European Journal of Cognitive Psychology

ISSN: 0954-1446 (Print) 1464-0635 (Online) Journal homepage: http://www.tandfonline.com/loi/pecp20

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To cite this article: Michel Denis & Marguerite Cocude (1997) On the Metric Properties of Visual Images Generated from Verbal Descriptions: Evidence for the Robustness of the Mental Scanning Effect, European Journal of Cognitive Psychology, 9:4, 353-380, DOI: 10.1080/713752568

To link to this article: http://dx.doi.org/10.1080/713752568

EUROPEAN JOURNAL OF COGNITIVE PSYCHOLOGY, 1997, *9* (4), 353–379

On the Metric Properties of Visual Images Generated from Verbal Descriptions: Evidence for the Robustness of the Mental Scanning Effect

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When subjects mentally scan across visual images of spatial configurations, the "mental scanning effect" is said to occur when there is a linear relationship between distances scanned and scanning times. This effect has been documented in studies where configurations were learned perceptually, and also when mental images of spatial configurations were constructed from verbal descriptions. The scanning effect is generally taken to indicate that visual images incorporate the metric structure of represented objects or configurations in an analog fashion. This article reports three experiments designed to test whether the cognitive salience of landmarks in a configuration can alter the mental scanning effect. Three manipulations of landmark salience were used, but there was no evidence of such an alteration. The scanning times towards salient and non-salient landmarks were quite similar, and the experimental manipulations had no effect on the time–distance correlation coefficients. We conclude that the structural organisation of visual images constructed from verbal descriptions is robust, since semantic variations in the descriptions did not affect the mental scanning effect. The experiments showed that high visuo-spatial imagers (as classified on the basis of their scores on the Minnesota Paper Form Board) consistently had shorter scanning times than low imagers, and that only the responses of high imagers gave the time–distance correlation coefficients

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This research was supported by a DRET Grant (#89/242) to the first author. Philippe Breuil, Sylvie Fontaine, Marie Olivier and Sophie Cocude contributed to the data collection. A first draft of the paper was written during the first author's stay at the Faculty of Psychology of the University of La Laguna, Tenerife, Spain, supported by a Human Capital and Mobility Grant (#CHRXCT940509) from the Commission of the European Communities. The authors thank Manuel de Vega, Steve Kosslyn, Lars-Göran Nilsson, Endel Tulving and an anonymous reviewer for their insightful comments.

characteristic of the mental scanning effect. These findings suggest that the visual images constructed by high imagers include more accurate metric information than those constructed by low imagers.

INTRODUCTION

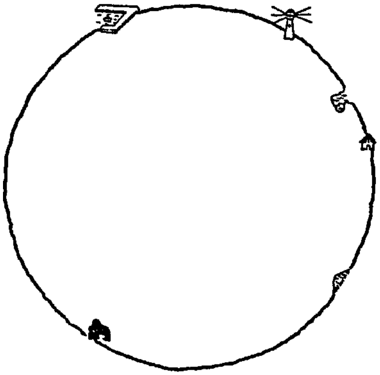
Imagery and language are two essential components of the human cognitive architecture (cf. Kosslyn & Koenig, 1992; Landau & Jackendoff, 1993; Paivio, 1991; Rumelhart & Norman, 1988). Many aspects of people's adaptation to their environment depend on the functional integrity of these systems (e.g. Behrmann, Winocur, & Moscovitch, 1992; Farah, 1995; McCarthy & Warrington, 1990) and on their capacity to cooperate in specific cognitive tasks. This is the case, for instance, when a subject seeing a scene must describe verbally the shapes, or the topological relations of objects in the scene, to another person who cannot see it. Another characteristic situation requiring articulation between the two systems is illustrated by people trying to report their internal mental images of objects (or cognitive maps of environments) to other people so that their addressees can construct similar internal representations. Efficient communication between speakers and addressees depends on the capacities of the linguistic and imagery systems to cooperate, and in particular the capacity of each system to recode the outputs of the other system in its own representational format. This is particularly remarkable since visuo-spatial and linguistic representations have quite different structural and functional properties (cf. Denis, 1996; Kosslyn, 1984; Logie, 1995). While the imagery system generates and manipulates representations that preserve topological relations among represented objects in an analog fashion, including their metric characteristics in some cases, the linguistic system uses arbitrary symbols and generates linear outputs. Nevertheless, both systems are constantly required to cooperate in normal cognitive functioning, and a number of investigations have examined the possibility of articulating the processing of texts and visuo-spatial information (e.g. Bower & Morrow, 1990; Kulhavy et al., 1993; Rinck & Bower, 1995).

Imagery research has provided evidence that speakers can rely on their visual imagery to deliver well-structured descriptions of their internal representations (cf. Robin & Denis, 1991). Several studies have been devoted to investigating the capacity of addressees to process linguistic descriptions of objects or configurations they have never seen, and to construct accurate mental representations of these objects (e.g. Finke, Pinker, & Farah, 1989; Foos, 1980; Wagener-Wender & Wender, 1990). But the issue of whether these representations exhibit the same properties as images derived from perceptual experience remains open. In particular, will computations performed by the subjects on these representations be as valid in both cases? Franklin and Tversky (1990) reported evidence that people can compute the relative positions of objects from the processing of texts describing the positions of these objects relative to a fictitious character, even when the character's orientation is changed. Franklin and Tversky assumed that subjects adopted the point of view of the character and used a ''spatial mental model'' (or ''spatial framework'') to determine which object was in each direction (see also Franklin, Tversky, & Coon, 1992; Tversky, 1991). Although the original experiments were not intended to evaluate the contribution of visual imagery proper to the construction of mental models from verbal descriptions, further replications indicated that subjects who scored high on a test of visuo-spatial imagery made fewer errors and responded more rapidly than other subjects when they had to verify the relative positions of objects (cf. De Vega, 1994, 1995).

These findings are compatible with the assumption that a purely *topological model* may be sufficient to represent the spatial relations among a set of few items, therefore imposing minimal demands on a subject's visual imagery. In some circumstances, however, it may be desirable to incorporate the *metric structure* of the represented configuration. Starting from a gross topological model, subjects then proceed to represent distances accurately in a representation that preserves the whole set of inter-object spatial relations. Visual imagery is especially useful in such a case, because of its capacity to build representations that accurately reflect the structure of the described configuration. While it is helpful for a mental model to be relatively schematic and abstract in some contexts (cf. Taylor & Tversky, 1992), the research reported here investigated situations in which subjects were required to construct fine-grained visual images of described patterns because they expected to have to make fine decisions on these images. Visual imagery is most important when the internal model must be detailed enough to preserve the Euclidean properties of the patterns.

