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Visuospatial working memory and the processing of spatial descriptions

Emilie Deyzac[1], Robert H. Logie[2] and Michel Denis[1]*
[1] Groupe Cognition Humaine, LIMSI-CNRS, Orsay, France
[2] Department of Psychology, University of Edinburgh, UK

The dual-task paradigm was used to determine whether the spatial, visual and verbal components of working memory are engaged in the processing of spatial descriptions. Participants listened to route or survey descriptions of urban-like spatial environments and then drew corresponding maps. The position of each new landmark was described either in terms of the direction to move toward this landmark (route descriptions) or its relative location with regard to the previously mentioned landmark (survey descriptions). Route and survey descriptions resulted in similar recall performance in the absence of an interfering task and landmarks were consistently less well recalled than their associated moves/locations. The pattern of interference resulting from the secondary tasks indicated that the processing of landmarks called upon both the visual and spatial components of working memory in the route perspective, whereas the processing of moves/locations essentially relied on the spatial component in both the route and the survey perspectives. The verbal component of working memory was only involved in the processing of landmarks in the survey perspective. The results suggest that distinct cognitive processes support memory for route and survey descriptions, and that distinct working memory resources support the processing of landmarks and landmark positions.

A large amount of research has been devoted to the cognitive processes elicited by the description of spatial environments or configurations of objects, attesting to the cognitive value of the 'spatial mental models' that people construct from spatial texts or discourse (e.g. Denis, 1996; Ehrlich & Johnson-Laird, 1982; Johnson-Laird, 1996; Pazzaglia & Cornoldi, 1999; Taylor & Tversky, 1992, 1996). Most of this work, however, has dealt with descriptions of static environments as seen from an external point of view, while largely ignoring that the reader of a spatial description is likely to move through the corresponding environment some time later. Interestingly, studies on the description of spatial arrays or environments such as apartments showed that the constraints imposed on to the speakers in linearizing their discourse elicit strategies that

* *Correspondence should be addressed to Michel Denis, Groupe Cognition Humaine, LIMSI-CNRS, BP 133, 91403 Orsay Cedex, France (e-mail: denis@limsi.fr).*

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consist for them of inviting their addressees to make an 'imaginary tour' (cf. Levelt, 1996, 1982; Linde & Labov, 1975). However, the process of creating spatial models from discourse intended to assist a moving person has inspired a limited amount of research. This is surprising, since research in this domain is likely to provide valuable information for both basic and applied science (e.g. Michon & Denis, 2001; Rinck & Denis, 2004). The motivation of the research project reported here was to fill a gap, and hopefully better account for the processing mechanisms that apply to spatial descriptions, particularly when these include directional instructions to be used by a person in need of navigational assistance.

Studies of the production of verbal route directions have established that their content is to a large extent saturated with visuospatial information, and that this content comprises two sets of components; namely, those referring to visual landmarks and those prescribing actions (e.g. Allen, 2000; Denis, 1997; Klein, 1982; Michon & Denis, 2001). References to landmarks constitute the descriptive part of route directions (*a Gothic cathedral*, *a square with a fountain*, *a big statue*), whereas references to actions constitute their procedural part (*go straight on*, *turn right*, *make a left*). Instead of just remembering lists of verbal instructions, most people using route directions tend to construct visuospatial representations of the environments described. Readers endowed with high visuospatial capacities have been shown to process route directions faster than low visuospatial imagers (Fernandez, 2000). This finding suggests that they make efficient use of their ability to create visuospatial representations while reading. Furthermore, items of information with a marked visual content (landmarks) tend to be memorized better than the actions associated with these landmarks (Fernandez, 2000). It is thus reasonable to expect that distinct cognitive processes apply to the two sets of items, depending on whether they have a visual or procedural content, with the likely consequence that their memory will be affected differentially.

In this context, articulated hypotheses are required as to the cognitive resources involved in the processing of spatial descriptions. It is no longer sufficient simply to postulate that spatial text or discourse calls for undifferentiated 'visuospatial capacities'. What is required is an approach based on the current distinctions made by the working memory model, in particular, the distinction between the visual and spatial components (Baddeley & Logie, 1999; Cornoldi & Vecchi, 2003; Logie, 1995, 2003). Experiments intended to test a selective interference hypothesis for the different parts of discourse could then be carried out to test the concept that processing spatial discourse involves a set of differentiated cognitive capacities.

However, in this domain, the experimental approach is rendered more complicated by the fact that spatial discourse itself is quite diverse. Depending on the use of specific linguistic devices, such as egocentric (*right*/*left*) or allocentric (*east*/*west*) terminologies, spatial language can convey either a route perspective or a survey perspective to a reader/listener (cf. Taylor & Tversky, 1992, 1996). Each perspective is primarily attached to a communication objective. The use of a survey perspective generally is intended to help a reader to build an overall view of an environment, whereas the route perspective tends to focus on the objective of helping a person move through the environment to reach a specified target. However, these two perspectives do have some features in common, in particular, the fact that both types of descriptions refer abundantly to landmarks, and that the spatial relationships between these landmarks have to be made explicit. In route descriptions, the expression of these relationships takes a clear procedural form, in which the moves from one landmark to another are specified. In survey descriptions, inter-landmark relationships are not expressed in terms of the motion of a person, but in terms of topological relations between the landmarks. For instance, in a survey description, once the existence of a theatre has been posited, the library may be said to be *to the east of the theatre* (or *to the right of the theatre*, in the frame of reference provided by a map). In a route description, the position of the theatre is first established (or, more precisely, the person is virtually located relative to the theatre, e.g. facing it), then the instructions will invite the person to *turn right and proceed to the library*. The same environment and its content may thus be validly described by these two instructional systems. The issue, then, is to establish whether the construction of spatial internal representations will be similar after these two types of descriptions have been processed, and if so to what extent. Moreover, how would we expect this to affect the memory of the environment described?

A long-standing view on this matter has been that the content and use of spatial memories closely depend on the source of learning. In particular, the point of view adopted during learning was thought to be preserved in spatial representations, and to command the processes by which the person would later access the stored information (Thorndyke & Hayes-Roth, 1982). This position was challenged by empirical work showing that memories of large-scale spaces are sometimes independent of the viewpoint adopted during learning (Evans & Pezdek, 1980; Presson, DeLange, & Hazelrigg, 1989). A similar debate took place in the particular case of spatial knowledge constructed from the processing of texts. Perrig and Kintsch (1985) argued for the maintenance of perspective in spatial representations built from route or survey descriptions. However, further studies demonstrated that spatial memory can be equally accessible from multiple perspectives (Taylor & Tversky, 1992). When presented with route or survey descriptions of spatial environments, participants showed similar accuracy in answering questions formulated from the learned perspective or the other perspective. In this context, the concept of an 'architect's 3D model', as advanced by Taylor and Tversky, assumes that spatial knowledge is incorporated in abstract representations that can be viewed or visualized from several different perspectives.

However, it remains true that perspective can affect the comprehension of spatial texts. Switching perspectives in narratives has a cognitive cost, as reflected by a corresponding increase in reading times (Black, Turner, & Bower, 1979). Lee and Tversky (2001) reported that using a consistent perspective during learning facilitates the acquisition of new environments. They also provided evidence that retrieving spatial information from memory was less perspective-dependent than on-line comprehension. This suggests that a given perspective is only maintained until the spatial representation is complete. Further evidence was reported that people often use mixed perspectives when describing naturalistic environments (Taylor & Tversky, 1996). Spatial memory remains perspective-dependent in several circumstances, such as when only a limited time is allowed for learning (Bosco, Filomena, Sardone, Scalisi, & Longoni, 1996; Perrig & Kintsch, 1985), when texts are indeterminate (Perrig & Kintsch, 1985; Schneider & Taylor, 1999) or when they are very complex (Ferguson & Hegarty, 1994; Pazzaglia & Cornoldi, 1999). Moreover, learning goals can induce perspective-dependent representations that are independent of the learning perspective (Schneider & Taylor, 1999; Taylor, Naylor, & Chechile, 1999).

