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COMPREHENSION AND RECALL OF SPATIAL DESCRIPTIONS

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Abstract

A series of four experiments compared the processing of two versions of a text describing a spatial configuration. One version was a linear, systematic description, proceeding according to a sequence adjusted to readers' expectations. The second version was characterized by structural discontinuities and poor internal organization. Sentence-by-sentence reading times were consistently shorter for the first than for the second version. When information was recalled on a blank map, subjects performed better after reading the well-structured version. These findings indicate that readers' construction of the representation of a configuration is affected by the sequencing of the description of this configuration. The assumption that visual imagery contributes to the elaboration of the representation is examined, and evidence is provided that reading times are modified by the type of task subjects expect to perform after reading. The discussion centers on the role of spatial mental models in the representation of information conveyed by descriptive texts.

Key words: Text processing, comprehension, reading times, recall, spatial configurations, visual imagery, mental models.
Mots clés : Traitement de textes, compréhension, temps de lecture, rappel, configurations spatiales, imagerie visuelle, modèles mentaux.

This paper deals with the processing of texts intended to provide readers or listeners with information about spatial configurations. An example of this type of situation is the following. A given individual, A, who is in the presence of a physical configuration, undertakes to describe it to another person, B, exclusively through discourse, such that B constructs a mental representation of the configuration.[1] It is assumed that A has constructed her own (perceptual) representation of the configuration, and that her intention is to have B construct a mental representation of the configuration as similar as possible to her own solely on the basis of language. Theoretically, B's representation, derived from the processing of A's discourse, should allow him to perform cognitive operations with efficiency comparable to that of A (for example, reconstructing the configuration by drawing, inferring non-explicitly stated information, comparing distances between points in the configuration).

This example is representative of a large number of natural communicative situations. In addition, it has the theoretical interest of bringing together two fields of research which have proved to be highly productive in recent years, but have not yet derived full benefit from their potential interrelations. The first of these is the field of prose processing studies, and the second is that area of research devoted to spatial knowledge and cognitive maps.

Prose processing research has expanded considerably in the past ten years, the main impetus being the analysis of processing units in terms of propositions, and their organization into higher-order (macrostructural) units (see Denhière, 1984; Kintsch, 1974; Kintsch & van Dijk, 1978). More recently, several theoretical proposals have been put forward to articulate the notion of "model" with the notion of propositional textbase. Models are not considered to be representations of the *text* itself, as is the case for the propositional textbase, but rather are thought to provide readers with a non-linguistic representation of the *situation* or *state of affairs* described in the text (cf. van Dijk & Kintsch, 1983; Johnson-Laird, 1983; Perrig & Kintsch, 1985). This notion of model has particular bearing on cases where the text is intended to have the reader elaborate a picture-like representation of a set of objects connected by spatial relations (Ehrlich & Johnson-Laird, 1982; Mani & Johnson-Laird, 1982). It subsumes a number of more specific sorts of representations (see Johnson-Laird, 1983, chap. 15), but most of the theories based on this concept recognize visual imagery as being of special relevance in the processing of texts describing spatial configurations.

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1. In order to avoid the typical problems associated with person pronominalization in English and their consequences on article readability, the convention that Subject A is a female speaker and Subject B a male listener has been adopted here.

The second field of research deals with the processing of visuo-spatial information, in particular in the context of cognitive or mental mapping. Internal representations of environmental spaces have been shown to affect the way people orient themselves and plan their navigation in these spaces. The functional role of cognitive maps relies to a large extent on their capacity to preserve the Euclidean properties of physical space (e.g., Byrne, 1979; Hirtle & Jonides, 1985; Hirtle & Mascolo, 1986; McNamara, 1986; McNamara, Ratcliff, & McKoon, 1984; Moar & Bower, 1983; Pailhous, 1970). Spatial knowledge is based on various sources. The primary source is people's direct experience of their environments (including perception and navigation), but knowledge derived from the processing of symbolic information, such as maps or schemas, is equally important. Each of these sources of information has its own qualities, which have been shown to be closely related to the types of decisions subjects make when using their mental maps (cf. Thorndyke, 1981; Thorndyke & Hayes-Roth, 1982). However, there has been virtually no work done in this area on the potential role of language in the acquisition of spatial knowledge. There are some indications that workable knowledge can be acquired from texts describing spatial configurations, although such types of learning require longer processing times than learning from maps (cf. Perrig & Kintsch, 1985). In addition the order in which pieces of information are presented in the description tends to affect the processes involved in the construction of the mental map (cf. Foos, 1980; see also Ehrlich & Johnson-Laird, 1982; Mani & Johnson-Laird, 1982).

Returning to our example of the communicative situation described above, it is clear that Subject B's cognitive activities lie at the intersection of these two fields of research. Constructing a mental representation of a configuration from purely verbal input not only requires the ability to grasp *what is said* in the text, but also the ability to convert the information extracted from the text into a *non-linguistic model* of the configuration. The nature of the representational processes brought into play by Subject B will to some extent depend on his expectations concerning the use he will make of the representation. If B anticipates that an upcoming task will require calling on the configuration itself (for instance, find the shortest route between two points), he is likely to elaborate some spatial, map-like representation. If, on the other hand, B anticipates verbatim recall, his best strategy would consist of capitalizing on propositional processing. But in any case, the reader/listener is confronted with the fundamental problem of processing *linear* informational material (text or discourse) to construct a two- or three-dimensional representation. It is more than likely that this construction will be dependent on the specific sequencing of the linguistic input he will have to process.

The cognitive difficulties Subject B must deal with have their counterparts in the problems of text *production* that Subject A faces. These essentially consist in using discourse to place B in optimal conditions for constructing the representation. To do so, A will have to take into account several relevant factors, for instance her assumptions as to B's previous knowledge of the configuration, as well as B's processing abilities. She will also probably adapt her production to the medium used (e.g., written vs. oral). All these factors contribute to the planning of discourse and in particular affect the sequencing of the description (cf. Levelt, 1989).

Descriptive texts, in this respect, have structural characteristics which differentiate them considerably from the text types which have received the most attention in prose processing studies, namely, narrative texts. In narratives, the order in which events are reported typically matches the order in which the events are assumed to have occurred. That is, in the absence of specific stylistic ("flashback") effects, the sequential structure of the text is tightly constrained by the temporal structure of the events. The same is true for texts describing the successive steps of a process, or those describing routes in natural environments (cf. Ullmer-Ehrich, 1982; Wunderlich & Reinelt, 1982). On the other hand, texts can describe spatial entities where constraints on the order in which the different parts of the configuration are entered in the description are either much weaker, or totally absent. If, for instance, Subject A has to describe a static scene or a set of objects in a two-dimensional space as is the case for geographical configurations, the set of objects the text is about has no intrinsic sequential structure, but the text, whose structure is linear in nature, will mandatorily introduce subparts of the configuration one after the other, in a specific, non-random sequence. The description of most spatially-extended objects, such as geographical material, can theoretically start from any point in the configuration, and the number of orders in which the subsequent points can be entered in the description is, if not infinite, at least very high (cf. Levelt, 1989, chap. 4; Shanon, 1984).

