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Visuospatial working memory and mental representation of spatial descriptions

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The purpose of the present research is to investigate whether different components of working memory (WM) are involved in processing spatial and nonspatial texts. The interference effects of two concurrent tasks on comprehension and recall of two kinds of text were investigated in two experiments. Each participant listened to a spatial and a nonspatial text, with one of two concurrent tasks: articulatory suppression or spatial tapping. The dependent variables in Experiment 1 were accuracy of recall and verification of information inferred from the texts. In Experiment 2 response times in the verification task were also considered. Results support the hypothesis that verbal and spatial components of working memory are differentially involved in the comprehension and memory of spatial and nonspatial texts, with a selective interference effect of the spatial concurrent task on the spatial text and an interference effect of the verbal concurrent task on both the spatial and nonspatial texts. These effects emerged for recall, sentence verification, and response times. Our findings confirm previous results showing that the verbal component of working memory is involved in the process of text comprehension and memory. In addition, they show that visuospatial working memory is involved, in so far as the text conveys visuospatial information.

The processes involved in the mental representation of space have been studied intensively since the concept of a ‘‘cognitive map’’, introduced by Tolman in 1948. An important feature of cognitive maps is that they can be constructed from different materials and experiences. Indeed, it is possible to construct

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mental spatial representations from navigation, inspection of maps and even from verbal descriptions. The latter is a very common real-life experience, such as when asked to listen to or produce the description of spatial configurations (Denis, 1997; Denis, Daniel, Fontaine, & Pazzaglia, 2001). Important interactions between spatial and linguistic systems within the cognitive architecture have also been reported (Bloom, Peterson, Nadel, & Garret, 1996; Bryant, 1997; Landau & Jackendoff, 1993).

The construction of mental spatial representations from different sources of information is well documented. Little, however, is known at present about the cognitive abilities implied in the construction of spatial representations from different media and, in particular, from verbal input. Moreover, construction is likely to rely on, and be constrained by working memory capacity. Manipulating spatial information derived from text description is also likely to involve visuospatial working memory as well as, or even more than verbal working memory. The aim of the present study, therefore, is to investigate whether constructing mental representations from spatial descriptions involves mainly the visuospatial or the verbal components of working memory.

Baddeley's model of working memory (Baddeley, 1986; Baddeley & Hitch, 1974; Cornoldi & Vecchi, 2003; Logie, 1995) offers a theoretical framework for approaching this question. Working memory is thought of as a temporary storage and processing system with a central executive and two slave systems: the verbal working memory (VWM) and the visuospatial working memory (VSWM). Verbal working memory keeps phonological entries active under the control of an articulated process. Visuospatial working memory maintains spatial and visual information, thus ensuring the formation and manipulation of mental images. Working memory is defined, like in many other models, as the dynamic control and coordination of processing and storage that takes place during the performance of complex cognitive activities, such as language processing and visuospatial thinking (Miyake & Shah, 1999).

Most previous research has focused on tasks implicating one particular subsystem or aspect of working memory within a single domain, but few studies have directly explored the role of VWM and VSWM in text processing. One way to explore this question is to use a dual-task methodology where subjects, while performing a primary task, also have to carry out a concurrent secondary task. The rationale is that if the secondary task competes for the same limited resources of working memory, then performance in the primary task should be less efficient compared with a single task condition. Many studies have explored the effects of various secondary tasks on performance during diverse cognitive activities, and it is now generally agreed that a task, such as articulatory suppression (continuous repetition of a series of digits or syllables) competes for maintenance of phonological information in the VWM, and that tasks such as spatial tapping (continuous tapping of a series of keys or buttons) compete for maintenance of spatial information in the VSWM (see, e.g., Farmer, Berman, &

Fletcher, 1986, for clear selective interference effects in verbal and spatial reasoning tasks).

It is generally acknowledged that VWM, viewed as a combination of the storage and processing of verbal material, is involved in text processing (see for example, Baddeley, 1986; De Beni, Palladino, Pazzaglia, & Cornoldi, 1998; Just & Carpenter, 1992), but direct evidence of the maintenance of phonological traces is scarce and partially contradictory. For example, Baddeley, Elridge, and Lewis (1981) showed that a concurrent phonological task impairs detection of semantic errors in sentences, while a simple tapping task does not. This suggests selective involvement of VWM. However, Waters, Komoda, and Arbuckle (1985) found no such selective interference with a shadowing task.

When texts are concerned with visuospatial information, there is even less evidence for the role of VSWM in text processing. Vandierendonck and de Vooght (1997), who were more concerned with reasoning than with comprehension, tested the use of working memory components with a dual-task paradigm. While reasoning with temporal and spatial relations in four-term series problems, subjects had to perform an articulatory suppression task, a tapping task, and a random interval repetition task. The latter was assumed to interfere with the central executive, placing only a minimal load on the slave systems. Results showed that all three secondary tasks interfered with reasoning accuracy. Moreover, the effects of articulatory suppression were restricted to the problem solution part of the reasoning task, not to the premise reading part. This seems to suggest visuospatial coding of the premise information using VSWM, but no phonological coding.

