evidence for the use of a specialised visuo-spatial temporary memory system.

Working Memory and Complex Cognitive Skills

An opportunity to carry out a further investigation of the general load associated with the Brooks material arose from a project concerned with the role of working memory in learning and performing complex cognitive tasks. Logie et al. (1989) studied a small group of subjects learning to perform a complex computer game known as Space Fortress. A diagram of the screen layout for the game is shown in Fig. 4.6.

Space Fortress involved a high level of perceptuo-motor control of a space ship which was manoeuvred around the screen (in a simulated frictionless environment) using a joystick. The game also involved accurate timing of responses, a verbal short-term memory load and the development of long-term and short-term strategies. The general aim of this work was to determine whether performance on the Space Fortress task might be fruitfully subdivided into a number of subcomponent skills. Our approach was to test this directly by means of the secondary task procedures that had proved fruitful in the development of working memory.

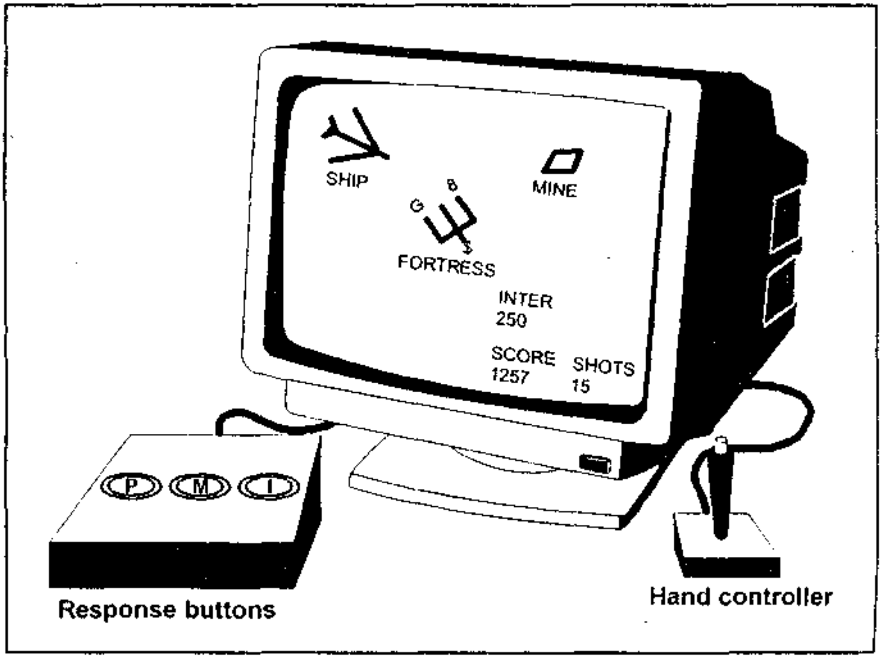

FIG. 4.6. Layout of display and controls for the Space Fortress game used by *Logie et al.* (1989).

task rather than on different tasks. The dual-task methodology allows us to do just that. Instead of comparing performance on the two Brooks tasks, we can compare performance on a single secondary task that is combined in turn with recall of Brooks verbal material or of the number matrix pattern. In this sense we are turning the experiment around, treating the two Brooks tasks as secondary tasks, each of which is combined with a single primary task. With judicious choice of such a primary task where we are fairly confident of a general processing load we might be in a position to determine the relative general processing load involved in each of the Brooks tasks. In Salway's experiments this was accomplished by examining performance on the random generation task as a function of whichever Brooks task it accompanied. The data for this comparison are shown in Fig. 4.5 in the form of the Evans (1978) RNG index of redundancy, where a higher number indicates more redundancy in the responses, or less randomness (i.e. poorer performance). Here again, it appears that the Brooks matrix task resulted in the greatest impairment in performance, although the interaction shown in Fig. 4.5 just failed to reach significance, $F(1,46)=3.37$; $P=0.073$. Nevertheless Salway's results support the suggestion from Quinn's data that the Brooks matrix task probably relies heavily on general-purpose resources, at least during encoding, and thus