It is fairly easy to find instances of configurations where the object to be described has properties which constrain the order of description to some extent, for example when the subparts of the configuration have a semantic content that is hierarchically ordered. In describing a country and the locations of cities in it, an individual can start the description with the capital and then introduce, in decreasing order of importance, the major regional cities, less important towns, and so on, each of which is located relative to the more important ones. However, in the absence of any explicit hierarchy among these points, describing will entail making a *choice* of a specific descriptive sequence. In most cases, a configuration can be described in a variety of ways, and each discourse structure can vary widely in its internal organization. The issue, to return to Subject B, is whether some of these structures are "better" than others in terms of efficient communication. Are there "canonical" descriptions, whose on-line processing requires minimal cognitive resources, and can generate a representation that is implemented easily by the reader/listener? The answer is an affirmative one in the case of texts with a narrative structure, but little is known about texts describing objects or spatial entities.

The present series of experiments was designed to explore this issue by examining the factors involved in the on-line elaboration of the representation constructed by the reader and its final content, as a function of the internal structure of the text. The first assumption is that the processing which readers/listeners of a descriptive text undertake normally results in the elaboration and storage of a propositional textbase of the description. Second, readers/listeners exposed to descriptive texts are assumed to elaborate a spatial model of the configuration, which may prove to be of particular use if they anticipate they will be required to recall the spatial structure of the configuration. The main issue in this series of experiments centers on the processes an individual's cognitive system calls into play when using a linear sequence of verbal statements to construct a non-linguistic mental representation distributed over a coordinate representational space. More specifically, the question is whether the order in which statements are presented will affect processing, both at input, during reading, and at output, when the reader has to retrieve information in a recall task.

PRELIMINARY EXPERIMENT

The experiments reported below focus on how readers process texts describing spatial configurations, and how their comprehension is affected by the internal structure of these texts. The ultimate objective of this study is to show that comprehension processes depend on the structural characteristics of a text, and thus by extension on the processes which originally governed the production of this text. The first step therefore consisted in observing the descriptive behavior of subjects required to produce a text describing the configuration targeted for the experiments. This preliminary experiment provided spontaneous descriptive sequences, which were later used to construct the materials for the experiments.

Method

Materials. A map of an imaginary island containing six geographical features (a mountain, a forest, a lake, a meadow, a cave, a desert) was devised. These features were drawn in a fairly schematic fashion and were labelled underneath. The overall shape of the island was rectangular, with the six features aligned along two horizontal rows of three items each (see Figure 1).

Figure 1. Map of island.

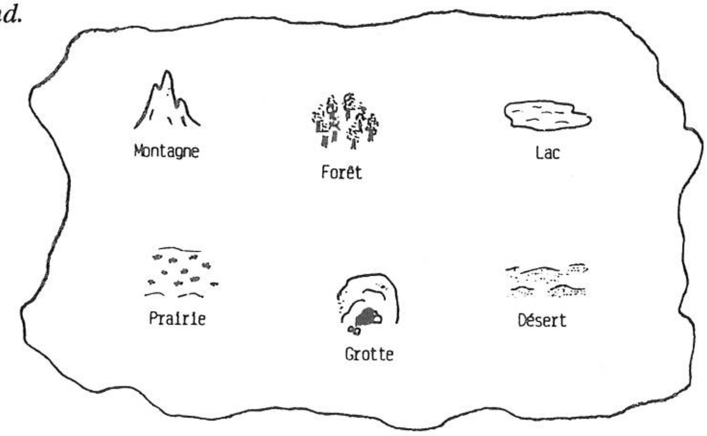

Figure 1. Carte de l'île.

Procedure. Each subject received a sheet of A4 paper. The map was reproduced on the upper third of the sheet, and the remaining two thirds of the sheet were left blank for subject's response. Subjects were instructed to write a description of this island as though they were addressing themselves to someone who had no previous knowledge of this island, but needed to have as accurate a representation of it as possible. No time limit was imposed.

Subjects. Thirty-five undergraduates from the Orsay campus were used as subjects.

Results and discussion

Of the 35 descriptions obtained, 32 met minimal criteria for adequate description, that is, all six features were mentioned and correctly located in such a way that a reader would be able to reconstruct an accurate map from the description. Since the main focus of the subsequent experiments was the sequential structure of descriptions, analysis essentially dealt with the *order* in which the six features were entered in the descriptions.

The 35 responses yielded a total of 22 different descriptive patterns. Figure 2 presents these patterns and the number of subjects producing each. Twenty-six subjects produced a pattern with intrinsic systematicity, while no convincing indication of systematicity could be detected for the 9 remaining descriptions. Of the 26 responses exhibiting systematicity, the vast majority relied on linear scanning, with an obvious prominence of horizontal scanning patterns.

Figure 2. Patterns of description in the preliminary experiment.

PATTERNS REFLECTING SYSTEMATICITY (N = 26)

Linear Scanning (N = 22)

- Horizontal (N = 14)

1 2 3
4 5 6 (N = 9)

4 5 6
1 2 3 (N = 1)

1 3 2
4 6 5 (N = 3)

2 1 3
5 4 6 (N = 1)

- Vertical (N = 7)

1 3 5
2 4 6 (N = 2)

3 5 1
4 6 2 (N = 2)

1 5 3
2 6 4 (N = 1)

5 1 3
6 2 4 (N = 1)

3 1 6
4 2 5 (N = 1)

- Boustrophedon (N = 1)

1 4 5
2 3 6 (N = 1)

Circular Scanning (N = 4)

- Strict (N = 2)

6 1 2
5 4 3 (N = 1)

1 6 5
2 3 4 (N = 1)

- Non-strict (N = 2)

1 5 6
2 3 4 (N = 1)

1 5 2
4 6 3 (N = 1)

NON-SYSTEMATIC PATTERNS (N = 9)

Complete Patterns (N = 6)

1 2 4
3 6 5 (N = 2)

1 2 4
3 5 6 (N = 1)

1 3 4
2 6 5 (N = 1)

2 6 5
1 3 4 (N = 1)

6 5 4
3 1 2 (N = 1)

Unidentifiable Patterns (N = 3)

Figure 2. Types de description dans l'expérience préliminaire.

The most striking feature of these results is the wide variety of orders in which even a rather simple configuration can be described. As a matter of fact, any of the six features can in principle be used as a starting point, followed by any of the remaining five, and so on. Nevertheless the data show that some orders were used more frequently than others. Most subjects chose orders reflecting reasonable systematicity (according to the authors' intuitions), which was assumed to be indicative of their efforts to plan the description to some extent. Some systematic orders were apparently preferred over others. Horizontal linear scanning was chosen by one subject out of four, which reflects the relatively high availability of this pattern. Note that several descriptive sequences with weak systematicity could still provide readers with exhaustive, non-ambiguous information on the configuration.

EXPERIMENT 1

Experiment 1 was designed to compare the processing of two contrasted versions of a descriptive text. One version was devised to be as systematic and coherent as possible, and to proceed according to a sequence adjusted to the expectations of most readers. In contrast, the second version was constructed to create substantial cognitive difficulties in readers through structural discontinuities and poor internal organization. Sentence-by-sentence presentation was expected to yield reading time patterns reflecting these cognitive difficulties. Recall performance was also examined. The prediction was that the processing difficulties resulting from poorly-organized text would be reflected by poorer recall.