The experiments reported here are extensions on the mental scanning paradigm (cf. Kosslyn, 1973; Kosslyn, Ball, & Reiser, 1978). Kosslyn found that the scanning times for a subject scanning the visual image of a previously learned configuration are linearly related to the distances scanned. This finding is generally taken by imagery researchers as reflecting the structural isomorphism of mental images with the visual objects they represent (cf. Denis, 1991; Finke, 1989; Kosslyn, 1994). Kosslyn's experiments provided evidence that information may also be stored in non-imaginal formats (cf. Kosslyn et al., 1978, experiment 3). However, the internal organisation of information embodied in a visual image does reflect the spatial (metric) structure of the configuration, in particular the relative distances between the individual parts of an object. Although it was suggested that this finding might be a result of subjects' knowledge of time–distance relationships interfering with the implementation of the scanning process, mental scanning has been shown to resist empirical efforts to reduce it to a pure consequence of tacit knowledge or task demands (see, e.g. Denis & Carfantan, 1985; Jolicoeur & Kosslyn, 1985; Pinker, Choate, & Finke, 1984). Scanning effects have recently been confirmed in new variants of Kosslyn's original paradigm (cf. Dror & Kosslyn, 1994).

The mental scanning paradigm was originally devised to investigate mental images reactivating previous visual experience. The paradigm later proved to be useful for investigating the processes by which subjects manipulate (and, more specifically, scan over) images generated from verbal descriptions (cf. Denis & Cocude, 1989). The issue was that of testing the structural similarity of visual images of spatial configurations derived from perception or constructed from verbal descriptions. Our first attempt to compare the mental scanning that follows perceptual learning or learning from a verbal description was based on the material shown in Fig. 1. In one condition, subjects memorised the map of a fictitious circular island with six landmarks situated at the periphery (harbour, lighthouse, creek, hut, beach, cave). In another condition, subjects were not given the map, but a short text in which the landmark locations were defined in the conventional clock-dial terms of aerial navigation. Subjects



MAP

"The island is circular in shape. Six features are situated at the periphery. At 11 o' clock, there is a harbor. At 1, there is a lighthouse. At 2, there is a creek. Equidistant from 2 and 3, there is a hut. At 4, there is a beach. At 7, there is a cave."

TEXT

FIG. 1. Map of the island and the text describing it.

listened to the description three times in one group, and six times in another. They were then invited to form as vivid an image of the map as possible. All subjects subsequently performed mental scanning on the visual image of the map, according to the following instructions. They were asked to reconstruct the visual image of the map and mentally focus on a landmark that was given to them orally. They then had to scan across the map to another given landmark. Subjects were required to indicate the moment when scanning had been completed by pressing a button, which stopped a timer triggered by the onset of the second landmark name. Subjects had to press another button if the landmark named did not belong to the map.

Analysis of response times for positive items in the first condition (map learning) confirmed Kosslyn's original finding that the longer the distance separating two landmarks, the longer the time to scan the corresponding distance. The positive correlation between scanning times and distances (or "mental scanning effect") was interpreted as indicating that mental images accurately preserve information on distances (provided that sufficient time has been devoted to learning), and that the structure of images reflects the structure of previously perceived objects in an analog fashion. The mental scanning test also revealed a positive correlation between response times and distances for the subjects who processed the description instead of the map. However, the correlation for the group of subjects who were exposed to six learning trials was higher than that for the group exposed to three learning trials, and the correlation coefficient reached a value similar to that of the correlation produced by the group involved in map learning.

Following this demonstration that subjects not only construct mental images from verbal descriptions, but that their images have structural properties similar to those of images derived from perception, we found that the specific sequencing of the sentences in the description affected the internal structure of the images of described objects, including their metric properties. In particular, discontinuous descriptions required additional exposure to achieve the structural coherence of images constructed from continuous descriptions (cf. Denis & Cocude, 1992). Thus, the capacity of images to reflect accurately the objects they refer to is not an all-or-nothing property, but results from stepwise elaboration. A quantitative model was designed to account for the gradual process of image elaboration and the progressive increase in image accuracy. The model posits that the location of a landmark mentioned in a description is not represented as a sharp point in the mental image, but is instead associated with a region around this point. Learning the description essentially consists of gradually reducing the size of each region associated with a landmark to its exact location (cf. Denis, Gonçalves, & Memmi, 1995). The findings indicating a mental scanning effect with images constructed from verbal descriptions were corroborated using more objective tasks, such as distance comparisons, where similar symbolic distance effects were obtained when subjects compared distances mentally for configurations learned from a map or from a description (cf. Denis & Zimmer, 1992).

It is thus reasonable to conclude that, provided optimal conditions are met for the processing of descriptions (in particular, appropriate sequencing and sufficient learning), mental representations elaborated without any perceptual contact with visual scenes contain information structured much like perceptual representations. Subjects can use text-derived representations in a similar way to perceptually based ones, by short-circuiting corresponding perceptual experience. This procedure, obviously, has a cost for the cognitive system in terms of time and the capacity used. Constructing a detailed visual image is a demanding task that requires substantial cognitive resources (cf. Kosslyn, 1980; Kosslyn, Reiser, Farah, & Fliegel, 1983). Once the image is constructed, however, the information available is basically the same as after perceptual learning, and can be used in a similar fashion for the same cognitive objectives. It is important, in addition, to emphasise that the newly constructed representation contains *more* information than the text from which it has been elaborated. The text only mentions the positions of landmarks, without stating anything about their relative distances. The mental scanning task reveals that the representation not only contains landmarks, but also the relative distances separating them. In short, the assumption of structural isomorphism of visual images to objects also holds true for images constructed from verbal descriptions without visual input (cf. Denis, 1991, 1996).

However, one limitation of our experiments is that no consideration was given to possible effects of the semantic content of the geographical landmarks on the map or in the description. For instance, ‘‘harbour’’, ‘‘lighthouse’’, and so on, were used as instantiations of points for which only topological and metric properties were considered. But it is well established that the structure of mental representations of real-world spatial configurations depends to a large extent on knowledge, experience and the value attached by the subjects to the landmarks. In natural environments, distances to well-known landmarks tend to be underestimated, whereas distances to less frequently visited landmarks tend to be overestimated. This bias is likely to operate in the experiments showing that distances are underestimated in the centre of cities, whereas they are overestimated in peripheral zones (cf. Byrne, 1979; Moar & Bower, 1983). More generally, distortions in cognitive maps reflect a systematic trend towards increased schematisation of internal representations (cf. Holyoak

& Mah, 1982; Stevens & Coupe, 1978; Tversky, 1981). This has been established in a number of empirical contexts, including those involving navigation in real environments and the processing of map information (cf. Giraudo & Pailhous, 1994; McNamara, Halpin, & Hardy, 1992; Sadalla, Staplin, & Burroughs, 1979; Sholl, 1987; Thorndyke, 1981; Thorndyke & Hayes-Roth, 1982).