Thus, it is reasonable to expect that perspective-dependent representations would be only an intermediate, albeit inevitable, stage in the construction of spatial representations. The purpose of this research was to find out whether distinct cognitive processes are engaged in the memory for route and survey texts describing the same environment. Once again, we situated our research within the framework of the visuospatial working memory model (Baddeley & Logie, 1999; Logie, 1995). The study was intended to investigate the impact of visual and spatial components of working memory on the processing of the two main ingredients of spatial texts (references to landmarks and specifications of their relationships), depending on whether they were acquired from a survey or a route description.

In this context, Pazzaglia and Cornoldi (1999) have reported data suggesting that working memory is involved in the processing of spatial texts, but they failed to find any evidence for the differential involvement of visuospatial working memory in the processing of route and survey texts. The authors explained this in terms of the difficulty encountered by the participants in memorizing the survey text. In the present research, the verbal descriptions were inspired by the spatial texts designed by Brooks (1967), in which short sequences of sentences are used to describe simple spatial patterns. Spatial configurations were constructed, and descriptions were generated in such a way that every new landmark in a description was introduced either in terms of the direction to move towards this landmark (in the route description) or of its relative location with respect to the previously mentioned landmark (in the survey description). The descriptions were presented sentence-by-sentence, each combining a landmark and move or location information. The same sequence of landmarks and move/location information was used in constructing the route and survey descriptions.

The distinction between landmarks and moves appears to be useful for testing the existence of a perspective effect in the construction of spatial representations. Differential effects on the processing and memorization of landmarks and moves were found by Fernandez (2000). In this experiment, participants were presented with route directions and invited either to imagine a walk within a city (route instructions), or to imagine the city from a bird's eye view (survey instructions). In comparison with a third condition in which no such instructions were given, landmarks appeared to be better remembered with the route instructions than with the survey instructions. The memorization of moves benefited from both types of instructions. The two classes of items thus displayed different properties depending on the perspective adopted during learning.

In the present set of studies, the first experiment was designed to explore the effects of selective interference of a spatial task on the processing of spatial descriptions. The role of the visual component was explored in the subsequent two experiments. Finally, the verbal component of working memory was investigated in the fourth and last experiment. We made three sets of predictions concerning the possible sources of interference.

(1) The spatial task was expected mainly to interfere with the processing of directional instructions presented from a route perspective. In the survey perspective, participants have to memorize the relative positions of landmarks and this can be maintained in a simultaneous system, whereas sequential integration of the information is necessary in route perspective. Moreover, comprehending route directions requires continuous changes of orientation and updating of landmark positions. The moving reference frame can be assumed to result in an additional load on the spatial component of working memory.

(2) The second prediction concerned the involvement of the visual component of working memory. In the route perspective, the participants were invited to imagine walking through an environment. We expected that the visual characteristics of landmarks would trigger the participants' tendency to develop visual imagery to a substantial extent. Such visual processing should be less

relevant for the comprehension of survey descriptions. Accordingly, the visual component of working memory was expected to be more involved in the processing of route descriptions. The rationale for these expectations was grounded in the nature of the views that the route perspective offers to a person imagining him/herself moving through an environment. Whereas the survey perspective offers a view of an environment 'from above', where the focus is on the relative positions of simultaneously seen landmarks, the route perspective offers a succession of frontal views, in which the visual content of the landmarks (their shape, colour, details, etc.) is more salient than their spatial relations. In sum, the route perspective gives the best equivalent of a visual perception of landmarks, which justifies the hypothesis that, if this is true, visual interference will be more detrimental to landmark processing in route than in survey perspective.

(3) The involvement of the verbal component was expected to be weak in both perspectives. The construction of a corresponding visuospatial representation should not primarily rely on the phonological loop, even if the spatial configurations are described verbally. It is nevertheless necessary to account for this component in order to find out whether the phonological loop is recruited for information storage.

EXPERIMENT 1: SPATIAL INTERFERENCE (SPATIAL TAPPING)

Experiment 1 addressed two general issues and a more specific one. The first general issue was the effect of the perspective taken on an environment during the processing of a spatial description of this environment. There are good reasons to expect that recall would be facilitated when spatial information has been processed according to a survey perspective. Previous findings suggest that people experience more difficulty in processing route than survey descriptions. In particular, reading times are longer for route than for survey descriptions (Taylor & Tversky, 1992). However, a number of empirical arguments have been provided, suggesting that the memory representations constructed from the processing of a route or a survey description are similarly accessible to further processing, such as the production of inferential judgments (cf. Schneider & Taylor, 1999; Taylor & Tversky, 1992).

The second general issue was the differential memory for landmarks and for their positions, as specified by directional instructions. By 'landmark positions', we do not refer to exact metric positions, but to gross topological relations of landmarks relative to those previously mentioned. Experiments on memory for route directions indicate that landmarks are better memorized than the actions related to these landmarks (Fernandez, 2000). We wondered whether this trend would similarly appear in route and in survey descriptions. The above-mentioned landmark superiority was found in situations where participants had to provide verbal recall of route directions. The situation examined here involved drawing responses from the participants. The graphic content of the response may create a stronger emphasis on the directionality of moves, and thus affect the salience of landmark content in favour of landmark positions (as specified by the moving instructions).

The more specific goal here was to determine whether spatial working memory is involved in the processing of spatial descriptions, and whether this involvement depends to any extent on the perspective imposed on the participants by the texts. The comprehension of spatial descriptions is generally thought to involve the spatial components of working memory. This assumption is based on the cognitive mechanisms engaged in the understanding of spatial texts; namely, the construction of spatial mental models (cf. Ehrlich & Johnson-Laird, 1982; Johnson-Laird, 1996). Kruley, Sciama, and Glenberg (1994) showed that the disruption of a spatial task by reading of a text accompanied with illustrations could be removed when participants were told that they did not need to understand the text. The authors assumed that in this latter condition, participants were not constructing a spatial mental model any more (see also Gyselinck, Cornoldi, Ehrlich, Dubois, & De Beni, 2002). Pazzaglia and Cornoldi (1999) showed that memory of descriptions of spatial environments was disrupted by a spatial interference task, even when the descriptions were not accompanied by pictures. Based on these previous findings, we expected to find that a task tapping the spatial component of visuospatial working memory would impede the processing of spatial descriptions, and ultimately their recall.

There is good evidence that the spatial component of working memory is involved in the planning and control of movements. A number of studies have reported that the recall of spatial sequences is disrupted by spatial tracking. This is the case for arm movements accompanied by an auditory feedback (Baddeley & Lieberman, 1980), for hand movements following a pattern drawn on a table (Quinn & Ralston, 1986) and for tasks consisting of copying the movements of a human model (Logie & Marchetti, 1991; Smyth & Pelky, 1992). In several experiments, tapping in a regular pattern was shown specifically to disrupt the functioning of the inner scribe of working memory (cf. Pearson, Logie, & Gilhooly, 1999; Salway & Logie, 1995; Smyth & Pelky, 1992). It has also been shown to affect memory for a route that participants have to learn by following an experimenter in a real environment (Garden, Cornoldi, & Logie, 2002). Thus, it is reasonable to expect that this task would impede the concurrent processing of directional information conveyed by a spatial description.

Landmark processing should also rely, although to a lesser extent, on the spatial component of working memory in the route perspective. Even if landmarks can be stored as visual images, their maintenance also requires active rehearsal by the inner scribe. Furthermore, landmarks in route directions have to be remembered sequentially. The ordered recall of items requires active processing in spatial working memory. In the survey perspective, the sequence is less relevant for the configuration. Participants can mentally imagine the localization of every new landmark within a cognitive map. If spatial relations stated in the description may be forgotten as such, this is to the benefit of an integrated model of inter-landmark positions, which results in easier production of inferential judgments (Mani & Johnson-Laird, 1982). Consequently, the spatial component should be more strongly involved in the processing of landmarks in the route than in the survey perspective, and landmark recall should be disrupted to a greater extent in the case of route descriptions.