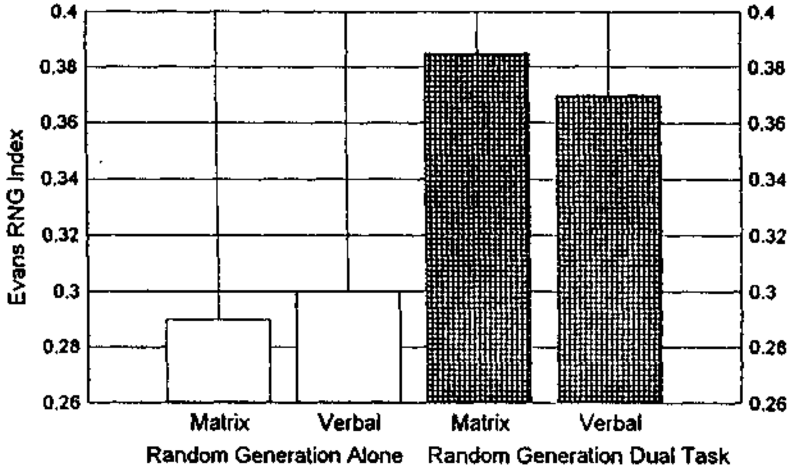

FIG. 4.5. Random generation performance (Evans, 1978, RNG Index) when performed alone and coupled with the Brooks matrix and verbal tasks. Data from Salway (1991).

system that also played a role in movement, but that the storage function was provided by a system that was quite independent of initial encoding.

In the case of the Farmer et al. studies the tapping task was performed concurrently with encoding of both the AB reasoning task and the Manikin test so their data cannot address this particular difficulty. Indeed much of the work on visuo-spatial temporary memory discussed so far has been concerned with visuo-spatial storage and processing as studied during encoding and recall of visual and spatial information. There is very little literature addressing the means by which information is *retained* in visuo-spatial memory tasks.

One further series of studies (in addition to those of Quinn) did directly compare interference effects at encoding with those during a retention interval. Morris (1987) presented subjects with circles shown in random positions on an otherwise blank screen. After the circles were removed subjects had to draw the circles in their appropriate positions. Accurate recall of the positions of the circles was disrupted by non-visual tracking performed concurrently with the presentation of the circle display. However, there was no disruption associated with tracking performed only during a retention interval between offset of the circles and the start of recall of circle positions. Articulatory suppression had no disruptive effect whether performed at encoding or during the retention interval.

Taking the Morris and Quinn results together they seem to suggest that whatever system is involved in encoding the Brooks matrix patterns or the circle patterns is also involved in controlling movement. In terms of the working memory model such findings present something of an anomaly because it seems reasonable to assume that a visuo-spatial scratch pad ought to be involved in temporary *retention* of visual and spatial information as well as its encoding.

A possible interpretation is that the *encoding* of such material places a load on general attentional resources. If we assume that movement control also requires general attentional resources then the disruption observed in both the Quinn and the Morris studies can be interpreted as a general distraction effect rather than reflecting competition for specialised visuo-spatial resources. I have already argued about the inherent difficulty of the Brooks tasks and the argument could in principle also apply to the Morris tasks.

The Role of Spatial Resources

What then is the role of visuo-spatial working memory in these tasks? One possibility is that it is involved in retention rather than encoding and that encoding is more the prerogative of the central executive. There certainly is evidence that the central executive is involved in learning, of which

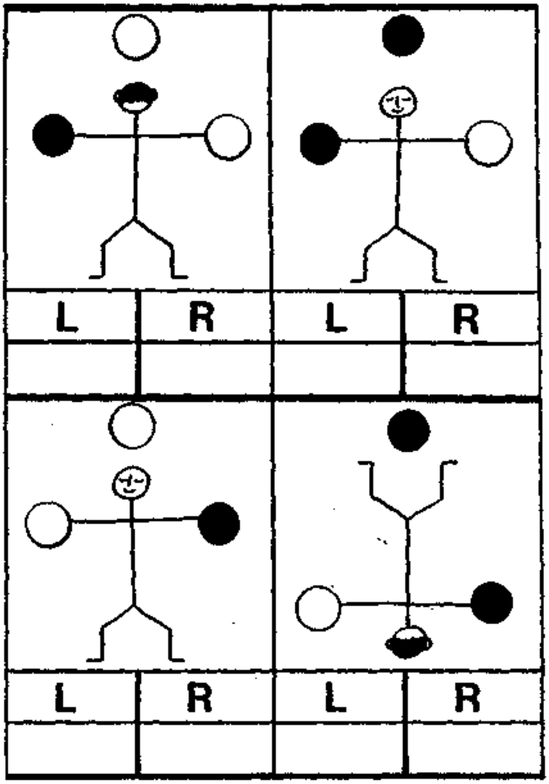

FIG. 4.7. Example stimuli for the Manikin test.

processing. What is rather more surprising about these results is that the AB reasoning task appears to rely on resources other than the phonological loop or visuo-spatial processing. This may give some insight into the characteristics of a central executive involved in reasoning, but this is not a topic for debate in this volume. More pertinent here is that the results also support a distinction between the possibly general-purpose executive system (responsible for reasoning) and visuo-spatial processing involved in tapping and in the Manikin test.