Method

Materials. Figure 3 presents the two texts used in this experiment (translated from French). One version (Text 1) adhered to the order of description used most frequently by subjects in the preliminary experiment (horizontal linear scanning). This version was based on horizontal scanning of the upper row, followed by horizontal scanning of the lower row. There were two anchor points in this description, namely, the first feature at the extreme west end of each row. The other version (Text 2) was adapted from one of the weakly systematic patterns obtained in the preliminary experiment. In this version, the order of description completely deviated from linearity. One anchor point was the feature at the extreme west end of the upper row, and the other anchor point was the feature at the extreme east end of the lower row. The text repeatedly violated the principle of connectivity which requires that the next point to be described is in the immediate proximity of the current point. Text 2, while providing readers with essentially the same information as the other text, was judged by a set of five pilot subjects to present the information in a very poorly organized manner, in contrast to Text 1.

Figure 3. Two versions of the description.

TEXT 1

1. In the extreme north-west part, there is a mountain.
2. To the east of the mountain, there is a forest.
3. To the east of the forest, there is a lake.
4. In the extreme south-west part, there is a meadow.
5. To the east of the meadow, there is a cave.
6. To the east of the cave, there is a desert.

TEXT 2

1. In the extreme north-west part, there is a mountain.
2. To the east of the mountain, there is a forest.
3. To the south of the mountain, there is a meadow.
4. In the extreme south-east part, there is a desert.
5. To the west of the desert, there is a cave.
6. To the north of the desert, there is a lake.

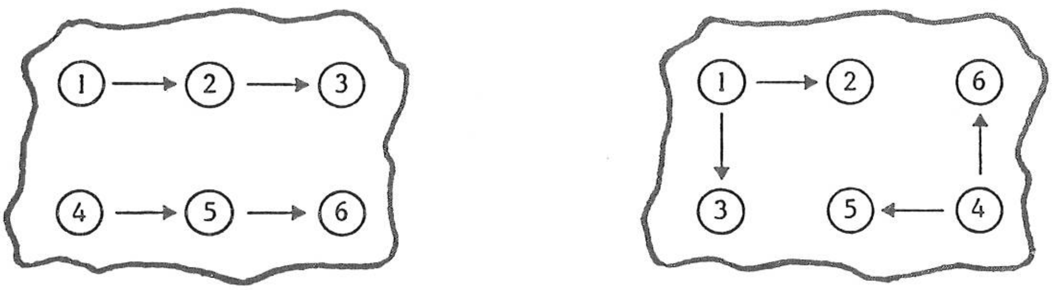

Figure 3. Deux versions de la description.

Alternate versions of the two texts were devised, with the natural features replaced by artifactual ones (following the order of presentation in Text 1: a factory, a church, a train station, a viaduct, a farm, a hospital).

Design. Each subject was given two texts, one describing the island with natural (N) features, the other describing the island with artifactual (A) ones. This variable was crossed with the type of text structuration (Text 1/Text 2). Order of presentation of the two texts was varied. The four resulting combinations were as follows: N1-A2; A2-N1; N2-A1; A1-N2. Six subjects were assigned to each of these combinations. This design was replicated in all subsequent experiments reported below.

Procedure. Subjects were tested individually. They were asked to read each text in a sentence-by-sentence self-presentation procedure. Sentences were displayed on a monitor connected to a computer.

The first phase of the experiment was a practice trial designed to familiarize subjects with the use of the computer and give them an accurate idea of what would be expected from them during the subsequent phases of the experiment. Subjects were first presented with a blank map of a diamond-shaped island, with X's printed at each angle of the island. They were informed that they would read a description on the screen of what was to be found at each of the four locations, and that they would later be tested for recall. They were told that the description was four sentences long, and that they should make each sentence appear on the screen one by one at their own pace using the space bar on the keyboard, but that they could not go back. They were instructed that after reading they would be provided with the blank map and would have to fill it in. The sentences used in the practice trial were as follows: "At the extreme north of the island, there is a beach. In the south, directly opposite the beach, there is a lighthouse. At the extreme west, there is a harbor. In the east, directly opposite the harbor, there is a cliff." During the reading phase, the map was removed from subjects' visual field. After having completed the reading phase, subjects received the blank map again and were asked to write the word for the corresponding feature below each X.

The processing of the two experimental texts and recall on blank maps followed. The procedure was identical to the one used for the practice trial, with the two exceptions that in both cases maps were rectangular shaped islands (that is, maps identical to the map shown in Figure 1, with all six features replaced by X's), and the instructions were for texts comprising six sentences.

Subjects. Subjects were 24 undergraduates from the Orsay campus. None had participated in the preliminary experiment reported above.

Results and discussion

Reading times. An analysis of variance for total reading times indicates two main effects. Reading times were overall shorter for Text 1 than for Text 2, $F(1,20) = 17.59, p<.001$, and it took longer to read the first text presented than the second, $F(1,20) = 5.23$, $p<.05$. There was no significant overall difference between reading times for the text describing natural and the text describing artifactual features. None of the interactions reached significance.

Figure 4 shows mean reading times per sentence for Texts 1 and 2. (Numbers on this figure and the subsequent ones refer to sentence position in each text.) Reading times for Text 1 sentences exhibit a fairly homogeneous pattern, about 10 s per sentence, with a somewhat longer reading time for Sentence 4, which corresponds to the introduction of the second anchor point. Individual *t*-test comparisons were performed on reading times for pairs of sentences in immediate succession. These comparisons showed no significant effect, except between Sentences 3 and 4, $t(23) = 2.19$, $p<.05$. The overall regular pattern of reading times for individual sentences in Text 1 is congruent with the hypothesis that readers of Text 1 were placed in a situation of low cognitive load, that is, in which processing followed a highly expected sequence.

Figure 4. Experiment 1: Mean reading times per sentence (upper half) and recall frequencies per feature (lower half).

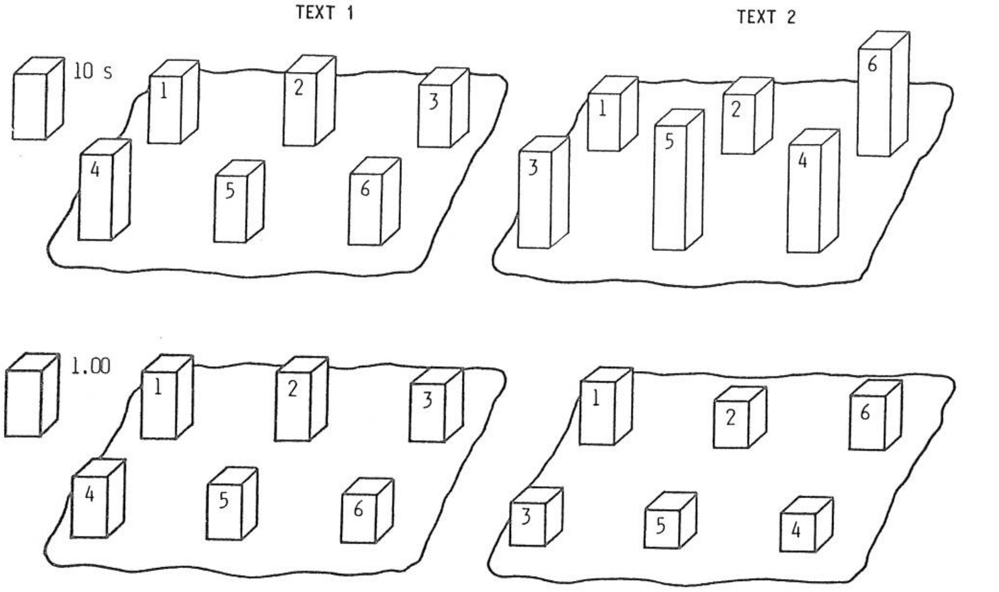

Figure 4. Expérience 1 : Durées moyennes de lecture par phrase (en haut) et taux de rappel par détail (en bas).