The experiments reported here were designed to test the sensitivity of the mental scanning paradigm to descriptions in which certain landmarks have undergone special processing likely to confer on them increased cognitive salience. Our purpose was to determine whether specific semantic manipulations of the description result in systematic bias in the mental representation constructed from it, as is the case for real-world environments. The mental scanning process is likely to be especially useful for testing this hypothesis. For instance, a manipulation that increases the salience or prominence of a given landmark should lead to the scanning of this landmark being executed more quickly. The resulting time–distance correlation could also be measurably affected, depending on whether its computation uses scanning responses directed towards salient or non-salient landmarks. Such a result would cast doubt on the validity of mental scanning measurements, since they could be suspected to be contaminated at least to some extent by semantic factors. The validity of the paradigm as reflecting basic cognitive processes should thus be questioned. In contrast, if the manipulated variable has a limited effect (or no effect at all) on scanning times, this would indicate that the geometric properties of the mental representation are not distorted by semantic factors. This would support the claim that the scanning effect is robust.

As a further relevant issue, the effect of individual imagery characteristics on mental scanning was also explored. Mental scanning is a process that calls upon visuo-spatial imagery, but there have been few, if any, systematic investigations of individual differences in mental scanning. One such attempt was reported by Kosslyn, Brunn, Cave and Wallach (1984) in their extensive survey of imagery differences, but they obtained mixed results. While they used the scanning paradigm with a much larger number of subjects than in the original experiments (Kosslyn et al., 1978), they did not obtain any reliable mental scanning effect; nor was there any correlation between individual scanning times and scores on imagery tests and questionnaires. More recently, however, Dror, Kosslyn and Waag (1993) reported that subjects who have special expertise in the processing of visuo-spatial information, such as aircraft pilots, performed better than control subjects in a battery of imagery tasks, including mental scanning.

In the present set of experiments, we collected psychometric data on the subjects' visuo-spatial imagery and compared the mental scanning performance of subjects who obtained high and low scores in the test used. This part of the investigation had two objectives. First, it was designed to examine the question of whether some subjects are really more "proficient" than others at mental scanning; in particular, whether high imagers perform better (in terms of scanning times) than low imagers in mental scanning. If mental scanning is based on the modules postulated by Kosslyn, including the notion of variations in these modules among individuals, it is reasonable to expect that high visuo-spatial imagers will execute the scanning task faster. Their scanning times should also reflect the fact that they have constructed more accurate representations than low imagers, and that these representations incorporate valid metric information. This should be expressed by higher time–distance correlation coefficients based on the data from these subjects. Secondly, the performance of high imagers may be of special interest for determining whether the structure of visual images is robust. If more salient landmarks elicit faster scanning than landmarks of secondary importance, but the effect is small, then subjects who have constructed the most vivid representations from the additional semantic information might reveal the scanning bias more than the other subjects. If the effect does exist, it should at least be evident in high imagers.

EXPERIMENT 1

The first experiment was an adaptation of the paradigm used by Denis and Cocude (1989, experiment 3). The same description was used, with the additional feature that three of the six landmarks were processed by the subjects in a particular way. To ensure this, the descriptions of these landmarks not only provided information regarding their location in the configuration, but they also provided a short narrative containing many concrete, vivid details. This additional information was designed to increase landmark salience. In contrast, the other three landmarks were described in a rather neutral way, using conventional, highly predictable pieces of information. The relevant aspect of the data was the time taken to scan towards salient and non-salient landmarks.

Individual visuo-spatial imagery characteristics were measured using the Minnesota Paper Form Board (MPFB; Likert & Quasha, 1941). This test was used because it provides well-differentiated measures of visuo-spatial aptitudes in the rather limited time required for its completion. The psychometric value of the MPFB has been documented in several imagery studies (see, e.g. Ernest, 1977; Hoffmann, Denis, & Ziessler, 1983; McGee, 1979), and recent research in our laboratory has confirmed that it is a reliable instrument for contrasting subjects on visuo-spatial imagery (cf. Denis, 1996; Mellet, Tzourio, Denis, & Mazoyer, 1995).

Method

Subjects. The subjects were 32 undergraduates from the Orsay campus of the University of Paris-Sud, all of whom volunteered to participate in the experiment.

Materials. The text shown in Fig. 1 was used, with the landmarks introduced in clockwise order, starting with the harbour. The French names for these landmarks were all pronounced as one-syllable words. Two expansions of comparable length were constructed for each sentence that located a given landmark. One was designed to increase the landmark's salience, while the other was a quite commonplace description. For example, the "non-salient" (or "neutral") variant of the expansion for the lighthouse was: "At 1, there is a lighthouse. This granite lighthouse, built fifty years ago, raises its lofty grey silhouette at the edge of the coast. From the top, twenty-five metres up, its powerful beam guides boats through the night. When fog sets in, its halo in the mist is extremely useful to ships who have lost their way". The "salient" variant for the same landmark was: "At 1, there is a lighthouse. This strange lighthouse is painted red and white. It has been famous ever since the storm when a luxury liner ran into the cliffs nearby, with more than two hundred casualties. Since this catastrophy, jewellery and precious objects lie sunken at the foot of the lighthouse". The neutral and salient variants were of comparable length (an average of 50.7 and 48.5 words, respectively).

A group of 18 subjects was involved in a pilot experiment designed to check whether the manipulation described above increased the cognitive salience of the landmarks as intended. Each subject was given the non-salient variants of three landmark descriptions and the salient variants of the other three descriptions. Descriptions were presented to the subjects via a tape-recorder, alternating non-salient and salient descriptions. Each subject was presented with one of three possible sequences of descriptions (in an attempt to overcome any primacy or recency effect). Subjects were invited to listen carefully to each description and were informed that they would later be asked to respond to questions about the landmarks. After listening to the descriptions, the subjects were given a distracting task for one minute ("list as many European countries as possible"). They then completed three tasks: written free recall of landmarks (time limit: 30 sec); written cued recall of descriptions of landmarks (the subjects used a response sheet on which the names of the six landmarks were printed); rate the interest of each description (written descriptions were given to the subjects; the subjects were invited to read each description and rate how much this description had elicited their interest on a 7-point scale).