Until now direct involvement of VSWM in text comprehension has been tested using illustrated texts. The positive effect of pictures in comprehension is generally interpreted in the framework of Johnson-Laird's (1983) theory of mental models (Glenberg & Langston, 1992; Gyselinck, 1995; Gyselinck & Tardieu, 1999; Hegarty & Just, 1993; Kruley, Sciama, & Glenberg, 1994). Pictures are particularly useful for making explicit the relationship between elements described in the text, by helping construct an internal representation that is analogical to that described in the text.

Some authors suggest that the construction of internal representations involves VSWM. For example, Kruley et al. (1994), demonstrated that VSWM is implied in the integration of texts and pictures, when pictures display structural relationships between parts of objects described in the texts. Adopting a dual-task paradigm, they found that memorising illustrated texts interferes with memorising the position of dots on a grid. Their interpretation of this result was that pictures facilitate implementation of an analogical representation of the text and, consequently, that the spatial memory load competes with text comprehension for limited VSWM resources.

Using the same kind of task, Gyselinck, Ehrlich, Cornoldi, De Beni, and Dubois (2000), also investigated the role of VSWM in integrating verbal and pictorial information. In their experiments, participants had to learn a series of physics concepts by means of computer-assisted presentations of illustrated and nonillustrated texts, with and without spatial or verbal interference. The results showed that comprehension was better when pictures accompanied a text, and that this beneficial effect was greater for inferential questions, which suggests a beneficial effect of pictures on the construction of a mental model. However, analyses failed to find an interference effect of visuospatial tasks on illustrated texts, probably due to the specific features of the task and texts.

In a further study, Gyselinck, Cornoldi, Dubois, De Beni, and Ehrlich (2002), showed that with a concurrent spatial tapping task, the beneficial effects of illustration on comprehension disappeared, whereas a concurrent verbal task (articulatory suppression) impaired performance, whether the texts were illustrated or not. Taken together, these studies support specific involvement of VSWM in the integration of texts and pictures, and involvement of VWM in text comprehension.

However, when texts describe spatial configurations or environments, pictures are not essential for an analogical representation from texts. In this regard many studies (Bryant, Tversky, & Franklin, 1992; Denis, 1996; Pazzaglia, Cornoldi, & Longoni, 1994; Perrig & Kintsch, 1985; Taylor & Tversky, 1992; Tversky, 1991) have demonstrated that spatial mental models are spontaneously constructed as a result of reading descriptions of spatial patterns and environments. One unresolved question concerns the extent to which VWM and VSWM concur in constructing spatial models derived from spatial descriptions.

Pazzaglia and Cornoldi (1999, Exp. 2) investigated the involvement of verbal and visuospatial WM in memorising short abstract and spatial texts, by adopting a dual-task paradigm. With reference to Brooks (1967), their abstract texts consisted of sequences of seven short sentences in which numbers were associated with adjectives. For example: ‘‘For the first concept put 1. For the abstract concept put 2. For the common concept put 3.’’ and so on. The spatial texts consisted of instructions that required filling in cells in an imagined 4 × 4 matrix, in order to follow a route inside it (see Brooks, 1967). For example: ‘‘In the first cell put 1. In the one above put 2. In the one to the left put 3.’’ and so on. Participants were required to listen to the texts while performing either concurrent verbal or spatial tasks. The concurrent verbal task was to count backwards by twos starting from 57. In the concurrent spatial task, a sequence of five figures was projected on a computer screen. In the next sequence the figures were presented either in the same order, or with the order of two figures reversed. Participants had to detect when the figure layout was different from the layout immediately preceding it, and press the spacebar only when a change was detected.

The results showed an interference effect of the concurrent verbal and spatial tasks on the abstract and spatial sentences, respectively. The average recall of abstract texts in the concurrent verbal task condition was significantly lower than for the concurrent spatial condition, and recall of spatial texts in the concurrent spatial condition was lower than in the concurrent verbal condition. However, in the absence of a control group who listened to the texts without the concurrent tasks, it cannot be excluded that the verbal task also had an interference effect on the spatial text, or, vice versa, an effect of the spatial task on the verbal text.

Further problems derived from the nature of abstract texts, and from differences between the abstract and spatial texts. Abstract texts were composed of lists of sentences unrelated to each other and listeners could not integrate the meaning of each single sentence in a unique mental model. On the other hand, in spatial texts, each single sentence could be connected to the next to construct a mental model of a virtual route in the matrix. Thus, the different effects of the two concurrent tasks might be due to the fact that in the abstract texts, participants maintained single pieces of information, focusing on superficial features of the text, whereas in the spatial texts they could connect them in a more global model. A comparison of abstract and spatial texts, similar for coherence and composed of strongly connected sentences, should yield clearer evidence.