The pattern of reading times for Text 2 was quite different. While reading times for Sentences 1 and 2 remained within the typical range of reading times for Text 1, a sharp increase occurred for Sentences 3 to 6. The difference between Sentences 2 and 3 is significant, $t(23) = 3.37$, $p<.01$. Sentence-by-sentence comparisons between the two texts revealed that the overall effect detected by the analysis of variance was in fact selective. Reading times for Sentences 1 and 2 did not substantially differ from those for the same sentences in Text 1, which is not surprising since these sentences were the very same in both texts. Sentence 3 marks the point from which Text 2 diverges from Text 1 (that is, the first time Text 2 departs from the principle of connectivity). Reading times for Sentence 3 in Text 2 were significantly longer than for Sentence 3 in Text 1, $t(23) = 4.89$, $p<.001$. This effect could not result from difficulties associated with syntactic processing, since both sentences were strictly identical in terms of their syntactic structures. A likely explanation is that the cognitive difficulty reflected by this time increase results from the fact that readers had to process an unexpected location, and to revise the current construction of their representation. Similar effects were observed for reading times on subsequent sentences. For Sentence 4, the difference between Texts 1 and 2 was less marked, given the relatively long reading times for this sentence in Text 1, $t(23) = 1.75$, $p<.10$. Differences were again quite clear for Sentence 5, $t(23) = 3.95$, $p<.001$, and Sentence 6, $t(23) = 2.67$, $p<.02$. Sentence 5 is of special interest since it describes the same feature in both texts, has exactly the same syntactic structure, and occupies the very same position in both texts. Reading times for this sentence were much longer in Text 2 than in Text 1, virtually twice as long.

These chronometric data reflect the cognitive load resulting from processing conditions which require readers to adapt themselves to a poorly-structured description that introduces an unexpected anchor point, and uses horizontal and vertical scanning alternatively. Thus, Text 1 certainly fits most readers' expectations, while Text 2 clearly deviates from most descriptive schemes. In addition, it is likely that the construction of a model of the island (in the form of a mental map) is made more difficult, and less efficient, in Text 2 than in Text 1. Such consequences on the construction and storage of the representation of the object described were expected to be reflected in subjects' recall performance.

Recall scores. The number of features recalled at their exact locations was computed for each subject and each text. Recall scores were submitted to an analysis of variance, which revealed two main effects. First, subjects produced higher recall scores after Text 1 than after Text 2, $F(1,20) = 13.33$, $p<.005$. In addition, the first text read elicited overall lower recall than the second, $F(1,20) = 5.51$, $p<.05$. There was no effect for text content (natural vs. artifactual features), and no significant interaction.

Figure 4 shows recall frequencies for each feature. For Text 1, retention reached a maximum for the first features entered in the description, then steadily decreased to the last feature. There was no indication of any recency effect, a finding which may be accounted for by assuming that text encoding implies successive incorporations of new features into the model that readers construct of the configuration. Features incorporated first may be more efficiently integrated into the representation than features encountered later when the representation is more saturated in information and memory load is increased.

Recall frequencies for Text 2 were overall lower than those for Text 1. There is some indication that recall of the features mentioned at the start of the text (Sentences 1 and 2) was not as high after Text 2 as after Text 1, but the effect is not significant. On the other hand, comparison of the features described in Sentences 3-6 clearly showed recall to be higher after Text 1 than Text 2, $t(23) = 2.74, p < .02$. Finally, contrary to Text 1, recall frequency for Sentence 6 of Text 2 clearly shows a recency effect when compared to recall frequencies for Sentences 3-5.

These findings as a whole indicate that longer processing times (in the case of Text 2) were *not* reflected in higher recall scores. Rather, longer processing times are indicative of readers' adaptation to processing constraints that violated some kind of "canonical", or at least highly expected order of presentation of information. In addition, these constraints had obvious consequences on the construction and storage of the representation elaborated from the description.

As complementary information, the order in which the subjects filled in the blank map during the recall task was examined. This information was considered to reflect the order in which the subjects were reading out the information from the mental representation they had constructed. It seemed relevant to check whether the order in which this representation was accessed during recall reflected the order in which it was constructed during reading. For this purpose, during subjects' recall, the experimenter noted the order in which subjects filled in the different locations.

After Text 1, of the 15 subjects who labelled all six locations, 11 responded in an order reflecting the actual order of presentation of sentences. If analysis is extended to the subjects who filled in five locations, 19 out of the 24 subjects produced response patterns indicating repeated horizontal scanning. One subject produced a response pattern reflecting circular scanning, and four produced unclassifiable patterns.

After Text 2, of the 16 subjects who gave responses for each of the six locations, only 4 replicated the order in which information had been presented in the text, while 1 exhibited repeated horizontal scanning and 2 circular scanning. For the 22 subjects who filled in at least five locations, 4 replicated the sequence in the text, 2 produced responses reflecting horizontal scanning, and 3 exhibited circular scanning. The remaining 13 subjects produced unclassifiable response patterns, yielding 12 different sequences.

These data clearly indicate that accessing information in the representation is to a great extent affected by the processing constraints imposed on readers by the structural properties of the text. However, while the highly expected order of presentation was replicated at recall by the majority of subjects, there was no indication that the poorly-organized, unexpected sequence was replicated by a large number. Rather, this sequence seemed to elicit a considerable amount of inconsistencies at recall.

EXPERIMENT 2

The data collected in Experiment 1 establish that a given order of presentation of verbal information (Text 1) is "better" than another (Text 2) in terms of processing efficiency and recall. However, the extra reading times for sentences in Text 2 still need to be accounted for. In particular, at what *level* of text processing do these additional time components intervene? Do they occur at rather low levels of processing, such as those concerned with the analysis of the verbal string? Or do these extra processing times occur at higher levels of processing, such as those concerned with the integration of sentence meaning into the meaning of the previous set of sentences, and its coding into a spatial model?

Experiment 2 tests the hypothesis that extra reading times reflect processing steps occurring essentially once low level sentence processing has been completed, by replicating Experiment 1 with a modification. While in the original experiment reading times were controlled by subjects, sentences in Experiment 2 were presented for brief durations, and the subjects controlled the *intervals* between sentences. That is, they called up the subsequent sentence after an interval that could be interpreted as being occupied by high level processing of the previous sentence. If these intervals exhibit the same regularities as reading times from Experiment 1, this would indicate that previously observed variations can be accounted for in terms of integration of meaning into the current representation of the configuration.

Method

Materials. The texts and maps were the same as those used in Experiment 1.

Procedure. The procedure replicated the procedure of Experiment 1, except that sentences were presented for brief, fixed durations (1.4 s). The subjects were instructed to press the space bar on the keyboard to make the next sentence appear at their own pace. As in Experiment 1, they learned from a practice trial that they would have to recall features on a blank map after reading each text.

Subjects. Twenty-four undergraduates who had not participated in the previous experiments were recruited as subjects.

Results and discussion

Processing times. The analysis of variance for processing times reveals two main effects. Times were consistently shorter for the processing of Text 1 than Text 2, $F(1,20) = 23.07, p < .001$, and were longer for the first text read than for the second, $F(1,20) = 4.41, p < .05$. No other main effect or interaction was significant.