Free recall of landmarks resulted in comparable and near-maximal performance for salient and non-salient landmarks (2.6 and 2.9, respectively). The first landmark recalled by ten subjects was a salient one; it was a non-salient one for the other eight. A much clearer contrast was obtained from analysis of the description recall. Each subject's response was coded in terms of the number of information units recalled from the corresponding description. The number of units recalled appeared to be significantly greater for the sets of salient than non-salient descriptions [23.17 *vs* 20.33; $t(17) = 2.60$, $P < 0.05$]. Finally, salient descriptions were consistently rated as being more interesting than non-salient ones [3.91 *vs* 3.13; $t(17) = 2.81$, $P < 0.05$]. These data clearly indicate that the manipulation of the descriptions actually affected the cognitive salience of the landmarks in the expected direction.

Two versions of the text were constructed for presentation in the learning phase. In Version A, the harbour, the creek and the beach were described neutrally, whereas the lighthouse, the hut and the cave were described as salient. In Version B, the neutral landmarks of Version A were described as salient, and vice versa.

A tape-recording containing 60 pairs of words was prepared for the scanning test. Each landmark was named ten times and was followed 4 sec later by a second word. The second word in five of these trials did not name a landmark on the island. The "false" objects were landmarks that could reasonably have been found on the island (meadow, bridge, well, mine, moor); again, the French words for these landmarks were pronounced as one-syllable words. The first word in the other five trials was followed by the name of one of the other five landmarks. Thus, every pair of landmarks occurred twice, alternating the landmark that appeared first. The order of the pairs was randomised, with the constraints that the same landmark could not occur twice in two successive pairs, that a "true" landmark occurring as the second member of a pair could not occur in the next two pairs, and that no more than three "true" or three "false" trials could occur in succession. Presentation of the second word started a clock. A new trial began 8 sec after the probe word was presented. The test trials were preceded by eight practice trials (four "true" and four "false"). The practice trials used the names of French cities as "true" items. The whole procedure was driven by a computer program adapted to the needs of this experiment.

Procedure. At the beginning of the learning phase, the subjects were told that they would hear a description of the map of an island. They were told that they would have to create as vivid and accurate a visual image of the map as possible. The text was presented auditorily three times. The subjects were required to form a visual image of the map after the second and third text presentations and to check the exact location of each landmark.

At the beginning of the test phase, the subjects were told that each trial would first consist of hearing the name of a landmark on the island. They were to picture the entire map of the island mentally and then were to focus on the landmark named. The subjects were told that a few seconds after focusing on the named landmark, they would hear another word. If this word named a landmark present on the map, the subjects should scan to it and press a button with their dominant hand when they reached it. The scanning was to be accomplished by imagining a black speck zipping along the shortest straight line from the first landmark to the second. The speck was to move as quickly as possible while still remaining visible. If the second word of a pair did not name a landmark on the map, the subjects were to depress the second button with their non-dominant hand. Response times were recorded. The experimenter interviewed the subjects during the practice trials to make sure that they had followed the instructions about imagery use. During the test phase, for each text version, A or B, half of the subjects processed the items according to the randomised order defined above, whereas the other half processed the second half of the items and then the first half.

The subjects were tested individually. At the end of the experiment, the subjects were interviewed. Four subjects who reported having followed the imagery instructions less than 75% of the time during the test phase were replaced. The subjects were also asked whether they had relied on the location of the landmark depicted in their visual image, or first revised the hour-coded location of the landmark before mentally scanning to the second named landmark. Two subjects who said they had used this latter procedure were replaced. Finally, subjects were asked to complete the MPFB. The whole experiment took about 40 min.

Results and Discussion

Only the times for the correct "true" decisions were considered in the analysis. The error rate was very low (1.5%), and errors did not vary systematically with distance scanned.[1] The analyses were conducted in

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[1] Outliers were not excluded from the analysis of scanning times, although they are discarded in most scanning experiments. Kosslyn (e.g. Kosslyn et al., 1978) recommended that times exceeding twice the other time for the same distance be discarded. The procedure has been used by us previously (Denis & Cocude, 1989, 1992). They were not discarded in the present experiments, since this would have tended to mask any manifestation of the phenomenon under study by eliminating data that could reveal different scanning times for the two directions of a given distance. Not discarding outliers meant that further calculations were based on slightly longer overall scanning times, but this did not affect the analyses substantially, since only 1.4% of the total number of critical pairs of scanning times could have been classified as outliers.

three steps. The first step was an overall analysis based on the complete set of scanning times, with no consideration of the type of landmark (salient or non-salient) towards which scanning was directed. The second step of the analysis was restricted to the subset of the data that offered the possibility of such systematic comparison. These data were then used again in the third step to investigate the effects of individual visuo-spatial characteristics on mental scanning.

Overall Analysis. Analysis of variance (ANOVA) of the complete dataset revealed an overall significant effect of distance on scanning times [$F(14,420) = 4.55$, $P < 0.001$], with times increasing linearly with increasing distance [$F(1,30) = 17.66$, $P < 0.001$]. There was no difference between the two versions of the text. Times were averaged over subjects and the correlation between times and distances was calculated. The coefficient obtained was $r(13) = 0.80$ ($P < 0.01$; Fig. 2). The significant time–distance correlation was taken as evidence of the expected mental scanning effect and confirmed the data collected in previous experiments (e.g. Denis & Cocude, 1989, 1992).

Landmark Salience. Scanning times were contrasted as a function of the type of landmark targeted during scanning. Of the 15 inter-landmark distances, 9 were especially relevant; that is, those connecting two land-

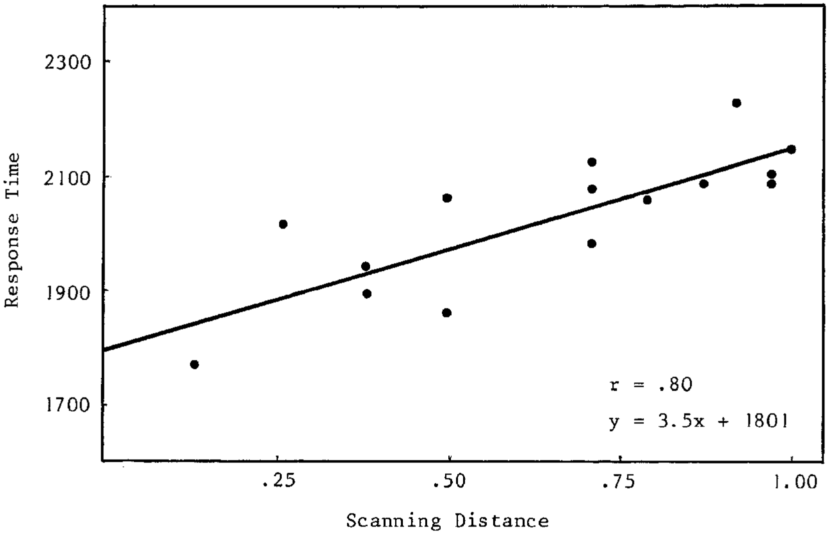

FIG. 2. Response time (msec) as a function of scanning distance. In this figure and those which follow, distances are expressed as their ratios to the diameter of the circular island.