Encoding versus Maintenance

There remains another puzzle arising from Quinn's work, namely the finding that concurrent movement had a disruptive effect during encoding of the Brooks spatial material but not if the secondary task was performed during a retention interval. It seemed as if encoding involved a cognitive

We employed a wide range of secondary tasks chosen to examine the cognitive demands of 17 identifiable components of Space Fortress out of more than 50 measures of performance that were recorded. For the purposes of the discussion here I shall describe the findings for two of these tasks, namely the Brooks matrix and verbal tasks.

In the early stages of training, subjects' performance on Space Fortress was very severely impaired by concurrent performance of either of the Brooks tasks. There was no evidence of differential interference; just a massive, across-the-board performance impairment. In contrast, none of the other secondary tasks had such a general effect on performance. For example a secondary task involving mental comparisons between locations on an imaged map affected only specifically perceptuo-motor control on the game.

After the subjects were more highly practised on the game they began to show differential disruption, with different clusters of performance measures affected by the two different Brooks tasks. The verbal task tended to affect measures of short-term verbal memory load, whereas the matrix task tended to affect components of the game involving perceptuo-motor control.

The interpretation of these findings was that during the early stages of practice, adequate game performance placed very heavy demands on all cognitive resources, (e.g. Gopher, Weil, & Siegel, 1989), and the general processing demands of the two Brooks tasks were indeed fairly substantial. When subjects became more highly practised on the game, the general cognitive processing demands for performance were rather less, and the specific verbal or visuo-spatial nature of the Brooks tasks could be demonstrated. The upshot of this is that the Brooks tasks are generally quite difficult. That is, they both place heavy demands on general cognitive resources in addition to their demands on verbal or visuo-spatial cognitive resources.

In the light of these findings, clearly it would be unwise to rely too heavily on data derived from the Brooks tasks. However, there remains a strong case for a specialised temporary visuo-spatial memory system that is separate from general-purpose resources, because in most of the published reports discussed so far the Brooks tasks were not the only tasks used (see e.g. Baddeley & Lieberman, 1980; Farmer, Berman, & Fletcher, 1986; Logie, 1986; Logie et al., 1989; Logie et al, 1990; Morris, 1987). From among these same studies there is also evidence that this system has a role to play in movement planning and control.

One very neat set of studies that speak to the separation of a visuo-spatial resource from general-purpose resources was reported by Farmer et al. (1986). These authors took the suggestion from Phillips and should be possible to find tasks that place heavy demands on the specialised system without a requirement for central executive capacity. Such a task would interfere with visuo-spatial processing and storage, but would not interfere with the performance of tasks that have a low visuo-spatial load but place substantial demands on general-purpose resources.

Farmer and his colleagues devised a visual tracking task that involved tapping four metal plates placed in a square arrangement on a table in front of the subject. On the basis of previous studies of tracking, this task was taken as one that loaded specialised visuo-spatial resources without loading the central executive. They also used a complementary task, articulatory suppression, to investigate the role of the specialised verbal system, the phonological loop.

As their first primary task, Farmer et al. adopted the Baddeley (1968) AB reasoning task described in Chapter 1. This was thought to place heavy demands on the central executive because of its reliance on logical reasoning but to have a minimal visuo-spatial component. It also appeared to have very little reliance on verbal short-term storage. You may recall that Baddeley and Hitch (1974) found that subjects could hold a sequence of three digits and perform the AB reasoning task without mutual interference. Moreover, Hitch and Baddeley (1976) reported that articulatory suppression had only a very small effect on performance of this task.

Farmer et al. (1986) found that concurrent spatial tapping had no effect whatsoever on performance of even the most demanding of the AB reasoning problems. Articulatory suppression had a small disruptive effect but only for the most difficult problems.