Given the procedure used, it was presumed that the last processing time for each text might be subject to artifact since the processing time following Sentence 6 was not followed by another sentence, and pressing of the bar provided no further information. This may have affected subjects' responsiveness to some extent. For this reason, the analysis of variance was replicated, dropping the processing time subsequent to Sentence 6. This analysis confirmed previous results. The only significant effects were those of text, $F(1,20) = 31.66, p < .001$, and time of presentation, $F(1,20) = 8.30, p < .01$.

Figure 5 shows mean processing times per sentence for Texts 1 and 2. Processing times for sentences in Text 1, not surprisingly shorter than reading times in Experiment 1, were again rather homogeneous, with a slight, non-significant increase following the introduction of the second anchor point

Figure 5. Experiment 2: Mean processing times per sentence (upper half) and recall frequencies per feature (lower half).

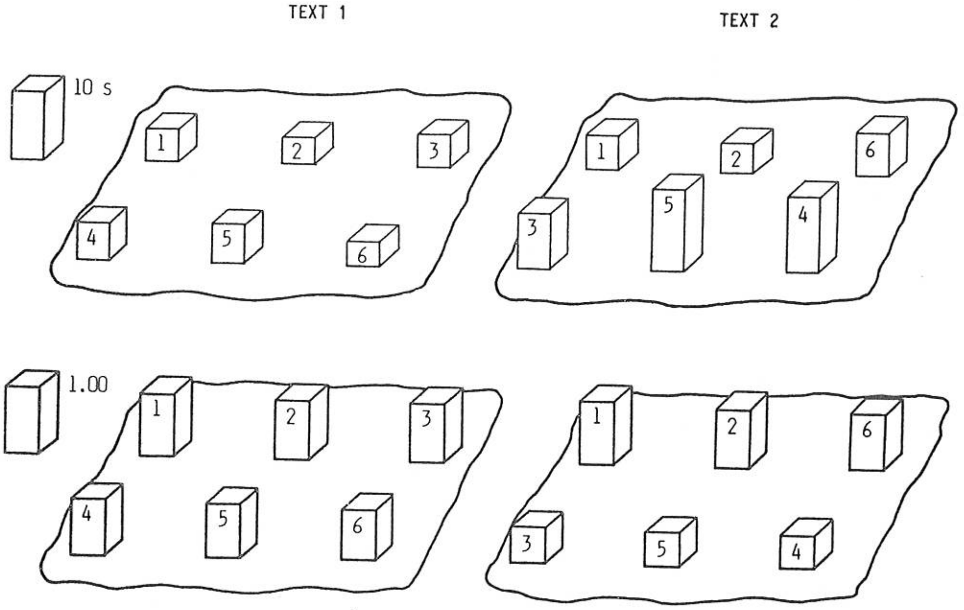

Figure 5. Expérience 2 : Durées moyennes de traitement par phrase (en haut) et taux de rappel par détail (en bas).

(Sentence 4). The fairly short processing time following presentation of the last sentence confirms its special status in this experiment.

A notably different pattern appeared for Text 2. While the processing times for Sentences 1 and 2 remained within the range of the corresponding times for Text 1, processing time for Sentence 3 increased dramatically (as compared to Sentence 2), $t(23) = 5.04$, $p<.001$, with an additional significant increase for Sentence 4 (as compared to Sentence 3), $t(23) = 2.39$, $p<.05$. The longest processing time occurred after Sentence 5. A shorter processing time followed Sentence 6, probably for the same artifactual reasons as mentioned above. Sentence-by-sentence comparisons between the two texts again revealed that processing times for Sentences 1 and 2 did not significantly differ from Text 1 to Text 2, while significant differences were observed for Sentence 3, $t(23) = 4.06$, $p<.001$, Sentence 4, $t(23) = 4.13$, $p<.001$, and Sentence 5, $t(23) = 3.37$, $p<.01$. For Sentence 6, the comparison yielded $t(23) = 1.78$, $p<.10$.

On the whole, the analysis of processing times in Experiment 2 reveals a pattern highly similar to what was evidenced in Experiment 1. This finding supports the assumption that in Experiment 1, variations in reading times were mainly dependent on processes occurring beyond the perception of the verbal string, that is, processes involved in the integration of individual sentence meaning into the reader's ongoing construction of the representation. These processes are obviously impaired when conditions force the reader to integrate unexpected pieces of information. Thus, structural deficiencies of the text have evident consequences on processing.

Recall scores. The analysis of variance shows that recall scores were higher for Text 1 than for Text 2, with a marginally significant effect, $F(1,20) = 3.68$, $p = .075$. Although less marked than in Experiment 1, the effect remains comparable. An analysis combining recall data from the two experiments shows no statistical difference between the two processing conditions, $F(1,40) < 1$. The strong effect of Text 1 vs. Text 2 is confirmed, $F(1,40) = 13.44$, $p<.001$, and there is no interaction between experiments and texts, $F(1,40) < 1$.

Recall frequencies per feature are shown in Figure 5. After Text 1, high recall frequencies for the first features described were followed by a steady, moderate decrease to the last feature. This pattern, which exhibits no indication of a recency effect, clearly replicates the corresponding pattern in Experiment 1.

Recall frequencies for Text 2 were overall lower than those for Text 1. While there was no difference as concerns the first two features mentioned (Sentences 1 and 2), the recall of features described by Sentences 3-6 proved to be significantly lower after Text 2 than Text 1, $t(23) = 2.35$, $p<.05$. The relatively high recall frequency for Sentence 6 reflects a recency effect, as was also the case for Text 2 in Experiment 1.

To summarize, the overall pattern of findings in Experiment 2 is highly comparable to that revealed by Experiment 1, as concerns both processing times and recall. Experiment 2 strongly suggests that in Experiment 1, the variations in reading time patterns between Texts 1 and 2 were regulated by the high level processes involved in the integration of the meaning of sentences into the representation of the configuration, and possibly in the recoding of linguistic meaning into a visual model of the configuration.

EXPERIMENT 3

The findings from Experiments 1 and 2 support the assumption that the processing of descriptive texts involves cognitive processes which serve to integrate newly received information into the ongoing representation, and that poorly-structured texts essentially create processing conditions which impair this integration. However, the findings do not directly indicate what sorts of processes contribute to the formation of this integrative representation.

A good proportion of subjects' post-experimental reports indicate that visual imagery was involved in the processing of descriptions. Subjects' comments stress that visual images were useful as representations which helped them to integrate informational units, especially when information was presented in a highly unexpected sequence. In order to collect information about the potential contribution of visual imagery, the original experiment was replicated with the additional feature that subjects were given explicit imagery instructions. Such instructions have proved to facilitate the retention of narratives (cf. Denis, 1982; Giesen & Peeck, 1984). If imagery instructions are effective in this task, they should facilitate the construction of an integrated representation, which should in turn be reflected in shorter processing times and higher recall.

Method

Materials. The materials were the same as those used in the two previous experiments.

Procedure. The procedure was similar to the procedure used in Experiment 1, with the only addition that subjects were explicitly instructed that they should form a clear visual image of the island while reading each sentence, and "put" each feature at its appropriate location in the image.

Subjects. Subjects were 24 undergraduates who had not participated in any of the previous experiments.

Results and discussion

Reading times. The analysis of variance reveals a strong effect for text, with overall shorter reading times for Text 1 than for Text 2, $F(1,20) = 28.21$, $p<.001$. No difference in reading times for the first and the second text read was observed. There was a consistent trend for the text describing artifactual features to elicit longer reading times than the text describing natural ones, $F(1,20) = 5.01, p<.05$. None of the interactions reached significance.