Method

Participants

Participants were 24 students at the University of Orsay who volunteered to take part in this experiment. They were between 20 and 30 years old and there were equal numbers of male and female participants.

Materials

Three pairs of descriptions were constructed. Each pair consisted of a route description and a survey description of the same fictitious, urban-like environment. The description adopting a route perspective consisted of sentences that looked like route directions (e.g. *turn left and walk as far as the garage*). It described the procedure that a user should follow to get from one point to another in a city. Instructions for navigation were made by reference to landmarks, and they adopted an egocentric reference frame using terms such as *turn right*, *turn left* and *go straight on* for specifying the directional instructions. In contrast, the text that adopted a survey perspective described the same layout of landmarks seen from a bird's eye view, similar to the perspective adopted by people who are looking at a map. Each landmark position was stated in reference to the previous one according to a relative frame of reference (e.g. *on the left, there is a garage*). The description used a terminology such as *on the left*, *on the right*, *above* and *below*. Each description contained a total of eight sentences. Except for the first one, which simply posited the starting landmark, each sentence introduced two pieces of information: the name of a further landmark, and a directional instruction making it possible to locate it relative to the previously mentioned one. The landmark names were the same in the route and the survey descriptions, and only the formulation of directional information differed between the two perspectives (as is evident from the two examples above). To summarize, each description referred to eight landmarks connected by seven directional instructions, either expressed in terms of moves to a new location (route descriptions) or of the location of a new landmark relative to the previously mentioned one (survey descriptions). There were a total of three pairs of route and survey descriptions, based on three distinct layouts. The three layouts and the corresponding pairs of descriptions are shown in Fig. 1. Each description was recorded and played back using the loudspeaker of a computer. The descriptions were all read out by a male voice at a rate of one sentence every 6 seconds.

The board used for the unseen spatial tapping task was a square matrix of 3×3 buttons. The buttons was 3×3 cm in size, and they were separated from each other by 1 cm. The tapping board was connected via the parallel port to a computer, which recorded the time intervals between responses. Every time a button was pressed, this was taken to be a response and the computer also recorded the buttons that were pressed.

Procedure

The primary task consisted of participants listening to the set of sentences composing a description, with the expectation that they would later have to draw a sketch map of the described environment on a sheet of paper. Each individual participant read only one type of description, either from the route or survey perspective. In the route perspective, participants were told to imagine they were walking in a city. In the survey condition, participants were told to imagine the city from above, as if they were in a helicopter. For both conditions, the participants were invited to use imagery for memorizing the descriptions. There was no limit on the time allocated for recall, and no constraint on the order in which the participants drew the map. A given participant listened to a total of three descriptions, two of which were processed without any concurrent task and one was processed with the concurrent spatial task.

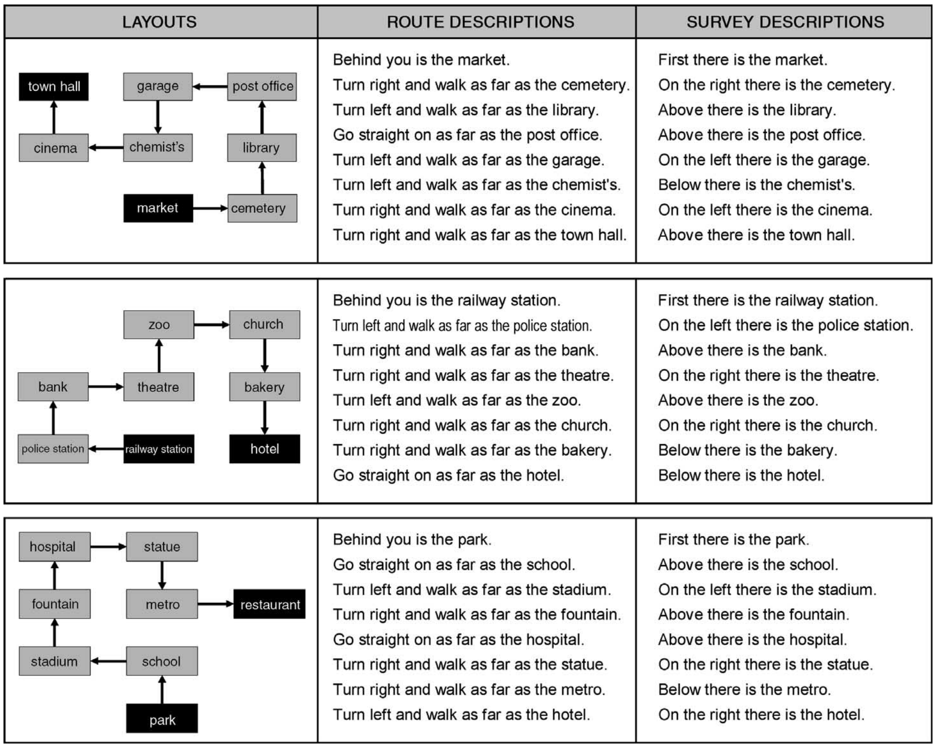

Figure 1. Three layouts, three route descriptions and three survey descriptions (originals in French).

The spatial tapping task consisted of moving a finger across keys in a regular '8' pattern, at a rate of one every second. The procedure was similar to the one used by Smyth and Pelky (1992). Participants had to close their eyes while performing this task in order to avoid any visual input. The task was performed in approximately 45 seconds; that is, for the same length of time as the presentation of the verbal description in the primary task. This task was performed three times, twice alone and once concurrently with the primary task.

A complete experimental session consisted of the following three phases. First, the participants had to perform the primary task and the spatial tapping task separately. The order in which the two tasks were performed was counterbalanced among the participants. Secondly, the participants were invited to listen to the description while performing the spatial tapping task. At the end of the listening episode, they had to draw the corresponding sketch map (without being submitted to any interference at this time). Thirdly, the primary task and the tapping task were performed once again in succession, in the same order as in the first phase. Figure 2 summarizes the three phases of the procedure for each participant. The participants completed the primary task three times, thereby requiring three layouts and the corresponding three sets of descriptions. The allocation of the three versions of the material to the three phases of the experiment was counterbalanced among the participants. The experimental population was randomly split into two halves, the first of which processed route descriptions and the other half survey descriptions.

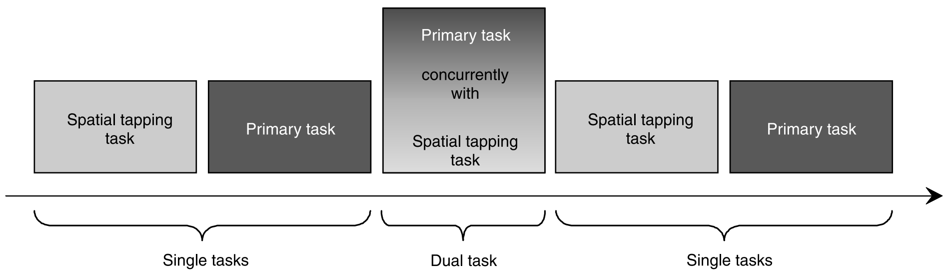

Figure 2. Summary of the experimental procedure.

Results

Primary task

Separate measures of recall were taken for each individual sketch map, respectively, for landmarks and for moves/locations. Each individual sketch map was scored for these two kinds of items. First, the sequence of recalled landmarks was compared with the sequence in which landmarks were introduced in the description. Consider the sequence of landmarks in a description of the first layout: market, cemetery, library, post office, garage, chemist's, cinema, town hall. Now, consider a given participant's response, in which items were recalled in the following sequence: market, cemetery, library, post office, garage, unknown, chemist's, town hall (Fig. 3). In this case, the number of landmarks recalled at their correct location was six. The same method was used with the corresponding sequence of moves/locations. In our example, the nominal sequence of moves was: right, left, straight, left, left, right, right. In this case, the sequence of moves exactly matched the nominal sequence. Consequently, the number of correctly recalled moves was seven.