TABLE 1
The Complete Set of 15 Distances Scanned, Each in Both Directions[a]

(a) Distances between non-salient and salient landmarks
creek–HUT (0.13)
creek–LIGHTHOUSE (0.26)
beach–HUT (0.38)
harbour–LIGHTHOUSE (0.50)
beach–CAVE (0.71)
beach–LIGHTHOUSE (0.71)
harbour–HUT (0.79)
harbour–CAVE (0.87)
creek–CAVE (0.97)

(b) Distances between two non-salient or two salient landmarks
LIGHTHOUSE–HUT (0.38)
beach–creek (0.50)
harbour–creek (0.71)
HUT–CAVE (0.92)
harbour–beach (0.97)
LIGHTHOUSE–CAVE (1.00)

[a] Upper-case letters are used to indicate salient landmarks in Version A; lower-case letters indicate non-salient landmarks (the reverse for Version B). Distances in parentheses are expressed as ratios to the longest straight distance (diameter) of the island.

marks of different types, one salient and one non-salient (Table 1a). Each of these distances was scanned twice by each subject, once towards the salient landmark and once towards the non-salient one. These data thus offered the opportunity to conduct a within-subject analysis of the effect of the main variable and to estimate time–distance correlation coefficients for each subset of data.[2]

ANOVA of the corresponding data revealed an overall significant effect of distance on scanning times [$F(8,240) = 4.40$, $P < 0.001$], with a significant linear component [$F(1,30) = 10.49$, $P < 0.005$]. The text version had no effect, and there was no difference between the times for scanning towards salient and non-salient landmarks [2011 *vs* 1994 msec; $F(1,30) < 1$]. The time–distance correlation for scanning towards salient

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[2] As a preliminary check, the time–distance correlation for the nine distances was calculated without consideration of the scanning direction. The coefficient obtained was $r(7) = 0.78$ ($P < 0.01$), quite similar to the value computed with 15 distances. This similarity indicates that restricting the analysis to the nine distances of interest did not distort the pattern of results based on the complete dataset. This check was repeated in the subsequent two experiments to ensure that the data based on the subset of nine distances were valid reflections of those based on the complete set of distances.

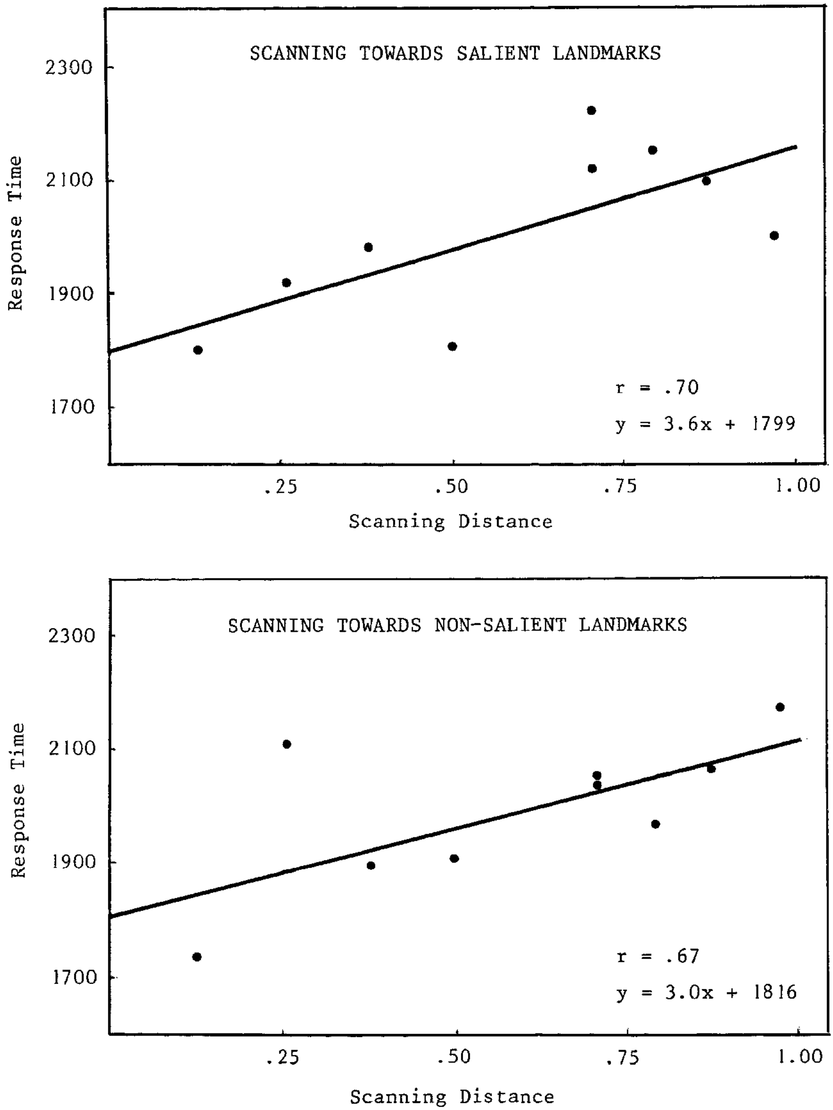

FIG. 3. Response time (msec) as a function of scanning distance. (Top) Scanning responses towards salient landmarks; (bottom) scanning responses towards non-salient landmarks.

landmarks was $r(7) = 0.70$ ($P < 0.05$), and for scanning towards non-salient landmarks it was $r(7) = 0.67$ ($P < 0.05$). Figure 3 reflects the similar patterns of data in both cases, with no difference between the intercepts or between the slopes of the regression lines.

These findings were checked by analysing the six distances which connected landmarks of the same salience (Table 1b). Each subject had produced scanning responses for three distances separating two salient landmarks and three distances separating two non-salient landmarks (in both directions). The average scanning time was 2082 msec for salient landmarks and 2051 msec for non-salient ones [$F(1,30) < 1$], confirming the absence of any effect of landmark salience on scanning times, even for distances between points having the same salience status.

The results thus clearly reflect the typical (expected) pattern of time–distance correlation that has been previously reported (cf. Denis & Cocude, 1989, 1992; Denis et al., 1995; Denis & Zimmer, 1992). The new feature here is that the targeted landmark does not influence the scanning pattern. This suggests that the time–distance correlation in the mental scanning paradigm is robust, since the additional semantic content in the material of this experiment did not affect it. The argument that the stimulus manipulation was ineffective and that the verbal descriptions expanding the original material did not really affect landmark salience was not convincing. The data provided by the pilot study reported above attest to the increased salience of those items intended to be salient. In addition, several subjects reported after the experiment that they had noted differences in the "importance" of landmarks, but that they had made an effort to ignore this aspect and concentrate on the geometric (non-semantic) properties of the configuration.