Figure 6 shows mean reading times per sentence for Texts 1 and 2. Text 1 presents a fairly homogeneous pattern. The only significant difference results from the comparison of reading times for Sentences 3 and 4, which corresponds to the introduction of the new anchor point, $t(23) = 2.18, p<.05$. This pattern is the same as in Experiment 1.

Reading times for individual sentences in Text 2 exhibited the very same pattern as the one observed in Experiment 1. While the reading times for Sentences 1 and 2 were similar to those for Text 1, a dramatic increase in reading times occurred from Sentence 3, $t(23) = 4.79, p<.001$, with reading times reaching high values throughout the remainder of the text. Sentence-by-sentence comparisons between the two texts showed that reading times for Sentences 1 and 2 did not significantly differ from those for the same sentences in Text 1.

Figure 6. Experiment 3: Mean reading times per sentence (upper half) and recall frequencies per feature (lower half).

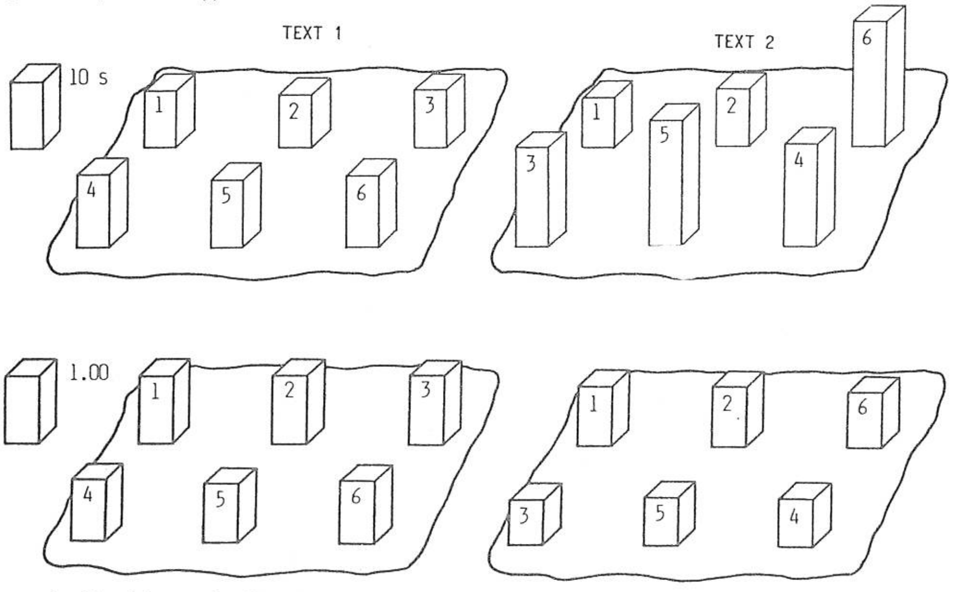

Figure 6. Expérience 3 : Durées moyennes de lecture par phrase (en haut) et taux de rappel par détail (en bas).

However, each individual comparison for the remaining sentences revealed that reading times were consistently longer for Text 2 than for Text 1: Sentence 3, $t(23) = 4.55, p<.001$; Sentence 4, $t(23) = 2.64, p<.02$; Sentence 5, $t(23) = 3.94$, $p<.001$; and Sentence 6, $t(23) = p<.05$.

Taken altogether, these findings clearly replicate those from Experiment 1. Reading time patterns for each text were extremely similar in the two experiments. But the most striking finding is that beyond these similarities of patterns, the *absolute values* of reading times were virtually identical to those in Experiment 1, where subjects were not explicitly instructed to image while reading. According to an analysis of variance combining the data from both experiments, there was no reliable effect of imagery instructions on reading times, $F(1,40) < 1$. This analysis confirmed the main effect of Text 1 vs. Text 2, $F(1,40) = 45.69, p<.001$, and no interaction was found between experiments and texts. Individual t-test comparisons performed on each sentence did not reveal any difference between Experiments 1 and 3.

While it is usually difficult to interpret the absence of a difference, a tempting hypothesis is that the imaginal processing required from readers in Experiment 3 was in fact developed spontaneously by subjects in Experiment 1. This interpretation is consistent with subjects' reports. In addition, it is well established that people possess valid knowledge about the efficiency of visual imagery in the comprehension and memory of verbal information (cf. Denis & Carfantan, 1985; Katz, 1987). Thus, it is likely that readers do make use of the encoding strategies they know or believe to be efficient in learning.

An alternate, equally valid interpretation of the lack of differences between Experiments 1 and 3 would be that imagery does not play a functional role in any of the experiments. This interpretation, however, is contradicted by the existence of strong differential effects of individual imagery abilities on reading times of descriptive texts. In particular, high visuo-spatial imagers show consistently shorter processing times than poor imagers (cf. Denis, 1989, chap. VII).

Recall scores. An analysis of variance on recall scores indicates higher recall for Text 1 than Text 2, $F(1,20) = 19.69, p<.001$. While recall scores tended to be consistently higher in Experiment 3 than in Experiment 1, the difference did not prove to be significant according to an analysis combining the data from the two experiments, $F(1,40) = 2.25$. The overall superiority of recall scores for Text 1 over Text 2 was confirmed, $F(1,40) = 31.61, p<.001$, and no interaction was found between experiments and texts.

Figure 6 shows recall frequencies for each feature. Recall frequencies were maximal or close to maximal for all features after Text 1, with no indication of a recency effect. Recall frequencies for Text 2 were lower than for Text 1, and exhibited a pattern comparable to the one in Experiment 1. No differences were found for the first two features mentioned (described by Sentences 1 and 2), but the recall of features described by Sentences 3-6 was significantly lower after Text 2 than Text 1, $t(23) = 4.14, p < .001$.

Thus, the recall data, as was the case for reading times, show no significant effect for imagery instructions. Given the repeated evidence for positive effects of imagery instructions in many learning contexts (cf. Paivio, 1986), the lack of measurable effects of this factor in Experiment 3 is considered as consistent with the hypothesis stated above. Even in the absence of explicit instructions, the learning context created in Experiment 1 strongly encouraged subjects to elaborate a representation equipped to incorporate spatial information in a format similar to perceptual experience. Since visual imagery is the most readily available representational process for encoding spatial information, it is more than likely that it was called into play once subjects recognized that this form of encoding was the most efficient way of processing the spatial relations in the text. This hypothesis is consonant with the definition of visual images as "functional sites" specialized in the encoding of unfamiliar spatial information (cf. Dean & Enemoh, 1983; Dean & Kulhavy, 1981; Schwartz & Kulhavy, 1981).

EXPERIMENT 4

Experiments 1, 2, and 3 have shown that the internal structure of a descriptive text affects the processing and recall of its content. However, this effect could be due to some extent to the nature of the task that readers expect to deal with. In the experiments reported above, the subjects were explicitly informed that recall would consist in recalling the locations of features on the map, a specification which may have increased the likelihood of subjects' engaging in strategies relying on visual imagery. Situations where the instructions prompt subjects to anticipate a different type of recall may produce different effects. For instance, if readers anticipate verbal recall, they may capitalize on imagery to a lesser extent and develop strategies placing greater demands on their attentional resources. This should be reflected in longer reading times, whereas the overall pattern of reading times should not differ fundamentally from what was previously observed on the same text. To examine this point, the original experiment was replicated, but subjects were instructed to read descriptions for verbal (written) recall.