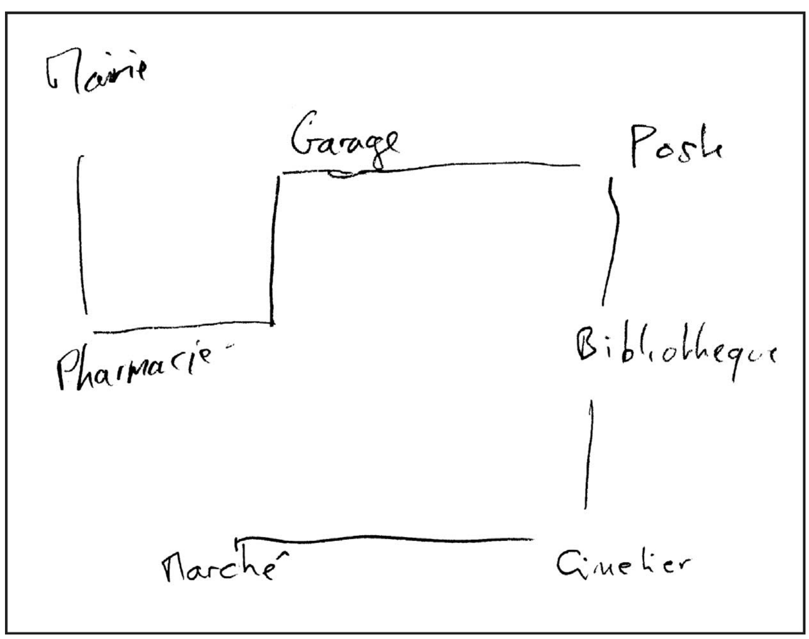

Figure 3. Example of a participant's response.

Since the maximum number of landmarks was eight and the maximum number of moves was seven, recall measures were expressed as the percentage of correct responses.

Less strict scores were also computed, which reflected the number of items recalled, irrespective of their position in the sequence. Although the absolute scores were slightly higher, the overall pattern of the results remained the same. We therefore only report the data based on the strict scoring method. Figure 4 shows the recall rates for landmarks and moves/locations after the processing of the route and the survey descriptions, with and without concurrent execution of the spatial tapping task by the participants.

Primary task alone

In order to determine the effect of perspective on the recall of described layouts, recall rates in the single-task condition (first and third phase) were submitted to a two-way ANOVA with perspective (route vs. survey) as a between-participants factor and items (landmarks vs. moves/locations) as a within-participant factor. Overall, the average recall rate was 60.2 after the processing of the route descriptions, and 56.7 after the processing of the survey descriptions. There was no main effect of perspective, $F(1, 22) < 1$. Overall, recall was higher for moves/locations than for landmarks, 68.5 versus 48.4, respectively, $F(1, 22) = 51.60$, $p < .001$.

Primary task with concurrent task

A subsequent analysis was conducted with perspective, items and condition (primary task alone versus with spatial tapping) as variables, with the last two factors as within-participant variables. No effect of perspective was found, with scores of 47.4 for the route perspective and 48.7 for the survey perspective, $F(1, 22) < 1$, but moves/locations were better recalled than landmarks, 54.2 vs. 41.9, respectively, $F(1, 22) = 36.90$, $p < .001$. Spatial tapping had a significant decreasing effect on memory performance, with recall rate decreasing from 58.4 to 37.6, $F(1, 22) = 25.21$, $p < .001$. There was no significant interaction between perspective and condition, but the interfering effect was quite strong for the route perspective, 60.2 vs. 34.6,

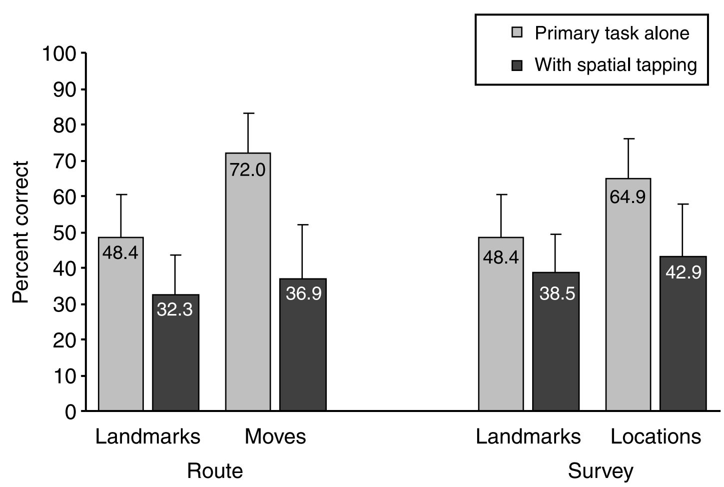

Figure 4. Experiment 1: Recall rates for landmarks and moves/locations after processing the route and survey descriptions, with and without the concurrent execution of the secondary task (spatial tapping). Error bars correspond to the 95% confidence intervals of the means.

$F(1, 22) = 19.15, p < .001$, while still being significant for the survey perspective, 56.7 versus 40.7, $F(1, 22) = 7.42, p < .05$. Lastly, there was a significant interaction between items and the presence/absence of spatial tapping, $F(1, 22) = 7.23$, $p < .02$. Planned comparisons revealed that the concurrent task had a detrimental effect on the recall of landmarks, with scores of 48.4 versus 35.4, respectively, $F(1, 22) = 8.18$, $p < .01$, but the effect was more evident for the recall of moves/locations, 68.5 versus 39.9, respectively, $F(1, 22) = 26.92$, $p < .001$. While moves/locations were better recalled than landmarks in the single-task condition overall, this was not true in the dual-task condition, $F(1, 22) = 1.16$.

The three-way interaction involving perspective, items and condition did not reach significance. Detailed inspection of the results, however, showed that the recall of landmarks was significantly disrupted by the concurrent task when landmarks had been processed under the route perspective, $F(1, 22) = 6.30, p < .02$, but that the decrease was not significant for the survey perspective. Stronger effects were found for moves/locations, which were significantly less well recalled when the concurrent task interfered with processing under both route and survey perspectives, $F(1, 22) = 20.34$, $p < .001$, and $F(1, 22) = 8.00$, $p < .01$, respectively.

Secondary task
Performance on the secondary task was also examined to check whether the participants neglected it for the benefit of the primary task. The mean variance of inter-response intervals for spatial tapping was computed for the conditions under which it was performed as a single task and for the dual-task condition. The ANOVA did not reveal any effect of the conditions, indicating that the participants performed the spatial tapping task with the same regularity in the single and the dual-task conditions (mean variances of inter-response intervals were 0.10 and 0.13 seconds, respectively).

Discussion

The results of Experiment 1 showed that in the absence of an interfering task, recall of spatial information was quite similar regardless of whether it resulted from processing a route or a survey description. The linear structure of the description used in both perspectives did not appear to favour memory of route descriptions rather than survey descriptions. An interesting finding was that moves/locations were better memorized than landmarks. Several studies have demonstrated the memory privilege of landmarks in the memory of route directions (Fernandez, 2000; Tom & Denis, 2004). In the present experiment, the better memory for moves/locations suggested that participants capitalized on the relative positions of the landmarks. Lastly, the perspective used in the descriptions had no significant differential effect on the recall of landmarks or of moves/locations.

A concurrent task involving the spatial component of working memory during encoding impaired memory, and was more pronounced in the route than in the survey perspective. This finding suggests that formation of a survey perspective was not prevented by spatial interference, and that participants might have constructed a highly integrated view of the spatial information conveyed by the description, making it more resistant to interference.

Spatial tapping interfered more strongly with the processing of moves/locations than of landmarks. Although this more extensive effect might be attributed to the fact that the higher initial recall of moves/locations gave more scope for a fall in performance, the recall of landmarks in the control condition was still well above floor, leaving considerable scope for disruptive effects to appear. Therefore, the effect is more likely due to the intrinsic characteristics of moves/locations. Stronger interference of spatial tapping with the processing of moves/locations is consistent with the fact that these are likely to be processed as spatial rather than visual memory components. The differential interfering effect of spatial tapping on landmarks and moves/locations is also consistent with our assumption that landmarks elicit more visual than spatial processing, and are consequently less sensitive to spatial interference than moves/locations.