Further research is thus necessary to analyse whether, and to what degree verbal and visuospatial working memory are specifically involved in comprehension and memory of spatial texts. This is the main goal of the present research, which adopted a dual-task paradigm. In two experiments participants had to understand and memorise a spatial text from a route perspective and a nonspatial text. Concurrently, they performed either a spatial or verbal task. Comprehension and memory performance were tested by recording the units of information recalled in a free recall task and the correct answers given in a verification task of information inferred from the text. The task aimed to assess the construction of a mental model. In the second experiment, response times in the verification task were also recorded.

We predicted that the two concurrent tasks would produce specific interference on memory performance of spatial and nonspatial texts. If constructing a spatial representation involves mainly visuospatial working memory, it should compete with a concurrent spatial task. On the other hand, the construction of a nonspatial representation should not involve VSWM, but VWM, leading to competition with a concurrent verbal task. First, we expected the concurrent spatial task to produce an interference effect on memory of the spatial description, but not for the nonspatial text. Second, considering that information also has a verbal format in the spatial description, we expected a concurrent verbal task to interfere with the comprehension and memorisation of both descriptions. This effect should, however, be less important for the spatial than for the nonspatial description. In addition, this effect should be less marked than that produced by the spatial tapping task.

EXPERIMENT 1

In order to determine the degree to which verbal and visuospatial WM are involved in the comprehension and memory of spatial texts, a dual-task paradigm was used. Participants were presented with a spatial and a nonspatial text, which were similar for coherence, and comprised closely linked sentences. The spatial text involved a route perspective (Taylor & Tversky, 1992) and was a description of a specific route in an open, large-scale environment. This is a special case of spatial text in which directional instructions are given. The nonspatial text comprised a description of wine production. Texts were presented aurally, since this has been found to facilitate analogical representation of visuospatial text content (De Beni, Moè, & Cornoldi, 1997). While listening to the texts, participants had to perform an articulatory suppression task, intended to compete with maintenance of phonological traces in VWM, or a spatial tapping task, intended to compete with maintenance of visuospatial information in VSWM, or to perform no concurrent task. Descriptions were presented twice, since a pilot experiment showed that participants were unable to perform the comprehension task after listening to the texts only once.

We expected that the concurrent verbal task would have a disruptive effect on both spatial and nonspatial texts. Information in both texts was presented verbally, so it was expected that the concurrent verbal task would interfere with the more superficial processes involved in comprehension. We expected interference from verbal and spatial concurrent tasks for the spatial text and interference from the verbal concurrent task for the nonspatial text. Further, we expected that a selective effect of the spatial concurrent task would be limited to performance in the spatial text.

Given that gender differences have been found to play a role in many visuospatial tasks (Voyer, Voyer, & Bryden, 1995), the same proportion of males and females was maintained in the experimental conditions.

Method

Participants

A total of 36 (9 male and 27 female) undergraduate students from the Faculty of Psychology of the University of Padova, participated in the experiment. Mean age was 23.

Materials

Texts. Two different texts were constructed: a nonspatial text, describing how wine is produced, which included many procedural instructions, as in the example below (see Table 1) and a spatial text describing a farm from a route perspective. This spatial text contained 12 landmarks and consisted of a

TABLE 1
Examples of part of the spatial and nonspatial texts and examples of sentences that refer to the texts

Spatial text
. . . Go straight along the side wall leaving the entrance behind you. Immediately on your left you will see a well, the water is useful for the plants. Go straight on until the end and you'll find a nice restaurant in front of you, situated in the other corner of the property. At the restaurant turn left and continue to walk on, leaving the restaurant behind you. You'll soon pass a little bridge crossing a small lake. On the left you can see a vineyard with many vines . . . At end of this side you will find several barns.
Sentences
After the well, if you turn right, you immediately find a bridge. (False)
Compared with the well, the barn is in the farthest corner. (True)
Nonspatial text
. . . To produce red wines, the grapes are crushed and left in casks for 5 days. The grapes are then subject to fermentation at a constant temperature of 15°–18°C. to maximise the bouquet. The wine is then poured while the crushed skins are used to make a second class of wine. Before bottling, crystallisation takes place by bringing the wine to subzero temperatures, about −5°C. This procedure lasts 2 days and allows the excess tartar to deposit so it can be eliminated later . . .
Sentences
During fermentation the new wine stands at subzero temperatures. (False)
To eliminate tartar from wine it is left to stand at subzero temperatures. (True)

description of a route with instructions such as ''turn left'', ''go straight on until . . .'', ''on your left you can see . . .'' (see example in Table 1). The two descriptions were 11 sentences long and consisted of 241 words for the non-spatial, and 257 for the spatial text.

Verification test. Twenty inferential questions of the same length, half true and half false, were constructed for each text (see examples in Table 1).

Concurrent tasks. Repetition of the series ''BA-BE-BI-BO-BU'' was chosen as an articulatory suppression task while the spatial tapping task required participants to tap four buttons located on a 20 × 20 cm square sequentially, without imposing a speed or rate (clockwise or counter clockwise). In the control condition, no concurrent task was performed.