Method

Materials. Experiment 4 used the same materials as those designed for Experiments 1-3.

Procedure. The procedure was identical to the one used in Experiment 1, with the exception that starting with the practice trial, the subjects were instructed that after reading the text, they would have to produce written recall of the information conveyed by the text. Subjects were informed that they should not necessarily try to produce verbatim recall, but that what counted most was to include the maximal amount of information provided by the text in their responses.

Subjects. Subjects were 24 undergraduates, none of whom had participated in any of the previous experiments.

Results and discussion

Reading times. Figure 7 shows mean reading times per sentence for Texts 1 and 2. The overall pattern of reading times for Text 1 was relatively homogeneous, as was the case in Experiment 1. The slight decrease from Sentence 5 to Sentence 6 replicated the pattern observed in Experiment 2.

The structure of reading times was considerably different in the case of Text 2, again reflecting a pattern similar to those previously observed. While there was no significant difference between reading times for Sentences 1 and

Figure 7. Experiment 4: Mean reading times per sentence (upper half) and recall frequencies per feature (lower half).

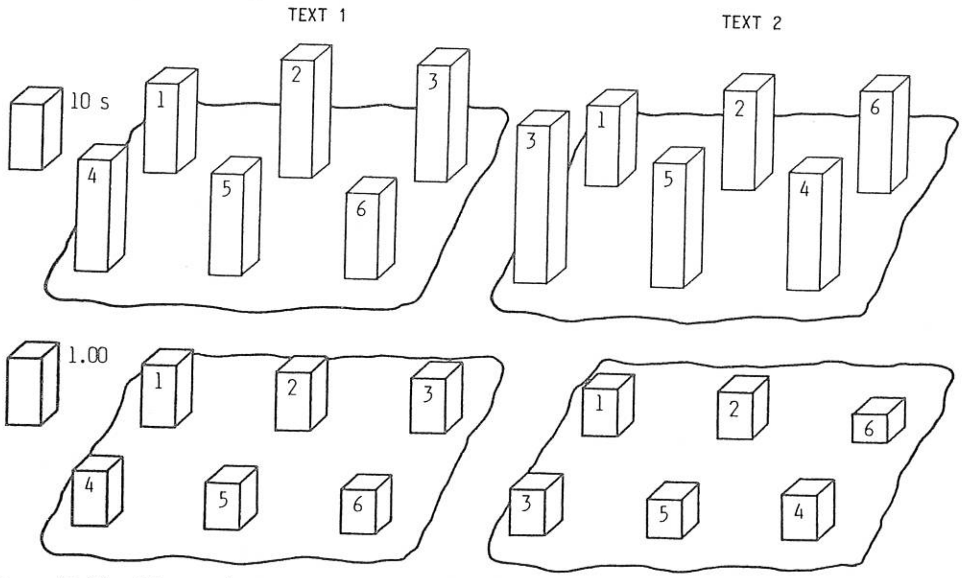

Figure 7. Expérience 4 : Durées moyennes de lecture par phrase (en haut) et taux de rappel par détail (en bas).

2, a sharp increase occurred from Sentence 2 to Sentence 3, $t(23) = 2.98, p<.01$. In spite of time decrease following Sentence 3, $t(23) = 2.30, p<.05$, subsequent reading times remained at a substantially high level. Lastly, the time decrease occurring from Sentence 5 to Sentence 6 again reproduced the specific pattern observed in Experiment 2. This pattern may reflect subjects' tendency to proceed as fast as possible on the last item in a situation with high memory load. Since they expect to produce their recall immediately after reading, subjects are likely not to spend excessive time on the item which is to be followed by the recall task, in order to alleviate the current load on their working memory. However, despite this local difference, the overall pattern of reading times in this experiment was similar to the pattern for Experiment 1.

The similarity with Experiment 1 was also confirmed by the comparison between reading times for Texts 1 and 2. Overall, reading times were shorter for Text 1 than for Text 2. The analysis of variance shows that the effect falls short of significance, $F(1,20) = 3.12, p = .095$, but reading times for Sentences 3-6 (that is, the sentences where Texts 1 and 2 differ) are consistently longer for Text 1 than for Text 2. In addition, while individual comparisons show no difference between Texts 1 and 2 as concerns Sentences 1 and 2, significant differences were found for Sentence 3, $t(23) = 2.38, p<.05$. On the whole, when subjects processed texts with the expectation of verbal recall, the structural characteristics of the texts affected processing times in a way which did not differ fundamentally from the situation where subjects expected recall on the map.

However, beyond the gross similarity between reading time patterns in the processing of texts for either verbal or map recall, a striking difference appeared between Experiments 1 and 4, with considerably *longer* overall reading times when instructions led subjects to expect verbal recall. An analysis of variance combining the data from Experiments 1 and 4 indicates a significant difference between overall reading times in the two experiments, $F(1,40) = 8.62, p<.01$. The analysis confirms the overall effect of Text 1 vs. Text 2, $F(1,40) = 16.75, p<.001$, and does not reveal any significant interaction between experiments and texts. For Sentences 2, 3, and 5 of Text 1, and Sentences 2 and 3 of Text 2, *t*-test comparisons revealed significant differences between Experiments 1 and 4, $p<.02$ or less.

Experiment 4 thus provides evidence that the nature of the task to be completed after the processing of a description exerts a measurable influence on subjects' allocation of their cognitive resources to reading. When subjects expect to produce written recall, they need more time to encode the very same sentences. Note that in Experiment 4, the nature of the material to be processed and the nature of the response were both verbal. In spite of this input-output similarity, subjects seemingly engaged themselves in additional processing, in comparison to the situation where they had to *recode* the verbal input into a spatial representation (which is presumably the most relevant kind of representation for recall on map).

Recall scores. Each recall protocol was used to reconstruct the island on the blank map. A given feature was scored as correctly recalled when it could be located unambiguously at its original position on the blank map. Recall scores thus reflect the number of features correctly located on the map from subjects' protocols.

Figure 7 shows recall frequencies for each feature for Texts 1 and 2. For Text 1, recall frequencies were close to the maximum for the first features entered in the description. They then steadily decreased to the last feature, thus reproducing the pattern observed for Text 1 in Experiment 1. For Text 2, recall frequencies similarly decreased from the first to the last sentence. The overall pattern was comparable to that observed for Text 2 in Experiment 1, except that there was no evidence for a recency effect.

Recall frequencies for Text 2 were overall lower than those for Text 1. The analysis performed on recall scores showed recall to be significantly higher after Text 1 than after Text 2, $F(1,20) = 5.61$, $p<.05$. Even the first features mentioned in the description (Sentences 1 and 2) reflect this effect, $t(23) = 2.32$, $p<.05$, which is still more pronounced than for the subsequent sentences, $t(23) = 1.94$, $p = .07$.

Comparing Experiments 1 and 4 shows that recall scores tend to be consistently higher in Experiment 1 than in Experiment 4, but the difference does not prove to be significant according to the analysis combining the data from the two experiments, $F(1,40) = 2.09$. Only the overall superiority of Text 1 over Text 2 was confirmed by this analysis, $F(1,40) = 16.50$, $p<.001$, and there was no interaction between experiments and texts.