Sequences of landmarks were assumed to be actively processed by the inner scribe in the route perspective, and, as expected, landmark recall was disrupted by the spatial tapping task in the route perspective (which requires landmark sequences), but not in the survey perspective (which requires landmark layouts). Participants may well have been able to remember the configuration presented in the survey perspective in terms of locations within a simultaneous-parallel system, such as the visual cache of working memory (Logie, 1995, 2003). It is well established that active rehearsal of temporarily stored material is more likely when information has to be remembered in the right order (Klauer & Stegmaier, 1997). This then accounts for the apparently greater involvement of the spatial component of working memory in the route perspective, particularly in landmark recall. In a recent study, Zimmer, Speiser, and Seidler (2003) reported data suggesting that memory for object locations does not rely on the visuospatial component of working memory. Unlike the Corsi task, an object location task does not require the participants to memorize a temporal sequence calling for active rehearsal of the locations. These data are consistent with the present results, and consistent with the separation between a visual cache that retains visual appearance of a static layout, and an inner scribe that retains sequences of movements between objects or landmarks.

The results of Experiment 1 showed that the processing of landmarks and of moves/locations share common resources in spatial working memory, and revealed little difference between the two perspectives of description. In light of these findings, the role played by the passive visual cache had to be investigated in order to clarify the processes involved in each perspective, and to further test our assumptions. This was the objective of the next experiment.

EXPERIMENT 2: VISUAL INTERFERENCE (BRIGHTNESS JUDGMENTS)

The fractionation of visuospatial working memory into a spatial and a visual system is now widely acknowledged. However, few studies have attempted to determine the role of the visual component in cognitive activities such as the comprehension of spatial descriptions.

The visual cache of working memory has been shown to be involved in visual imagery tasks (Baddeley & Andrade, 2000; Logie, 1986; Quinn & McConnell, 1996a, 1996b, 1999; Smyth & Waller, 1998). However, in the current theoretical framework of the working memory model, mental images are not maintained and manipulated by the means of the visual cache (cf. Baddeley & Logie, 1999; Logie, 2003; Pearson *et al.*, 1999). The cache is considered to be a passive component for the temporary storage of visual information or of intermediate stages in the construction of mental images. Both slave systems of visuospatial working memory are thought to be engaged during imagery tasks, when no other means of temporary storage are available (Baddeley & Andrade, 2000; Logie, 1995, 2003; Pearson *et al.*, 1999).

In Experiment 2, in addition to considering the two general issues common to the other experiments, we explored whether the involvement of visual working memory in processing directional information depended on the perspective. We also investigated the differential sensitivity of landmarks and moves/locations to visual interference. We expected moves/locations to be less sensitive than landmarks to visual interference. Moves/locations are not visual in nature, but are essentially spatial, as suggested by the results of Experiment 1. In contrast, we expected the processing of landmarks to be highly sensitive to visual interference, especially in the route perspective. Even if route directions did not explicitly provide visual details about the landmarks, the point of view taken on the described scenes should induce participants to imagine landmark features, such as their visual appearance, their colours and so on. This assumption was based on previous empirical findings. One of them is that visual interference has been shown to remove the recall advantage of high imagery words (Matthews, 1983). Estimations of the vividness of images were found to be lower when a visual interference task was performed concurrently with the construction of the mental image being rated (Baddeley & Andrade, 2000). An imagery task in which participants were requested to imagine a sequence of landmarks along a route should therefore be expected to engage them in constructing visual images of these landmarks. On the other hand, the survey perspective was not assumed to be so favourable to the visual processing of landmarks.

Because former studies of the visual cache suffered from methodological difficulties, the role of the visual cache in the processing of spatial descriptions must be examined in the context of a variety of visual interference tasks. In Experiment 2, the visual interference task was a brightness judgment task. Baddeley and Lieberman (1980) originally introduced this task, in which participants are invited to decide whether an illuminated screen is bright or dim. In the visual task designed by Logie (1986), participants were required to detect colour changes in series of shapes previously memorized. To avoid the implicit naming of colours, we used a visual task requiring participants to detect when two squares successively presented were similar in terms of their brightness.

Method

Participants
Participants were 24 students at the University of Orsay, between 20 and 30 years old, who volunteered to take part in this experiment. None of them had participated in the previous experiment. Equal numbers of male and female participants were recruited.

Materials
The stimuli for the primary task were the same as in Experiment 1. The secondary task involved brightness judgments. The stimuli were generated and monitored via the ERTS-VIPL software (Beringer, 1996). Participants were presented with primary yellow squares for 700 ms each, at a rate of one presentation every 2 seconds. The squares were 10×10 cm in size, and were displayed in the centre of the computer monitor. The hue of the squares was defined within the software, with the HSV Colour Model. We created four yellow squares having four distinct brightness values; namely, 52%, 70%, 87% and 100%. We used different values of yellow to avoid the use of names for the four stimuli.

Bright and dark yellows do not have specific lexical counterparts in French, in contrast to bright red (scarlet) and dark red (crimson).

Trials involved either no change in brightness or a change in brightness between one stimulus and the next. Each participant was presented with 28 randomly selected stimuli, including 21 change and 7 no-change trials.

Procedure

The procedure was the same as in Experiment 1, with the brightness judgment task replacing the spatial tapping task. In this task, the participants were asked to press a key when two successive coloured shapes were judged to be equally bright. A correct response consisted of pressing the space bar when a new shape had the same brightness as the previous one, and of not pressing it when two successive shapes had differing brightness. Scores were obtained by subtracting the total number of errors from the total number of correct responses. The highest possible score was 28.

Results

Primary task

As in Experiment 1, we computed the correct recall rates for landmarks and moves/locations based on the strictest criterion. Figure 5 shows the recall rates for landmarks and moves/locations after the processing of the route and the survey descriptions, when the participants were and were not carrying out the concurrent brightness judgment task.

Primary task alone

Recall rates were first analysed by a two-way ANOVA in the single-task condition (first and third phase). In the absence of any concurrent task, recall rates were 61.6 after the processing of the route descriptions, and 64.5 after the processing of the survey

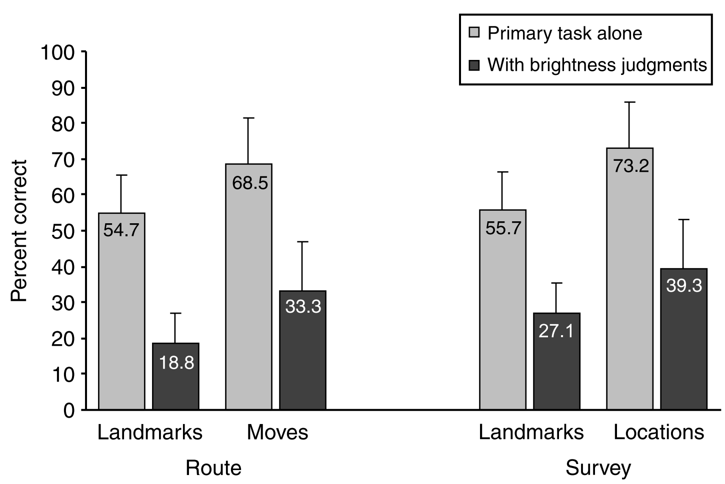

Figure 5. Experiment 2: Recall rates for landmarks and moves/locations after processing the route and survey descriptions, with and without the concurrent execution of the secondary task (brightness judgments). Error bars correspond to the 95% confidence intervals of the means.

descriptions. This difference was not significant, $F(1, 22) < 1$. The results also confirmed that the recall of moves/locations was better than that of landmarks, 70.8 versus 55.2, respectively, $F(1, 22) = 15.33$, $p < .001$.