Design

The design was mixed, with the requirements of the three concurrent task conditions as a between-participants factor: spatial or verbal concurrent condition, and control, and the two types of text as a within-participant factor. Participants were randomly assigned to one of the three different groups, each comprising 12 participants (3 males and 9 females). Each group performed one of the two concurrent tasks or no concurrent task.

Procedure

Each participant was tested individually for about 40 min. Participants were informed that the experiment required them to listen to and memorise two descriptions (to be able to answer a questionnaire), while performing a concurrent task, if any. They were randomly assigned to one or other concurrent task, or the control condition. After having been very briefly trained in the concurrent task, if any, participants listened to each description twice while performing the concurrent task. Descriptions were tape-recorded and their order was balanced. After listening to each description twice, participants had to write down on paper all the relevant information they could remember, in any order. Immediately after this recall task, participants had to perform the sentence verification task, by answering a list of 20 true/false questions presented on paper in random order. There was no time limit for the free recall task or verification test. At the end of the experimental session each participant was informed of the goals of the experiment.

Results

Free recall protocols were corrected using a predefined scheme comprising 30 information units for each text. Scores were assigned according to the number of information units correctly recalled, and were recorded by two independent judges. The (Pearson's) correlation between the scores of the two judges were .98 and .97, for spatial and nonspatial texts respectively ($p < .001$). It was therefore decided to analyse the scores of the first judge (the experimenter). The verification task was scored by totalling the number of correct true/false answers.

Free recall. The mean overall number of information units of the different text types correctly recalled (free recall task) for the three concurrent tasks are presented in Figure 1. A mixed 2 × 3 analysis of variance with text as within-participant factor and the concurrent task as between-participants factor was performed to decide whether concurrent spatial and verbal tasks cause selective interference on the two texts. A significant effect of the main factor concurrent task, $F(2, 33) = 23.38$, $MSE = 14.25$, $p < .001$ was found. A comparison between pairs of means, using Tukey's test ($CD = 3.12$, $p < .05$), confirmed that performance was better in the control condition than in the spatial and verbal concurrent task conditions (control condition, $M = 17.66$; spatial condition, $M = 11.96$; verbal condition, $M = 10.66$). The text by concurrent task interaction was significant, $F(2, 33) = 9.02$, $MSE = 18.82$, $p < .001$. A comparison between pairs of means using Tukey's test ($CD = 3.54$, $p < .05$) revealed that recall of the spatial text in the concurrent spatial condition ($M = 9.25$) was significantly lower than in

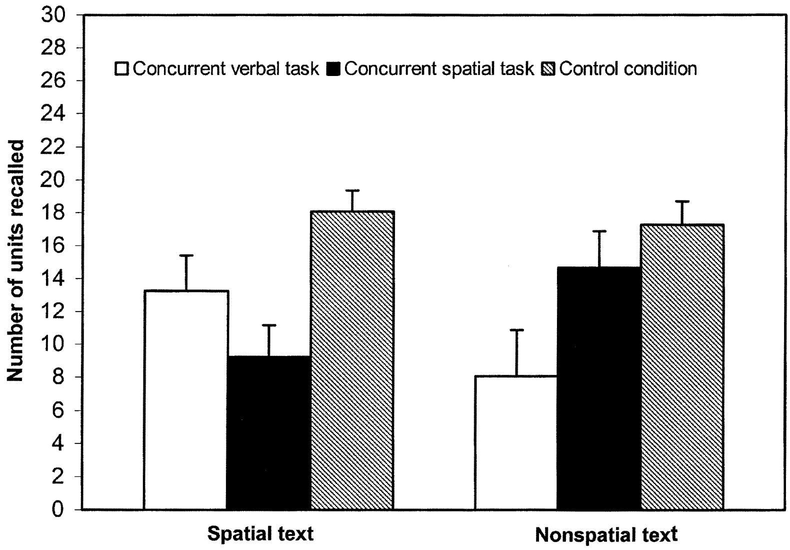

Figure 1. Experiment 1: Mean overall number of information units correctly recalled and standard deviations for the two texts as a function of the concurrent tasks.

the concurrent verbal condition (M = 13.25). Furthermore, both concurrent conditions were significantly lower than the control condition (M = 18.08). Finally, recall of the nonspatial text in the concurrent verbal condition (M = 8.08) was significantly lower than both the concurrent spatial (M = 14.67), and control conditions (M = 17.25); the concurrent spatial condition did not differ from the control condition.

As can be seen in Figure 1, when participants have processed the spatial text their memory performance is disrupted more by the concurrent spatial task than the concurrent verbal task, and the concurrent verbal task disrupted performance more than the control condition. When participants have processed the nonspatial text their memory performance is disrupted by the concurrent verbal, but not by the concurrent spatial task.