In the main, the data in Experiment 4 support the assumption that in comparison to the situation where subjects expected to produce their recall on a map and thus presumably capitalized on the encoding of the description in the form of a spatial model, the anticipation of verbal recall placed a new type of cognitive load on processing, since stronger emphasis on verbal encoding implies allocation of additional processing resources during reading. The overall pattern of reading times shows that in both conditions, readers reacted similarly to disruption of the continuity of the description. However, the total amount of cognitive resources called upon seems to be substantially higher in the condition with verbal recall. Recall scores do not significantly differ in the two conditions; that is, to achieve approximately the same level of performance at recall, subjects expecting verbal recall had to devote a much greater amount of cognitive processing to the task. The situation these subjects had to deal with contrasts with the relative cognitive "comfort" of the condition where instructions oriented subjects to encode the description mainly in the form of a spatial model.

Additional information was sought in recall protocols concerning the internal structure of recalled descriptions. For Text 1, virtually all subjects produced recalls replicating the order in which features had been entered in the description. Twenty-three of the 24 subjects in Experiment 4 again used horizontal linear scanning. Only one subject reorganized the description in the form of circular scanning. On Text 2 as well, there are indications that most subjects tended to base their recall on the structure of the description they processed. Out of the 24 subjects, 10 reproduced the structure of Text 2 entirely. Ten other subjects, while using the overall structure of Text 2 (that is, first locating one feature at the extreme north-west and its two adjacent features, then locating another feature at the extreme south-east and its two adjacent features), more or less deviated from the structure of the description. The last 4 subjects completely reordered the original description. It seems reasonable to assume that most subjects' reliance on the actual order of the description reflects their decision not to encode the description in the form of a spatial model. The high level of recall (in comparison with Experiment 1) suggests that when subjects have to cope with a situation with a heavy cognitive load and where spatial visualization is of little or no assistance, they are nevertheless able to turn to alternate strategies. These strategies are efficient, even though they imply additional cognitive cost. One interesting finding in this respect is that the degree of conformity of subjects' recall to the exact sequence of the original description indeed affects recall. When the 10 subjects who replicated the sequence of Text 2 were contrasted with the remaining 14 subjects who to some extent deviated from the sequence, the former had significantly higher recall scores than the latter, 5.00 vs. 2.86, respectively, $t(22) = 3.63, p<.01$, while the same two groups of subjects did not differ at all on recall of Text 1.

GENERAL DISCUSSION

The experiments reported above consistently indicate that the internal (sequential) structure of a description affects the rate of processing incoming information and recall. Texts describing spatial configurations with high connectivity and a highly expected internal structure create conditions for easier processing and better recall. In contrast, the processing of texts with low connectivity and poor internal structure places high demands on readers' cognitive resources. While further research is necessary on the relative weight of those characteristics which determine how well structured a descriptive text is (connectivity, expectedness of location, expectedness of anchor point, consistency of scanning), the data clearly show that texts differing in their internal structure differ in the ease with which they allow readers to construct an adequate representation of the described configuration.

This interpretation is congruent with the distinction made earlier between two types of mental representations in text processing, namely, a propositional textbase, and a model representing the situation or the configuration described in the text (cf. Kintsch, 1986; Perrig & Kintsch, 1985). It is not our claim that model-building only takes place for certain text structures, while other structures do not elicit the construction of such representations. Rather, it is likely that in addition to the textbase representation, readers of either well- or poorly-structured texts engage themselves in the construction of a spatial mental model. What differs is the amount of cognitive resources individuals must allocate to this construction. It is worth noting that poorly-structured texts, which are the most costly in terms of model-building, are at the same time those where the model is the most useful (because it compensates for insufficient text organization). The consequences for processing times and later retrieval are obvious.

This study sheds light on several factors likely to affect the processing of descriptive texts. First, manipulation of reading intervals shows that reading patterns are essentially regulated by processes devoted to the integration of sentence meaning in the currently constructed representation. This processing level probably includes the processing steps which contribute to the elaboration of a visual spatial model of the configuration. The processing constraints imposed on readers by inadequate sequential organization of the description ultimately weigh on the construction of the spatial representation, and consequently on the accessibility of information from this representation.

Secondly, our data are consistent with the assumption that visual imagery contributes to the elaboration of visual models from descriptions of spatial configurations. As an analogical mode of representation, imagery preserves relative distances among parts of configurations (cf. Kosslyn, 1980). However, in order to more reliably assess the role of visual imagery in the construction of mental maps from discourse, an individual differences approach might prove to be highly valuable. Individual imagery differences have been shown to affect the construction of spatial knowledge (cf. Thorndyke & Stasz, 1980). The processing of texts such as those investigated here is in fact sensitive to individual imagery abilities.

Lastly, the findings show that the processing of a descriptive text is highly dependent on the nature of the task the readers expect to carry out. In a situation where readers processed descriptions for verbal recall, a considerable increase of reading times was observed although the overall pattern of reading times in the two texts was not greatly modified. Thus, in a situation where readers can identify the low cognitive advantage of creating a mental spatial model, they tend to focus more on propositional processing, with clear consequences for reading times. This is in line with the assumption that the objectives associated with a task define cognitive constraints that readers normally take into account in the construction of the representation (cf. Schmidt, 1983).

As a whole, the findings from this study have implications for the two fields of research mentioned in the introduction. On the one hand, they illustrate the crucial issue of text organization and its effects on comprehension and recall. Furthermore, they demonstrate the value of extending this approach to one text type that has received insufficient attention in prose processing studies, namely, descriptive texts. Implementation of this approach leads directly to the question of the interactions of descriptive prose with other text types, in particular narratives (cf. Denhière & Legros, 1987; Morrow, Greenspan, & Bower, 1987). In terms of text production, it raises the associated problem of the discourse strategies involved in generating coherent descriptions of complex objects or scenes (cf. Flores d'Arcais, 1987; Paris & McKeown, 1987).

The present experiments also raise the issue of the functional significance of visual imagery in the elaboration of spatial models from descriptive texts (cf. Ehrlich & Johnson-Laird, 1982). There is little doubt that most people have the ability to process linguistic descriptions in order to construct relevant spatial knowledge. However, there is little data on whether mental maps constructed without any direct perceptual reference possess functional properties similar to those of representations derived from perceptual processing. There is evidence that people can use purely verbal inputs to construct mental representations which can subsequently be processed in a way identical to perceptually-based representations (cf. Denis, 1989, chap. VII; Denis & Cocude, 1989). Further research is needed on the processes involved in the translation of verbal descriptions into spatial mental models.

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RESUME

Dans une série de quatre expériences, des sujets ont été soumis à la lecture de deux versions d'un texte décrivant une configuration spatiale. L'une des versions était une description linéaire systématique, dont la structure séquentielle était ajustée aux attentes de la majorité des lecteurs. L'autre version était caractérisée par un degré élevé de discontinuité et par une organisation interne faible. L'analyse des temps de lecture phrase par phrase fait apparaître des durées de traitement dans l'ensemble plus courtes pour la première version. D'autre part, lorsque les sujets rappellent l'information sur une carte muette, leurs performances sont meilleures après la lecture du texte le mieux structuré. Ces données indiquent que la construction d'une représentation de la configuration par le lecteur est affectée par l'ordre dans lequel sont traités les composants de la description. La contribution de l'imagerie visuelle à l'élaboration de cette représentation est examinée, et la sensibilité des durées de traitement à la nature de la tâche de rappel attendue par le lecteur est mise en évidence. La discussion est centrée sur le rôle des modèles mentaux dans la représentation de l'information transmise par des textes descriptifs.

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