Primary task with concurrent task

As in Experiment 1, the effects of perspective, items and condition on recall rates were investigated using a three-way ANOVA. The difference between the recall rates after the route and the survey descriptions, 43.8 versus 48.8, respectively, was not significant, $F(1, 22) = 1.10$. As previously, moves/locations were better recalled than landmarks, 53.6 versus 39.1, respectively, $F(1, 22) = 16.22$, $p < .001$, and there was a main effect of the condition, with recall rate decreasing from 63.0 to 29.6 when the concurrent task was executed, $F(1, 22) = 59.46$, $p < .001$. There was no significant interaction among the factors. The brightness judgment task had an interfering effect of similar magnitude on the processing of the two perspectives. The recall rate decreased from 61.6 to 26.0 in the route perspective, $F(1, 22) = 33.63$, $p < .001$, and from 64.5 to 33.2 in the survey perspective, $F(1, 22) = 26.08$, $p < .001$. With the concurrent task, the recall of both types of items decreased in similar proportions, from 70.8 to 36.3 for moves/locations, $F(1, 22) = 45.49$, $p < .001$, and from 55.2 to 23.0 for landmarks, $F(1, 22) = 39.91$, $p < .001$.

Secondary task

Scores from the single and dual-task conditions were compared using a two-way ANOVA. We found a significant effect of the conditions, $F(1, 22) = 119.36$, $p < .001$. The mean number of correct responses was 25.9 in the single-task condition and 19.1 when the brightness judgment task was performed concurrently with the primary task.

Discussion

The slight advantage of the survey descriptions over the route descriptions was not confirmed by the statistical analyses, a null effect that is in line with Experiment 1. The superior recall of moves/locations over landmarks was also a confirmation of the findings of the previous experiment.

The brightness judgments interfered with the processing of spatial descriptions, but did not produce differential effects according to the perspective of the description. The interfering task similarly disrupted the processing of landmarks in both route and survey perspectives. Furthermore, the processing of moves/locations was disrupted by the brightness judgment task to a similar extent.

The absence of a differential effect on the memory for landmarks and moves/locations was not what we had expected to find. Unlike landmarks, moves/locations were not thought to be especially sensitive to visual interference since they have no access to the visual cache. An explanation of the present data could lie in the close relationship that connects landmarks and moves/locations in route directions (cf. Daniel & Denis, 2004; Michon & Denis, 2001). The difficulties met during the processing of landmarks may have affected the processing of the associated moves/locations. The visual task then may have indirectly disrupted the memory for moves/locations. However, this interpretation is hardly compatible with the consistently higher recall rates for moves/locations than for landmarks. Moves/locations can be remembered well, even if landmark content is forgotten.

An alternative explanation considers that our brightness judgment task may not have been a purely visual task. Fixing the eyes on the centre of the screen may inhibit the use of eye movements to assist in the mental rehearsal of movements (e.g. Pearson & Sahraie, 2003; Postle, Idzikowski, Della Sala, Logie, & Baddeley, 2006) and may therefore generate a form of spatial interference. Baddeley (1986) suggested that an implicit activity of the eye participates in the active spatial rehearsal of information stored in the visual cache, and so avoiding eye movements by staring at the centre of a screen may generate spatial as well as visual interference.

In the brightness judgment task, the participants were invited to decide whether two successive shapes had the same or different degrees of brightness. They were required to respond only when sameness was detected. This response mode had been adopted to avoid a binary decision. Decision processes engage the central executive (Klauer & Stegmaier, 1997), and may engender a disruptive effect on a concurrent task. Nevertheless, the choice between 'to respond' and 'not to respond' may have engaged decisional processes. Support for this hypothesis comes from the fact that the interference task was itself disrupted by the primary task. Concurrent execution of both tasks may thus have tapped some of the general resources of working memory.

The next experiment was designed with the objective of implementing an interference task that would be more likely to tap visual memory resources during the processing of the primary task.

EXPERIMENT 3: VISUAL INTERFERENCE (DYNAMIC VISUAL NOISE)

In light of the results of Experiment 2, we thought it necessary to repeat the experiment using a different visual interference task. The task used consisted of presenting irrelevant visual material during the processing of the spatial description. This method has been shown to produce selective disruption of the storage of visual material in working memory (Logie, 1986; Quinn & McConnell, 1996a, 1996b, 1999). The visual interference technique devised by Quinn and McConnell (1996b) is based on a continuous display of dynamic visual noise during the processing of the primary task. The underlying postulate is that dynamic visual noise disrupts visual imagery by gaining obligatory access to the visual cache of working memory (Quinn & McConnell, 1999), or to the process of generating an image from a verbal description (Andrade, Kemps, Werniers, May, & Szmalec, 2002; Logie, 2003). This is the technique we used in Experiment 3, as a substitute for the brightness judgment task.

Method

Participants

Participants were 24 students of the University of Orsay (11 female, 13 male, between 20 and 30 years old) who volunteered to participate in this experiment. None of them had taken part in any of the previous experiments.

Materials
The stimuli for the primary task were the same as in Experiments 1 and 2. The secondary task was the dynamic visual noise display developed by Quinn and McConnell (1996b). The display measured 10.5×10.5 cm on the monitor and consisted of an array of 80×80 dots. There was a continuous black/white change of a random subset of 291 dots every second. The software used to produce the dynamic visual noise on the computer was that used by Quinn and McConnell.

Procedure
The procedure was the same as in Experiments 1 and 2, with a dynamic visual noise display as the secondary task. Participants had to fixate the centre of the array without paying any attention to it. In this experiment, there was no record of performance in the secondary task. However, the single-task phases were maintained for the participants.

Results
As in Experiments 1 and 2, recall rates were analysed, following the same design as before. Since there was no measure of performance in the secondary task, the results only concern the primary task. Figure 6 shows the recall rates for landmarks and moves/locations after the processing of the route and the survey descriptions, when the participants were and were not exposed to dynamic visual noise.

Primary task alone
In the absence of the secondary task, the average recall rate was 65.6 after the processing of the route descriptions, whereas it reached 70.7 after the processing of the survey descriptions. This difference was not significant according to the ANOVA, $F(1, 22) < 1$. Moves/locations were once more better memorized than landmarks, 78.8 versus 57.5, respectively, $F(1, 22) = 33.35, p < .001$.

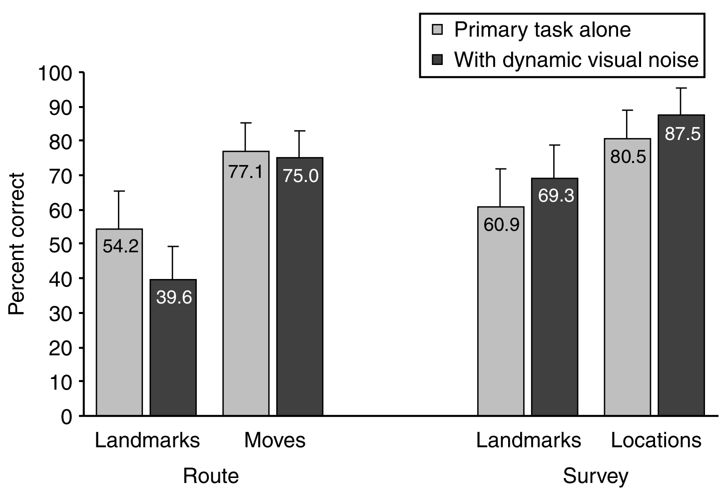

Figure 6. Experiment 3: Recall rates for landmarks and moves/locations after processing the route and survey descriptions, with and without the concurrent exposure to dynamic visual noise. Error bars correspond to the 95% confidence intervals of the means.