Verification test. Mean overall numbers of sentences answered correctly for the different types of texts with the two concurrent tasks are shown in Figure 2. An analysis of variance showed a significant effect of the concurrent task factor $F(2, 33) = 22.42$, $MSE = 3.59$, $p < .001$. A comparison between pairs of means, using Tukey's test ($CD = 1.44$, $p < .05$), confirmed that verification accuracy in the control condition was significantly better than in the concurrent spatial and verbal conditions (control condition, M = 16.70; spatial condition, M = 13.66; verbal condition, M = 13.41). A significant text by concurrent task interaction was found, $F(2, 33) = 8.86$, $MSE = 5.45$, $p < .001$. A comparison between pairs

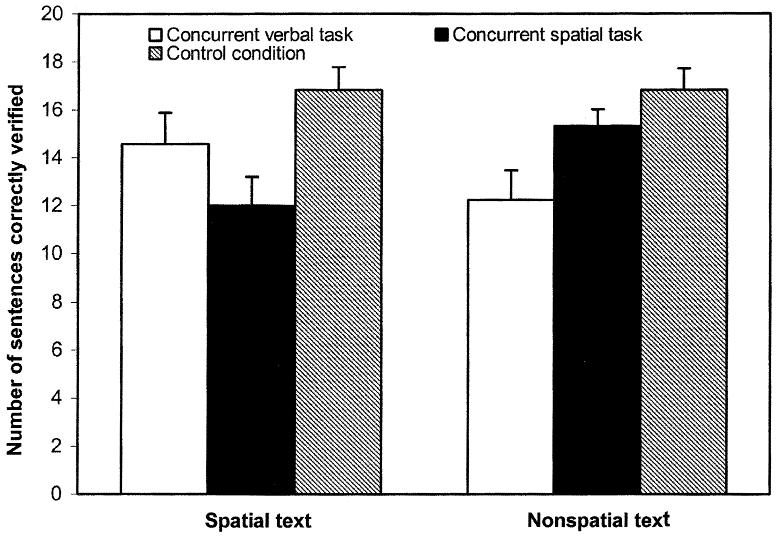

Figure 2. Experiment 1: Mean overall number of sentences correctly verified and standard deviations for the two texts as a function of the concurrent tasks.

of means using Tukey's test (CD = 1.86, p < .05) revealed that verification performance in the spatial text with the concurrent spatial condition (M = 12.00) was significantly lower than in the concurrent verbal condition (M = 14.58); performance under each of the concurrent conditions was significantly lower than for the control condition (M = 16.58). Verification test performance for the nonspatial text in the concurrent verbal condition (M = 12.25) was significantly lower than for both the concurrent spatial (M = 15.33) and the control conditions (M = 16.83); the concurrent spatial condition did not differ from the control condition. Although for this measure the difference between the two conditions (1.50) was only slightly less than the critical differences (1.86).

Discussion

Results show that the two texts were influenced differently by the two concurrent tasks. Comprehension and memorisation of the spatial text was disrupted mainly by the concurrent spatial task, but also by the concurrent verbal task. These results are in accordance with our hypotheses, as confirmed by both free recall and verification data. On the other hand, processing of the nonspatial text was disrupted by the concurrent verbal, but not by the concurrent spatial task.

An interference effect was also found for both texts with the concurrent verbal task, confirming the role of VWM in text processing. In this experiment, a free recall task was used to assess comprehension and memorisation of the whole content of the text. In addition, the verification task of inferred information allowed us to assess more directly the construction of a mental model. Results show that the entire comprehension and memorisation process is affected by the concurrent tasks. This suggests that the construction of a mental model from a text involves VWM and that construction of a spatial mental model involves VSWM. If this is confirmed, then we could assume that when a concurrent task competes with a WM component, the resulting mental model will be poorer, less structured, and thus will include fewer inferences. One way to check this proposal would be to test the construction of a mental model using finer measures and to investigate the involvement of WM components within it. This is what has been done in the second experiment.

EXPERIMENT 2

In order to study further the construction of a mental model from spatial and nonspatial texts, and to investigate the involvement of the components of WM in such a construction, a second experiment was conducted. The aims of the second experiment were the same as those in Experiment 1. We added a new index: response times in the verification task of information inferred from text. If a reader has built a mental model properly, with a lot of inferences, then these inferences should be readily and quickly available. This should result in faster verification times. On the other hand, if construction of the mental model has been impaired, for example by a concurrent task, then the reader, even if able to reconstruct the inferences for testing, needs time to do so. This should result in longer verification times. Thus in this second experiment, the same material and procedures were used, except that in order to measure response times to the verification task, the questions were presented using MEL software. We expected the results of Experiment 1 regarding accuracy to be confirmed and, in addition, we expected to find interference effects on response times.

Method

Participants

A total of 36 (7 male and 29 female) undergraduate students from the Faculty of Psychology of the University of Padova participated in the experiment. Mean age was 24 years.

Materials

Texts and concurrent tasks were exactly the same as in Experiment 1.

Design

The design was mixed, with three concurrent tasks as the between-participants factor, and the two text types as a within-participant variable. The participants were randomly assigned to three different groups each comprising 12 participants (2 males and 10 females for the verbal concurrent task and control groups; 3 males and 9 females for the spatial concurrent task group). Each group performed only one of the concurrent conditions.