It is possible that these results arose because neither articulatory suppression nor the tapping task was particularly difficult. Thus it is possible that even with the most difficult AB reasoning problems there was still residual capacity in the central executive to perform the tapping test efficiently. In order to test this Farmer et al. replaced the AB reasoning test with a spatial reasoning task which would be more likely to rely on visuo-spatial processing. This was the Manikin test (Benson & Gedye, 1963) which involved the display of a manikin figure holding in one hand a circle, and in the other hand a square. One of these shapes was displayed as a target below the figure. The subject's task was to indicate in which hand the target shape was being held. Examples of the kind of stimuli are shown in Fig. 4.7 where the targets are shown as black or white circles. The manikin figure could be in *a* number of orientations: facing away from or towards the subject, and upright or inverted. In this case there was no effect of articulatory suppression but a substantial impairment was observed with the tapping task.

An initial conclusion from these experiments is that they support the encoding is an important part (see e.g. Baddeley, Lewis, Eldridge, & Thomson, 1984).

One way to approach this apparent setback for visuo-spatial working memory is to consider in more detail the tasks used both by Morris and by Quinn. Their results cause a problem only if we assume that the cognitive processes involved in retaining the Brooks matrix or the Morris circles are similar to the cognitive processes involved in encoding that same material.

In the Brooks matrix task for example subjects are instructed to imagine moving through the squares of an imaged square matrix. Once encoding is complete, however, the subject need retain only a static pattern of the appropriate squares in the imaged matrix. They do not have to retain a sequence of imagined movements. This imagined static pattern can then be used as a mnemonic for later recall.

Thus we can envisage an essentially spatial process of imagined movement during encoding, but something rather more like a static visual image being used during retention. The recall process may also be spatial if we assume that subjects mentally scan their visual image in order to report the retained pattern. Thus a *spatial* process may be involved during encoding and retrieval of a sequence of verbal instructions that describe spatial positions. A *visual* temporary memory system could be responsible for retaining the imaged pattern of numbers in specific locations in a matrix. The same argument could apply to encoding and retention of a display of circles on a screen as in Morris's (1987) experiments.

This seems an appropriate point at which to return to the issue of whether the visuo-spatial scratch pad comprises one or two mechanisms. Many of the data described earlier could readily be accounted for if we were to assume two mechanisms, one spatial (in the sense of the loose definition given previously) and the other visual. It is clear that the initial process of encoding may not only be spatial but also effortful. That is, encoding uses general-purpose resources instead of or in addition to specialised spatial processing, at least in the case of the Brooks material and the Morris circles. Thus the visual temporary memory system would perhaps be more like a subsidiary system that requires little in the way of central executive or general-purpose resources to provide a temporary storage function.

However, there are still some questions unanswered. For example, need we necessarily tie in the spatial memory system with an effortful encoding process? I have already discussed evidence which suggests that the Brooks tasks are inherently effortful, and there remains the possibility of a distinction between memory for genuinely spatial material and the processes involved in initial encoding and in retrieval. That is, how do subjects retain sequences of movement? Do they continue to rely on system for movement? Given the results reported by Farmer et al. (1986) it seems that there is indeed such a separate spatial system.

Some further evidence for this last interpretation comes from a study by myself and a colleague, Clelia Marchetti (Logie & Marchetti, 1991). In this experiment subjects were required to retain information from one or other of two kinds of visually presented displays which we labelled respectively visual or spatial. The visual display comprised the simultaneous presentation of squares, each in a different hue of the same colour, and each shown in a different position on a computer screen. Thus, for example, the squares on any one trial could be shown all in different shades of red or all in different shades of blue. This procedure was adopted to encourage subjects to use a visual code for the colours rather than to rely on colour names. The spatial display consisted of a series of squares (each in a different shade of the same colour) presented one after another, and each at different locations on the screen.

After either the visual display or the spatial display there followed a retention interval of 10 seconds between presentation and a subsequent recognition test. In the case of the visual display subjects were shown squares in the same locations as before, but on 50% of occasions one of the colour hues had been changed. In the case of the spatial display the sequence of squares was repeated with the squares shown in the same locations as before, but on 50% of trials the order of presentation of the squares was altered.

Thus in the visual condition, subjects had to remember the shade of the colour presented in a particular location on the screen. In the spatial condition, subjects had to retain the order in which the squares had appeared at particular locations on the screen.

A primary motivation for this experiment was to explore the characteristics of the memory functions used to store spatial and/or visual material. Therefore we added two conditions involving contrasting secondary tasks performed during the 10-second retention interval. In one condition, the retention interval was filled by a concurrent movement task, along the lines of that used by Quinn (1988; 1991) where subjects had to make unseen arm movements. The contrasting secondary task involved presenting irrelevant pictures. You may recall the evidence that this latter kind of material interferes with the use of a visual imagery mnemonic (Logie, 1986) and the retention of other kinds of visual material (Matthews, 1983).