Primary task with concurrent task

The route descriptions elicited lower recall rates than the survey descriptions, 61.5 versus 74.6, respectively, $F(1, 22) = 8.04$, $p < .01$, and moves/locations were better recalled than landmarks, 80.0 versus 56.0, $F(1, 22) = 71.19$, $p < .001$. The overall effect of dynamic visual noise was not significant, with an average recall rate of 68.2 in the absence of visual interference and 67.8 in the presence of such interference, $F(1, 22) < 1$, but there was a significant interaction between perspective and the presence/absence of visual noise, $F(1, 22) = 10.03$, $p < .005$. This interaction reflected the fact that under the route perspective, there was a significant decrease of performance from 65.6 to 57.3 due to the visual noise, $F(1, 22) = 5.44$, $p < .05$, whereas performance increased from 70.7 to 78.4 under the survey perspective, $F(1, 22) = 4.60$, $p < .05$. This is why recall rates were lower in the route perspective than in the survey perspective, a difference that was significant only in the dual-task condition, $F(1, 22) = 18.18$, $p < .001$. There were no other significant interactions. Planned comparisons revealed that the only significant decrease due to the dynamic visual noise was that of landmarks processed under the route condition, $F(1, 22) = 6.44$, $p < .02$. Recall of moves/locations under the same condition was insensitive to visual interference, $F(1, 22) < 1$.

Discussion

In this experiment, the processing of route and survey descriptions resulted in similar performance in the absence of an interfering task. Consistent with the findings of the previous experiments, information about moves/locations was better recalled than information about landmarks.

The dynamic visual noise only produced a weak effect on the processing of descriptions. Furthermore, the recall of moves/locations was not affected by visual noise, suggesting that their processing primarily engaged the spatial component of working memory, as already indicated by the results of Experiment 1. Only the landmarks that were presented under the route perspective were sensitive to the visual interference task. Our hypotheses thus received good support from this experiment. The processing of landmarks engaged visual imagery in the route perspective, but not in the survey perspective.

In everyday life, the most frequently experienced perspective on spatial environments is the route perspective. Only a few people experience a city from a bird's eye view. For most people, the survey perspective is restricted to map reading. The visual features of landmarks stored in long-term memory are more often available from the route than the survey perspective. Baddeley and Andrade (2000) showed that the rated vividness of an image depends on the amount of information retrieved from long-term memory. It is not surprising that the survey perspective was not suitable for the visual processing of landmarks.

Of course, mental images could have been generated from the general knowledge of the participants. Even if the participants had never seen a pharmacy from above, they were certainly able to create the corresponding representation in the form of a mental image. However, this construction has a high cognitive cost and poor representational value. This strategy is thus unlikely to be implemented during the processing of survey descriptions.

In the survey perspective, visual interference did not appear to have any effect on memory. Recall rates for landmarks and moves/locations actually tended to be higher in the dual-task than in the single-task condition. A similar positive effect of dynamic visual noise was reported by De Moor, Werniers, Kemps, Van der Goten, and De Vooght (1997) and Zimmer *et al.* (2003). Visual interference can improve the memory for spatial configurations under certain conditions. An explanation of this result may be found in the fact that several participants reported that they visualised landmark locations within the dynamic visual noise matrix, and that they then shifted their gaze according to the directional instructions. The fact that a covert oculomotor process can improve the retention of a shape in working memory is well documented (Olivier, Labiale, & Celse, 2001). The rehearsing process engaged by eye movements on the screen was thus likely to help to maintain the configuration in memory. It is also possible that verbal codes might have been used to support memory for landmarks in the survey condition, making this condition less susceptible to interference from dynamic visual noise. The possible use of verbal codes was explored in Experiment 4.

EXPERIMENT 4: VERBAL INTERFERENCE (ARTICULATORY SUPPRESSION)

The last experiment examined the role of the phonological loop in the processing of spatial descriptions. Given that information was presented to the participants in a verbal form, this experiment was thought to be a necessary step in the series. Although information was presented orally to the participants, we did not expect that verbal interference in the form of articulatory suppression would affect the processing of descriptions. Text comprehension does not rely primarily on the phonological loop. When language is used to describe an environment or to elicit mental images, the visuospatial sketchpad is known to be more strongly implied than the phonological loop (Brooks, 1967; Pazzaglia & Cornoldi, 1999; Salway & Logie, 1995).

The sensitivity of mental imagery tasks to verbal interference depends on the material used and on the requirements of the task. The verbal component of working memory is not involved in the mental manipulation of abstract shapes (Bruyer & Scailquin, 1998; Logie & Salway, 1990). Moreover, when an imagery task requires the mental manipulation of letters, temporary storage appears to rely on the phonological loop (Finke & Slayton, 1988; Pearson *et al.*, 1999; Pearson, Logie, & Green, 1996). Verbal storage is made possible when participants are not required to retain the specific visual shapes of the material. The letters presented can be regenerated from long-term memory instead of being maintained as visual images.

In Experiments 1 through 3, we have collected data supporting the view that memory for landmarks relies on their visuospatial storage in working memory, as evidenced by data in the route perspective. However, in the survey perspective, spatial and visual interference did not appear to have any substantial detrimental effect on the memory for landmarks (Experiments 1 and 3). Visuospatial storage was unlikely to occur for retaining the sequence of landmarks in the survey perspective, because of its presumed high cognitive cost. We therefore suggest that in this case, the memory for landmarks can be supplemented by the verbal temporary storage system to the extent that no visual characteristics of the landmarks have to be recalled. If this hypothesis is correct, articulatory suppression should disrupt the recall of landmarks in the survey perspective.

Method

Participants

Participants were 24 students at the University of Orsay between 20 and 30 years old who volunteered to take part in this experiment. None of them had participated in any of the previous experiments. An equal number of male and female participants were recruited.

Materials

The stimuli for the primary task were the same as in the previous experiments. The secondary task involved articulatory suppression. A voice key connected with a computer via the parallel port recorded time intervals between successive oral outputs of the participants.

Procedure

The procedure was the same as in the previous experiments, with articulatory suppression as secondary task. In this task, participants had to repeat continuously the letter 'B' at the rate of one output every second.

Results

Primary task

Recall rates were analysed according to the same design as for the previous experiments. Figure 7 shows the recall rates for landmarks and moves/locations after the processing of the route and the survey descriptions, with and without articulatory suppression.

Primary task alone

In the absence of articulatory suppression, the average recall rate was 65.2 after the processing of the route descriptions versus 68.6 after the processing of the survey

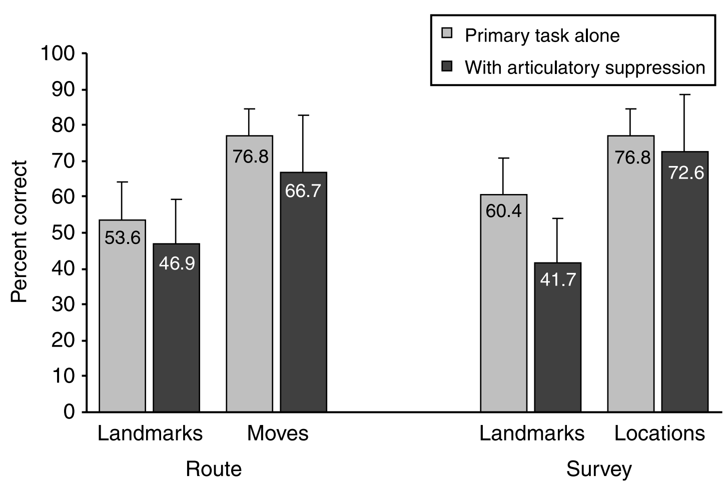

Figure 7. Experiment 4: Recall rates for landmarks and moves/locations after processing the route and survey descriptions, with and without the concurrent execution of the secondary task (articulatory suppression). Error bars correspond to the 95% confidence intervals of the means.

descriptions, a statistically non-significant difference, $F(1, 22) < 1$. Recall rates were higher for moves/locations than for landmarks, 76.8 versus 57.0, respectively, $F(1, 22) = 55.30$, $p < .001$.