Individual Differences. The responses of high and low visuo-spatial imagers in the mental scanning task were compared. The complete sample of 32 subjects was ranked as a function of their MPFB scores. Better contrast was obtained by selecting the 12 subjects with the highest scores ("high visuo-spatial imagers") and the 12 subjects with the lowest scores ("low visuo-spatial imagers"). Although the text version (A or B) had not affected the results of the previous analyses, we checked that equal numbers of subjects in each group had been given Versions A and B. The average MPFB scores were 23.1 for high imagers and 14.8 for low imagers.[3]

The scanning times of the two groups of subjects were entered into an ANOVA which took into account the subset of nine distances used in the previous analysis (that is, those for which each subject provided two scanning responses for each distance, one towards the salient landmark

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[3] In a previous study to establish norms, we collected MPFB scores from a larger sample of undergraduates belonging to the same population ($n = 69$). The scores of the subjects classified as high and low imagers in the present experiments were in the upper and lower thirds of these norms, respectively.

and the other towards the non-salient landmark). The analysis confirmed the overall effect of distance on scanning times [$F(8,176) = 3.55$, $P < 0.001$], with times increasing linearly with distance [$F(1,22) = 6.86$, $P < 0.025$]. The overall scanning times of high imagers were shorter than those of low imagers [1661 *vs* 2238 msec; $F(1,22) = 6.24$, $P < 0.025$]. There was no significant interaction between imagery capacities and the direction of scanning.

The time–distance correlations revealed another difference between the two groups of subjects. The two contrasting patterns shown in Fig. 4 indicate that the subjects with the highest visuo-spatial capacities were indeed those who produced the typical pattern of mental scanning indicated by a significant time–distance correlation coefficient [$r(7) = 0.84$, $P < 0.01$]. In contrast, the subjects with the lowest visuo-spatial capacities produced responses whose times indicated that their images had no stable, consistent structural properties. Not only were their scanning times considerably longer, which was confirmed by analyses testing for significant intercept differences [$t(22) = 2.95$, $P < 0.01$], but there was also no consistent relationship between scanning times and distances [$r(7) = 0.32$]. This pattern suggests that low imagers had particular difficulty controlling the generation and exploration of their images. These images probably contained a large amount of noise, perhaps due to the difficulty experienced by these subjects in keeping their visual images vivid enough to execute efficient mental scanning. The contrast reflects a qualitative difference between the subjects most apt at generating and manipulating accurate images and subjects less able to use their visual imagery efficiently.

The analysis of high and low imagers' scanning times showed no difference between scanning towards salient and non-salient landmarks, and this was true for both groups of subjects. The absence of any significant interaction thus suggests that one group of subjects was no more sensitive to manipulation of landmark salience than the other. To summarise, there was no sign that differential landmark salience had any effect on scanning times, but individual imagery characteristics proved to be a powerful determinant of the mental scanning times.

EXPERIMENT 2

Experiment 1 provided no hint that the salience of landmarks affected the time required for scanning towards them. However, the fact that there was no effect could simply have resulted from ineffective manipulation of the variable under study. One reason why the expected effect did not appear could be that our manipulation was based on descriptions that

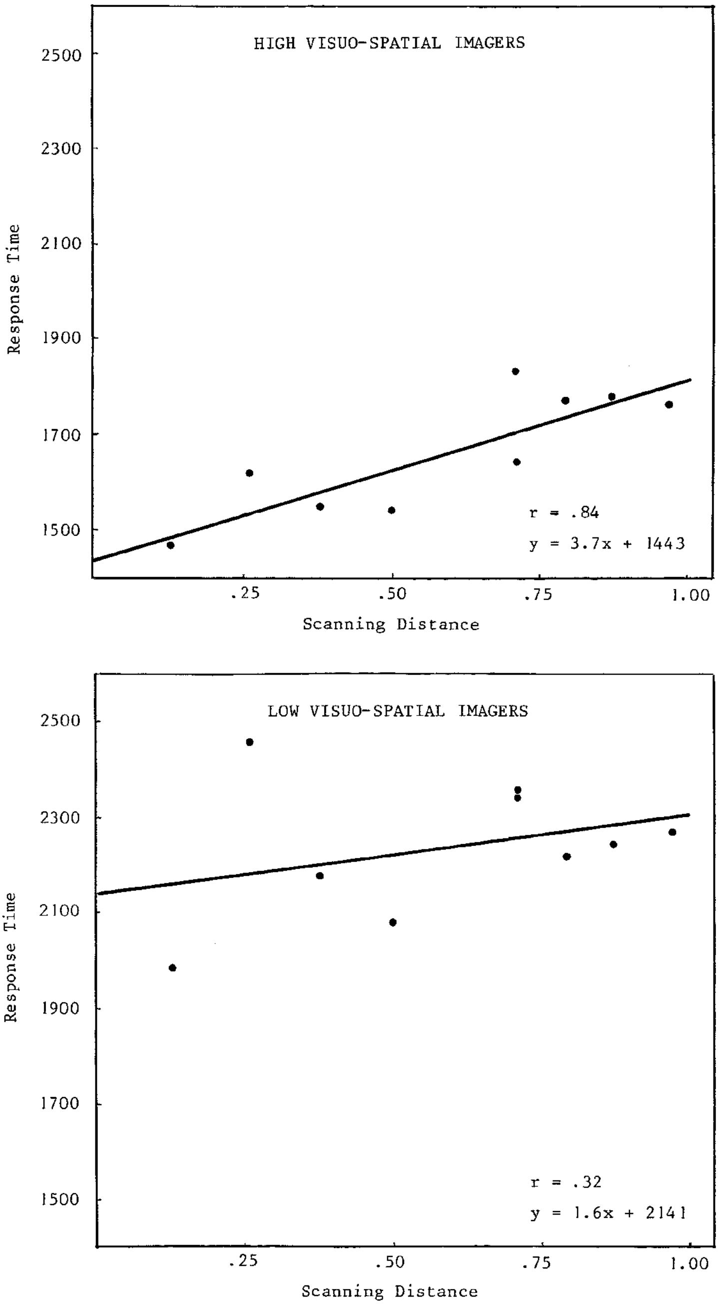

FIG. 4. Response time (msec) as a function of scanning distance. (Top) Scanning responses of high visuo-spatial imagers; (bottom) scanning responses of low visuo-spatial imagers.