Procedure

The procedure was the same as in Experiment 1, except that sentences in the verification task were projected one at a time on a computer screen in random order for each participant. To answer questions, participants had to strike one of two keys to indicate true and false answers. Each sentence remained on the screen until the participant had answered, then the next sentence was presented after an interval of 1.5 s. Sentences were projected for a maximum of 15 s. If the participant did not answer in that time, the sentence disappeared and the next one was projected after 1.5 s. The software program recorded correct and incorrect answers, as well as response times. Omissions were considered as errors.

Results

As in Experiment 1, free recall protocols were corrected by two independent judges using a predefined scheme of 30 units. Scores were assigned according to the number of information units correctly recalled. The correlation between the two judges' scores were .96 and .98 for the spatial and the nonspatial texts respectively ($p < .001$). It was therefore decided to carry out the analysis on first judge's scores (the experimenter). Sentence verification task scores represented the total number of correct true/false answers. Correct response times were also considered.

Free recall. Mean overall number of information units correctly recalled (free recall task) for the different types of text with the two concurrent tasks are presented in Figure 3. A mixed 2 $\times$ 3 analysis of variance was performed with text as within-participant factor and concurrent task as between-participants factor. An analysis of variance on free recall scores indicated a significant effect of the main factor, concurrent task, $F(2, 33) = 24.56$, $MSE = 20.36$, $p < .001$. A comparison between pairs of means, using Tukey's test ($CD = 3.73$, $p < .05$), confirmed that the best performance was found in the control condition (control condition, $M = 19.87$; spatial condition, $M = 13.25$; verbal condition, $M = 11.12$). The text by concurrent task interaction was found to be significant, $F(2, 33) = 18.25$, $MSE = 13.2$, $p < .001$. A comparison between pairs of means using Tukey's test ($CD = 3.01$, $p < .05$) revealed that recall of the spatial text in the concurrent spatial condition ($M = 9.58$) was significantly lower than for the concurrent verbal condition ($M = 13.75$). Both concurrent conditions were significantly lower than the control condition ($M = 20.00$). Recall of the non-spatial text in the concurrent verbal condition ($M = 8.50$) was significantly lower

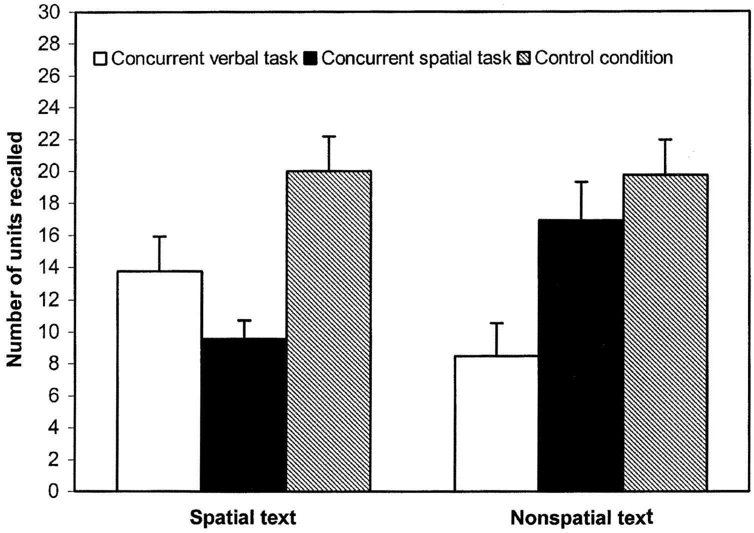

Figure 3. Experiment 2: Mean overall number of information units correctly recalled and standard deviations for the two texts as a function of the concurrent tasks.

than in the concurrent spatial (M = 16.92), and the control conditions (M = 19.75). The concurrent spatial condition did not differ from the control condition.

As can be seen in Figure 3, when participants processed the spatial text, their memory performance was disrupted to a greater extent by the concurrent spatial task than by the concurrent verbal task. The concurrent verbal task disrupted performance more than the control condition. When participants processed the nonspatial text, their memory performance was disrupted by the concurrent verbal but not by the concurrent spatial task, which was equivalent to the control condition.