If the disruptive effects reported by Quinn (1988; 1991) and by Morris (1987) were primarily due to general distraction during stimulus encoding, then we would anticipate no disruptive effect of either secondary task during the retention interval. However, if separate systems are involved rehearsal process, with the latter function related to the control of movement. The rehearsal process would also be akin to some form of mental scanning of the visual representation. Watkins, Peynircioglu, and Brems (1984) have provided evidence for a pictorial rehearsal function, and a number of the studies that I discussed earlier have provided independent support for the relationship between visual imagery and the retention of movements.

According to this interpretation, the retention of the colour hues in the Logie and Marchetti experiment was primarily the responsibility of a passive visual store. Irrelevant visual input is thought to have obligatory access to this store, thus causing disruption of its contents during a retention interval. Retention of a series of movements would be accomplished by the rehearsal mechanism. Because the rehearsal mechanism is also involved in the control of movement, a requirement to generate a series of irrelevant movements would disrupt this rehearsal mechanism, leading to poorer recall of the original movement sequence.

This interpretation has some considerable explanatory power, and has a highly seductive symmetry with the phonological loop described earlier. In this respect the model of the phonological loop as a framework for the VSSP has proved to be fruitful, although I would urge some caution in taking the analogy too far. Also, it generates a number of questions as to the role of the rehearsal function in retaining complex static visual images, as well as retaining information about movement to targets (e.g. Smyth & Pendleton, 1989). In so doing, it provides an extremely useful heuristic for the exploration of the relationships between movement control, visual short-term memory, and the human capacity to generate and manipulate visual images. The model is presented here only in outline, and it will be discussed in more detail in Chapter six. However prior to that it would be useful to discuss the neuropsychological evidence pertaining to visual and spatial temporary memory, to complement the data from healthy subjects that I have discussed so far.

NOTES

1. I am grateful to Peter Bates of the Psychology Department, University of Aberdeen for drawing this figure.

of spatial locations, while the irrelevant pictures (Logie, 1986; Matthews, 1983) should disrupt retention of the colour hues.

The results are shown in Fig. 4.8 from which it was clear that the differential disruption appeared, as predicted by the distinction between specialised systems for retaining respectively visual and spatial information.

This finding was replicated by Tresch, Sinnamon, and Seamon (1993) who asked subjects either to remember the location of a single dot on a screen, or to remember the form of a presented geometric shape. During a 10-second retention interval subjects were either given a movement discrimination task or a colour discrimination task, followed by a recognition memory test for either dot location or for the presented geometric form. As Marchetti and I found, the interpolated movement task disrupted retention of dot location but did not disrupt memory for the form, whereas the colour discrimination task disrupted retention of the geometric form but did not affect memory for dot location.

These results are consistent with separate visual and spatial temporary memory systems; however the picture is still not entirely clear. For example, how is maintenance in such systems accomplished? In a paper published in 1989 (Logie, 1989) I suggested that visuo-spatial short-term memory might comprise two functions; a passive visual store and an active

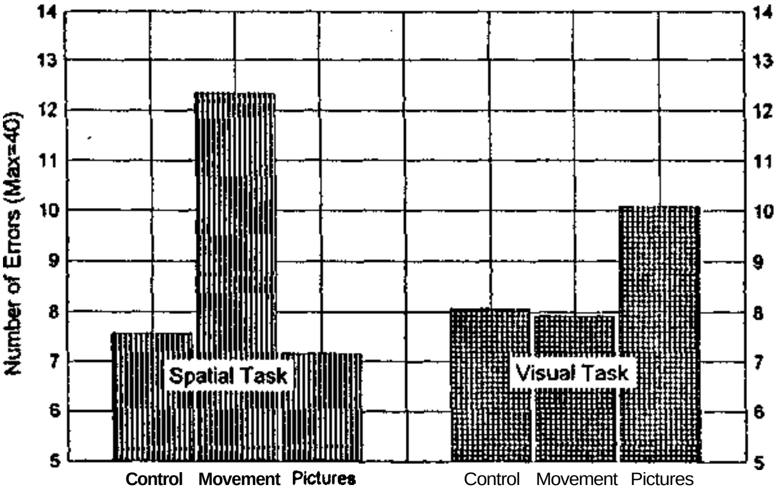

FIG. 4.8. Data from Logie and Marchetti (1991).