Primary task with concurrent task

Recall rates did not differ after the route and the survey descriptions, 61.0 and 62.9, respectively, $F(1, 22) < 1$. The recall of moves/locations was consistently higher than the recall of landmarks, 73.2 versus 50.7, respectively, $F(1, 22) = 56.15$, $p < .001$. With articulatory suppression, recall rates fell from 66.9 to 57.0, $F(1, 22) = 5.34$, $p < .05$. There were no significant interactions. Planned comparisons revealed that the only significant decrease in recall rates was that of landmarks in the survey condition, $F(1, 22) = 5.54$, $p < .05$.

Secondary task

The mean variances of inter-response intervals in single and dual-task conditions were compared by ANOVA. The difference between the two conditions was not significant (the mean variance was 0.12 seconds in the single condition and 0.20 seconds in the dual-task condition).

Discussion

Articulatory suppression had a slight overall effect on the processing of spatial descriptions. The most significant interference effect was limited to landmark recall under the survey perspective. The results confirm that the participants did not adopt a verbal strategy in order to memorize the sequence of moves/locations. However, as suggested by the results of Experiment 3, the landmarks memorized under the survey perspective appeared to benefit from temporary storage in the phonological loop. The maintenance of verbal representations within the loop reduces the load on working memory by reducing the requirement for visuospatial maintenance of generated images. The pattern of results in Experiment 4 thus fits well with the data from the previous three experiments.

GENERAL DISCUSSION

The first issue considered in the present research was whether the perspective taken on a described environment during encoding has an impact on the memory of the spatial description. Information presented according to the survey perspective is generally expected to benefit from better integration than when the same information is presented according to the route perspective (Taylor & Tversky, 1992). The allocentric reference frame is a fixed one, whereas in route perspective, the reference frame is continuously changing. This means than the perspective has to be updated every time a new reorientation is prescribed in the description. Taylor and Tversky suggested that integration of information in memory takes more time in the route than in the survey perspective. However, our experiments, where encoding times were equated in all conditions, showed that configurations were as well remembered in the route as in the survey perspective. The very slight advantage in mean recall in the survey condition compared with the route condition consistently failed to reach significance. Even if one considers that for the participants, drawing a sketch map is an activity more compatible with the survey than the route learning perspective (this implying a mismatch that should be detrimental to performance in the latter case), none of the experiments revealed any effect suggesting systematic superiority of one perspective over the other when the primary task was executed alone. Only one of the four experiments was indicative of a difference when the primary task was executed with a concurrent task.

The absence of a significant difference is at variance with the data reported by Ferguson and Hegarty (1994), who suggested that people seemingly construct more complete and accurate representations from route than from survey texts when the order of information matches the order in which the landmarks would actually be encountered on a route. Several factors may account for this divergence. First, the configurations used by Ferguson and Hegarty were more complex than ours, making it difficult for the experimenters to construct route and survey texts with similar levels of determinacy and complexity. Some clauses in their survey text were even more complex than in the corresponding route text. The second factor pertains to the manipulation of the reference frame and the associated spatial terms. In the survey descriptions used by Ferguson and Hegarty, some statements were typical of an egocentric reference frame (e.g. the description of the windows of a shop). Pazzaglia and Cornoldi (1999) encountered similar difficulties with survey descriptions, which turned out to be less well remembered than the description of the same environment from a route perspective. In their descriptions, information was introduced linearly in route texts, and hierarchically in survey texts, but here too, egocentric spatial terms were introduced in the survey texts (expressions like *in front of* were combined with cardinal referents). This suggests that changes of perspective, as well as residual indeterminacy in the survey texts, in contrast to the linear organization of route texts, provide a better explanation of the superior recall of route descriptions over survey descriptions in Ferguson and Hegarty. In addition, as our experiments have shown, a linear organization is not incompatible with a survey perspective.

The second issue considered in the experiments reported here compared memorability of information related to landmarks and of information related to landmark locations (be it specified through a movement instruction or the mention of relative positions). Most of the previous studies of spatial discourse have relied on responses involving the verification of statements or the localization of landmarks on maps. Our approach concentrated on the differential memory for the identity and location of landmarks. In all four experiments reported above, moves/locations were consistently better recalled than landmarks. This result apparently conflicts with the earlier demonstrations of the superiority of landmark over action recall. It is important to note, however, that in the experiments reported by Fernandez (2000), landmarks and actions were introduced in separate sentences, and consequently landmarks were presented twice – once when a new landmark was introduced, and then again when an action was prescribed relative to that landmark. Thus, the memory of landmarks probably benefited from this particular mode of description. In contrast, in our experiments, a landmark and its associated action were always introduced in a single sentence, thus making the comparison of their memorability more valid. The result was that actions were consistently better recalled than landmarks, and this is a new finding in research on the processing of spatial discourse.

The ultimate objective of the present research was to shed light on the role of visuospatial working memory in the processing of spatial descriptions. The involvement of visuospatial working memory in the processing of illustrated texts has been amply demonstrated (Gyselinck *et al.*, 2002; Kruley *et al.*, 1994). Pazzaglia and Cornoldi (1999) provided evidence for the involvement of visuospatial working memory in the processing of spatial texts, even in the absence of illustrations. On the other hand, they failed to demonstrate that different components of working memory were involved, depending on whether the readers adopted a route or a survey perspective. Our results offer a clear indication that different components of working memory are implicated in the situations considered.

First, our assumptions concerning the effect of spatial interference were confirmed. The processing of moves/locations was found to be more sensitive to spatial interference than that of landmarks. There was no overall difference resulting from the adoption of one particular perspective, but the detrimental effect of spatial interference was especially evident in the route condition. Our data also suggest that spatial working memory is primarily involved in the processing of landmarks when these are presented from a route perspective, and to a much lesser extent when they are presented from a survey perspective. Secondly, the involvement of the visual cache in the memorization of spatial descriptions proved to be dependent on perspective, but also on item type. There was clear evidence for the implication of visual processing of landmarks under the route perspective. In contrast, we found no visual interference in the case of the survey texts. This is consistent with our hypothesis that the visual imagery of landmarks is elicited when people adopt a route perspective, whereas it is moderately involved when the landmarks are primarily imagined in terms of their positions. Thirdly, the verbal interference task affected the two perspective conditions in a similar fashion. As expected, the processing of spatial descriptions did not appear to rely primarily on the verbal component of working memory, even if there is an indication that landmarks presented according to the survey perspective were processed through the articulatory loop.

Taken as a whole, our results provide support for the view that distinct components of working memory are involved in the processing of landmarks and moves/locations, suggesting that different cognitive processes apply to these two classes of items. Moreover, the processing of landmarks in working memory clearly appears to depend on the perspective used, in contrast to moves/locations, whose processing systematically calls for spatial working memory. These findings confirm previous observations that landmarks and moves show different properties depending on whether the route or survey perspective is used at encoding (Fernandez, 2000).

Our aim was also to find out whether the information encoded in working memory differs depending on the perspective imposed by the spatial descriptions. The four experiments reported here did not highlight any major differences between the processing of spatial descriptions in the route and survey perspectives. The expected effects were in fact limited to landmarks. However, the findings confirmed that route descriptions call upon both spatial and visual processing, whereas the processing of survey descriptions relies on the spatial and the verbal components of working memory. These findings support the view that distinct cognitive processes are engaged in memorizing route and survey descriptions. This perspective effect is measurable during processing, as demonstrated by the experiments conducted by other authors using the framework of the working memory model, but it seems to dissipate at the time of information retrieval, as demonstrated by our measures of recall.

This pattern of results is consistent with McNamara's (2003) theory of spatial memory, which is based on the postulate of multiple spatial representations. The theory claims that spatial memories are primarily composed of object-to-object spatial relations, and are therefore allocentric. Egocentric self-to-object spatial relations are also considered in the theory, but only as visual memories of layouts. The two systems, object-to-object and self-to-object, interact in several ways. For instance, the heading of the latter may define the orientation of the former.

To summarize, our study has provided empirical arguments for the view that the processing of route and survey texts engages the spatial component of working memory, whereas visual processing in working memory only applies to descriptions presented according to the route perspective, and specifically for landmarks. The present research offers new suggestions for the understanding of how spatial representations are constructed and used in the preparation of navigational performance.

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