Verification test. The mean overall numbers of sentences correctly verified for the different types of texts with the two concurrent tasks are presented in Figure 4. An analysis of verification accuracy showed a significant effect of the concurrent task factor $F(2, 33) = 35.34$, $MSE = 2.68$, $p < .001$. A comparison between pairs of means, using Tukey's test ($CD = 1.18$, $p < .05$), confirmed that performance was best in the control condition, compared with the concurrent spatial and verbal task conditions (control condition, M = 17.00; spatial condition, M = 13.58; verbal condition, M = 13.54). The text by concurrent task interaction was found to be significant, $F(2, 33) = 25.61$, MSE = 3.52, $p < .001$. A comparison between pairs of means using Tukey's test ($CD = 1.44$, $p < .05$) revealed that the verification performance of the spatial

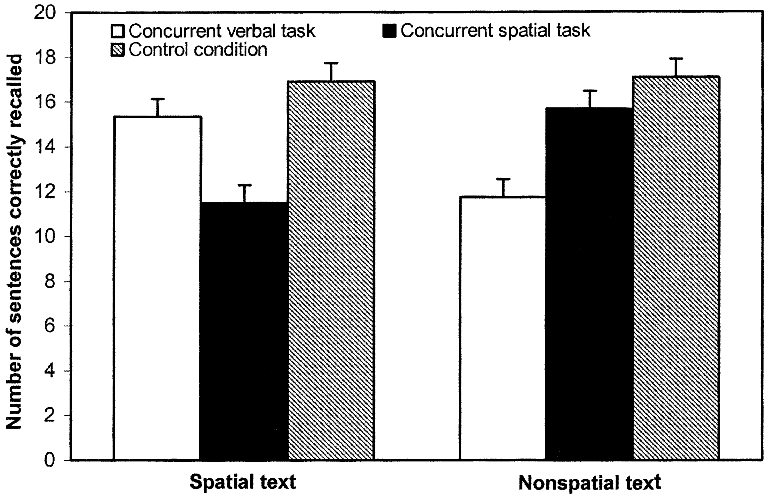

Figure 4. Experiment 2: Mean overall number of sentences correctly verified and standard deviations for the two texts as a function of the concurrent tasks.

text in the concurrent spatial condition (M = 11.50) was significantly lower than for the concurrent verbal condition (M = 15.33). Each of the concurrent conditions led to a significantly lower performance than the control condition (M = 16.92). The verification performance of the nonspatial text in the concurrent verbal condition (M = 11.75) was significantly lower than in the concurrent spatial (M = 15.67), and control conditions (M = 17.08). The concurrent spatial condition did not differ from the control condition. Even if the differences between the two means (1.41) is slightly lower then the critical differences (1.44).

Response times. Mean overall response times for correctly answered sentences for the different text types in the two concurrent tasks and control condition are presented in Figure 5. A mixed 2 × 3 analysis of variance was performed on response times. No main effect of conditions was observed, but a significant text by concurrent task interaction was found, $F(2, 33) = 8.52$, MSE = 365,857, $p < .01$. A comparison between pairs of means using Tukey's test (CD = 504, $p < .05$), revealed that response times for the spatial text were longer in the concurrent spatial task (M = 2135 ms), than in the concurrent verbal task (M = 1573 ms), but the control condition (M = 1835 ms) did not differ from the other two conditions. Response times for the nonspatial text were longer for the concurrent verbal task (M = 2573 ms) than for both the concurrent spatial task (M = 1739 ms) and control conditions (M = 1825 ms), which did not differ significantly from each other.

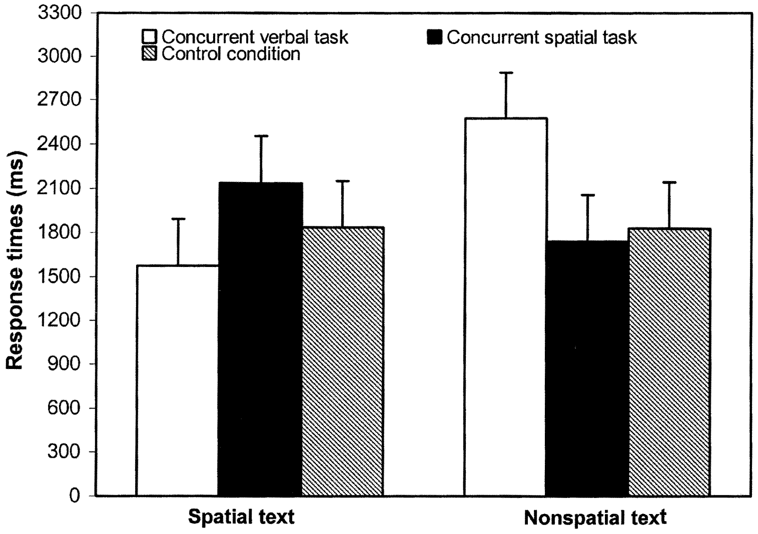

Figure 5. Experiment 2: Mean overall response times for sentences correctly verified and standard deviations for the two texts as a function of the concurrent tasks.

Discussion

The results of Experiment 2 confirm the selective interference effect of the concurrent tasks on the two different texts. Scores for the free recall task and accuracy in the verification test replicated the results of Experiment 1, i.e., an interference effect of the concurrent verbal task on the spatial and nonspatial texts and a selective interference effect of the concurrent spatial task on the spatial text.