did not affect the landmark representation well enough. Research on cognitive maps has shown that subjects' mental representations are biased mainly for locations and routes that involve the subject's activity or personal experience, rather than purely declarative knowledge (cf. Cohen, Baldwin, & Sherman, 1978; Kosslyn, Pick, & Fariello, 1974). Studies based on the paradigm of Bower and Morrow (1990) have shown that some personal spatial involvement of the reader is needed to obtain reliable effects during narrative comprehension (cf. Wilson et al., 1993).[4]

The previous experiment was therefore repeated, but with the expansions changed to provide salience to the landmarks by involving the reader more than in Experiment 1. The same neutral descriptions were used for three of the six landmarks. The short texts on the other three landmarks required the subjects to imagine themselves involved in specified interactions with the landmark. This was expected to increase the subjects' involvement in the construction of the representation of the corresponding landmarks. If the representation incorporates this dimension, and this dimension is to affect the scanning process, its effects should be more evident. Furthermore, measures of visuo-spatial imagery were collected from the subjects and used to check the effects of individual differences obtained in Experiment 1.

Method

Subjects. The subjects were 24 undergraduate students, none of whom had participated in Experiment 1.

Materials. The same text was used as in Experiment 1, with a new set of expansions referring to activities of the subject relative to each landmark (written in the second person). For example, this is the expansion designed to increase the salience of the lighthouse: "At 1, there is a lighthouse. You have visited this lighthouse frequently in the past. You have taken many photographs, trying to capture it amidst its imposing natural environment. At night, you enjoy observing its light beams and you play at counting them. Several times, you climbed its stairs without regaining your breath".

Version A of the text described the harbour, the creek and the beach in a neutral way, whereas the lighthouse, the hut and the cave included

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[4] In a study conducted at the University of La Laguna, subjects learned an environment from a map in which some landmarks had been given more salience both perceptually and by the use of semantic descriptions requiring imagination of personal involvement on the part of the subjects. Distance estimation from a given point in the environment was more accurate towards salient than less salient landmarks (M. De Vega, personal communication).

descriptions of the subject's activities. For Version B, the allocation of landmarks to the two categories of descriptions was reversed.

Procedure. The instructions for the learning phase were the same as in Experiment 1, with an additional specification. The subjects were asked to imagine that they were familiar with the island described. They were to create as vividly as possible images of each landmark and their actions, as described in the text. The instructions and procedure for the test phase were the same as in Experiment 1. Subjects completed the MPFB at the end of the session.

Results and Discussion

The analysis followed the same steps as for Experiment 1. The overall error rate was very low (1.9% of the trials), and errors did not vary systematically with distance scanned.

Overall Analysis. The ANOVA of the complete dataset revealed a significant effect of distance on scanning times [$F(14,308) = 4.49$, $P < 0.001$], with a strong linear component [$F(1,22) = 17.29$, $P < 0.001$]. No difference was found between the two versions of the text. The correlation between scanning times and distances was $r(13) = 0.73$ ($P < 0.01$). These results confirm those of Experiment 1.

Landmark Salience. The ANOVA for the subset of nine distances which could be used to analyse the effect of landmark salience confirmed the overall significant effect of distance on scanning times [$F(8,176) = 5.15$, $P < 0.001$], with times increasing linearly with distance [$F(1,22) = 14.80$, $P < 0.001$]. There was no effect of text version. Landmark salience resulted in no reliable effect on scanning times: 1609 msec towards salient landmarks and 1629 msec towards non-salient ones [$F(1,22) < 1$]. The time–distance correlation coefficients were $r(7) = 0.54$ and $r(7) = 0.74$ ($P < 0.01$), respectively. The difference between the two coefficients was not significant [$\chi^2(1) = 0.37$).

The overall scanning times for the six distances connecting landmarks of the same salience were similar for distances involving two salient and two non-salient landmarks: 1715 and 1635 msec, respectively.

Individual Differences. The upper third of MPFB scorers were classified as high imagers, and the lower third as low imagers, with eight subjects in each group. Their average MPFB scores were 25.0 and 16.6, respectively. These values indicate that the subjects in Experiment 2 tended to have greater imagery capacities than their counterparts in Experiment 1, although the difference was not significant [$t(54) = 2.00$, $P < 0.10$].

ANOVA confirmed the overall effect of distance on scanning times [$F(8,112) = 3.30$, $P < 0.005$], with a significant linear component [$F(1,14) = 7.19$, $P < 0.025$]. It also revealed that the scanning times of high imagers were consistently shorter than those of low imagers [1340 *vs* 1880 msec; $F(1,14) = 16.11$, $P < 0.005$]. The lack of an effect of scanning direction was confirmed, and there was no interaction between imagery capacities and scanning direction. The contrast between the two groups of subjects was again reflected in the time–distance correlation coefficients: $r(7) = 0.79$ ($P < 0.02$) for the high MPFB scorers, but only $r(7) = 0.49$ ($P > 0.10$) for the low MPFB scorers.

Comparison of the data from Experiments 1 and 2 shows that the absolute scanning times were shorter in Experiment 2 than in Experiment 1. It is not easy to identify why this should be so. The changes in the materials to emphasise the subjects' activities (even though they were only imagined activities) may have generated more salient representations towards which scanning was easier. But this does not explain why all scanning times were shorter in Experiment 2, in the direction of both salient and non-salient landmarks. A more plausible explanation is that the subjects who participated in Experiment 2 had a slightly better MPFB performance. This explanation is consistent with the fact that the time–distance correlation coefficient based on low imagers' scanning times was higher in Experiment 2 than in Experiment 1, suggesting that the low imagers in Experiment 2 were more efficient than their counterparts in Experiment 1.

The most remarkable result of Experiment 2 was its confirmation of the results of Experiment 1. Besides the clear-cut effect of individual visuo-spatial imagery capacities on scanning times and their correlation with distances, Experiment 2 confirmed the difficulty of producing a semantic bias likely to affect scanning times, even when subjects processed descriptions designed to involve them more effectively. We believe that the absence of such an effect in the two experiments suggests that the geometric structure of the mental representations constructed from descriptions was accurately inscribed in these representations and was not sensitive to bias.

However, as when discussing the results of Experiment 1, we cannot ignore the possibility that the manipulated factor simply did not produce the expected contrast for some experimental reasons. We therefore designed an experiment which required still more effective manipulation of the critical variable.