As far as response times are concerned, a clear interference effect of the concurrent verbal task on the nonspatial text was observed, resulting in longer verification times compared with both the spatial and control conditions. The results, however, failed to show a specific spatial interference effect on the spatial text. The spatial tapping task had only a slight detrimental effect, which did not reach significance when compared with the control condition, but was significant only when compared to the concurrent verbal task. It could be concluded that for the nonspatial text, construction of a mental model involves mainly VWM and is thus impaired by the concurrent verbal task, i.e., participants draw inferences from the representation mainly when they are prompted to do so by the verification test. This process takes time, resulting in longer response times, which could explain the significant interference effects observed in both accuracy and response times. With the spatial text, however, construction of the mental model appears to involve mainly VSWM. When a concurrent task is performed, construction is impaired. This results in poorer accuracy compared with no concurrent task. We can, however, assume that when inferences are drawn, they are mostly not about testing, but have been drawn during encoding and are thus readily available. This would explain the lack of an interference effect on response times.

GENERAL DISCUSSION

In the present study we have investigated whether processing spatial and nonspatial texts involves VSWM and VWM, the two slave systems of Baddeley's (1986) working memory model. In the two experiments, a dual-task paradigm was used: a concurrent tapping task intended to act on the spatial component of the VSWM, a concurrent articulatory task intended to suppress rehearsal in the VWM, and a control condition in which no concurrent task was required. Memory performance in these different conditions was measured by free recall and a verification test of information inferred from the texts.

The results obtained in the two experiments converge to show that in general, recall (like the verification performance of information inferred from texts) is impaired by concurrent tasks which have different interference effects depending on the type of text. Performance for the spatial text was impaired by both concurrent tasks, by the spatial task in particular, whereas performance in the nonspatial text was impaired by the concurrent verbal task. These results cannot be accounted for by the central executive, as articulatory suppression and spatial tapping do not call on executive functions but suggest that different components of WM are involved in text comprehension, depending on the nature of the text.

Considered together with previous results obtained with illustrated or nonillustrated texts (Gyselinck et al., 2002), our results confirm the involvement of verbal working memory, and more specifically the maintenance of phonological information in text processing. When participants have to read long texts, articulatory suppression impairs comprehension. In this case, it impaired both comprehension and memory performance of spatial and nonspatial texts. These results demonstrate that VWM is crucial in processing verbal information and that a visuospatial component of WM is involved in text comprehension. These results are useful for understanding which mechanisms and forms of representation operate in text processing. Considering data on free recall and the verification task for the spatial text, it is interesting that the detrimental effect of spatial tapping is greater, in spite of the interference effect of articulatory suppression. This pattern is congruent with Perrig and Kintsch's (1985) model of comprehension of spatial texts, which proposed at least two levels of text representation: a text-based representation of the propositional contents of the text and a situation spatial model, also called ''spatial mental model'' (Taylor & Tversky, 1992), which allows inferences about all possible relations between landmarks. It may be that in processing spatial texts, articulatory suppression impairs the construction of the text-based representation, and that spatial tapping damages construction of an analogical model with strong visuospatial features. Our results may be specific to the special spatial text we used, which was a route spatial description. It would be interesting to verify if the same results could be extended to different kinds of spatial text: those from a survey prospective and texts which describe visual details of the particular environment.

Response times in Experiment 2 also support the idea that processing spatial and nonspatial texts leads to different levels of representation. The response times for questions concerning spatial and nonspatial texts were influenced differently by the two concurrent tasks. Response times for the nonspatial text were longer for the verbal concurrent task group than for the tapping and control groups. The two concurrent task groups did not differ from the control group for the spatial text, but a significant difference between spatial and verbal groups was found, as times for the concurrent spatial group were longer. It seems that the effects of the verbal concurrent task during the encoding phase of text processing were not detrimental to response times for the spatial text only, when compared to times for the concurrent spatial task.

Overall, our results confirm the value of the working memory construct, particularly in the form proposed by Baddeley and Hitch (1974), and successively revised (Baddeley, 1986, 1992; Logie, 1995), in investigating mechanisms involved in complex cognitive tasks. The present research demonstrates that the spatial component of working memory is selectively involved in processing spatial texts, but further investigation is required to understand its specific role. Until now empirical evidence has supported the hypothesis that VSWM plays an important role in integrating information from texts and pictures in illustrated texts (Gyselinck et al., 2002), but our results suggest that it is also implied in constructing a representation of spatial, non-illustrated descriptions. An initial explanation, which refers to Paivio's (1971) double-code theory, is that VSWM plays a role in encoding visual features of landmarks described in the spatial text. This explanation does not fit our materials and results: Tapping is considered a typical spatial task (Logie, 1995) that interferes with spatial, not visual, components of VSWM. Furthermore, the verification test concerned only the relative position of landmarks, not their visual characteristics.

A second, more convincing explanation is that VSWM is involved in the construction of the spatial mental model, which makes implicit information about landmark positions explicit. While listening, participants mentally follow the route described in the text as if they were actually navigating it. The spatial component of WM plays a special role in constructing and updating this sort of representation. This explanation is congruent with Pazzaglia and Cornoldi's (1999) results, which showed a selective interference effect of visual and spatial concurrent tasks on memorising visual and spatial texts respectively.

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