EXPERIMENT 3

The above results showed no effect of the manipulations designed to affect landmark salience. This may mean that there is no effect of this variable on mental scanning, or that the demonstration needs even more effective manipulation. Providing additional descriptions or describing the activities to be imaged by the subject may not be sufficient. Obtaining an effect may require a manipulation that increases salience by providing a rich sensory input that increases landmark vividness. In Experiment 3, the cognitive prominence of landmarks was induced by giving the subjects detailed, vivid pictorial illustrations of the landmarks, in an attempt to make them more salient.

Method

Subjects. The subjects were 24 undergraduates who had not participated in the previous experiments.

Materials. The text used was the version shown in Fig. 1. Detailed, colourful pictures were prepared as illustrations of each landmark. Each picture was designed to provide subjects with rich cues for the construction of vivid mental representations.

Procedure. The instructions for the learning phase were the same as in the previous experiments. Additional instructions specified that pictures of three of the six landmarks would be presented during the learning phase. These pictures were shown to the subjects three times, before each presentation of the text describing the island. Each picture was shown for 30 sec. Half of the subjects were given a version of the materials with pictures of the harbour, the creek and the beach. The remaining subjects had a version with pictures of the lighthouse, the hut and the cave. The instructions and procedure for the test phase were the same as in Experiment 1. Subjects completed the MPFB at the end of the session.

Results and Discussion

The error rate was very low (1.9%), and errors did not vary systematically with distance scanned.

Overall Analysis. Distance had a significant effect on scanning times [$F(14,308) = 3.86$, $P < 0.001$], with times increasing linearly with distance [$F(1,22) = 15.37$, $P < 0.001$]. There was no difference between the two versions of the material. The time–distance correlation was $r(13) = 0.82$ ($P < 0.01$). These results confirm those of Experiments 1 and 2.

Landmark Salience. Analysis of the data for the nine distances used for testing the effect of landmark salience confirmed the overall effect of distance on scanning times [$F(8,176) = 5.11$, $P < 0.001$], with times increasing linearly with distance [$F(1,22) = 12.75$, $P < 0.005$]. There was no difference between the two versions of the materials, and there was no reliable effect of landmark salience produced by showing the subjects pictures of landmarks. The response times were 1529 msec when scanning was directed towards an illustrated landmark and 1468 msec when scanning was in the opposite direction [$F(1,22) = 2.05$]. The time–distance correlation coefficients were $r(7) = 0.89$ ($P < 0.01$) and $r(7) = 0.77$ ($P < 0.02$), respectively.

Analysis of the scanning times for the six remaining distances did not reveal any difference whether these distances involved two illustrated landmarks or not [1588 *vs* 1587 msec; $F(1,22) < 1$].

Individual Differences. The procedure described in Experiment 2 was used to classify the eight subjects with the highest MPFB scores as high visuo-spatial imagers, and the eight subjects with the lowest scores as low visuo-spatial imagers. Their average scores were 25.5 and 18.8, respectively.

The overall effect of distance on scanning times was indicated by the analysis [$F(8,112) = 2.93$, $P < 0.01$], with a significant linear component [$F(1,14) = 6.89$, $P < 0.025$]. The scanning times of high imagers were shorter than those of low imagers (1364 *vs* 1543 msec), although the difference was not significant [$F(1,14) = 1.41$]. The time–distance correlation was $r(7) = 0.83$ ($P < 0.01$) for high imagers, but only $r(7) = 0.49$ ($P > 0.10$) for low imagers. Finally, no interaction was found between scanning direction and individual imagery characteristics.

The main result of Experiment 3 was again a lack of any consistent effect of landmark salience on scanning times. Landmark salience was manipulated by providing subjects with a visual experience associated with their learning of landmark locations (an experience with rich semantic content, obviously richer than in the previous manipulations). In spite of this, it was impossible to bias mental scanning in favour of salient landmarks. We interpret this as indicating that the mental representations constructed from descriptions (after repeated learning trials) have attained an internal coherence that fully preserves their geometry from biasing semantic factors. This is true for high imagers, despite the expectation that more salient or more vivid representations would accelerate scanning in their direction. It is also true for low imagers, suggesting that they have constructed a representation incorporating some metric information, despite its poor structural quality (as indicated by their relatively low time–distance correlation coefficient).

The high visuo-spatial imagers confirmed their characteristic cognitive capacities in this experiment. These were the subjects who contributed most to the mental scanning effect, probably because they were better at generating representations containing accurate metric information. The pattern of their scanning times reflected the metric properties of their mental images.

GENERAL DISCUSSION

The subjects who took part in the three experiments based on the mental scanning paradigm were invited to construct the mental image of a spatial configuration, including the exact locations of six landmarks, as specified in detailed verbal descriptions. Experimental manipulations were designed to confer more salience on a subset of these landmarks, so that scanning towards them would be faster, biasing the resulting time–distance correlations. In spite of these manipulations, the scanning times were not altered. There was no difference between scanning towards salient and non-salient landmarks, and the time–distance correlations remained high in both cases.

One issue to consider with such a set of results is that of the acceptance of the null hypothesis. Although the absence of a difference in principle limits the conclusions that can be drawn, the absence of any biasing effect was confirmed in all three experiments, despite repeated attempts at more effective experimental procedures. Salience had no effect on scanning times, in spite of the fact that differential salience was demonstrated by independent measures. Note also that the numbers of subjects who took part in each experiment were much higher than in most previous mental scanning studies. Our samples were two to three times larger than those used in the experiments by Kosslyn et al. (1978) and Denis and Cocude (1989, 1992). Larger samples normally show differences more clearly, provided differences exist. The present experiments clearly showed other effects, particularly the significant contrast between the scanning times of high and low imagers. The existence of such a contrast means that the mental scanning responses are able to consistently differentiate the results of experimental manipulations. Previous experiments actually showed such differentiations, in particular their dependence on the structural organisation of the descriptions (e.g. Denis & Cocude, 1992). The study reported by Denis et al. (1995) also revealed that the mental scanning effect depends on the exact time when scanning tests are administered during learning.

The mental scanning paradigm thus appears to be rather sensitive. Because it is sensitive to a number of variables, the absence of any biasing effects in the present three experiments may indicate that the structural organisation of the representation constructed from descriptions was at most only moderately affected by the semantic content of the objects present in the representation. When subjects build the set of topological relations among objects and inscribe in their representation the metric values specified by a description, any additional semantic information that enriches the representation does not alter its metric parameters. In combination with the results of Denis and Cocude (1992), the present results suggest that the structural aspects of the description, rather than its semantic content, determine the internal structure of the representation. Our results can therefore be interpreted in terms of the robustness of the representation, and consequently of the mental scanning effect, rather than in terms of the absence of a semantic bias effect.

All three experiments clearly showed the effects of individual differences in imagery. In addition, our results suggest that all subjects do not contribute equally to the mental scanning effect. The subjects whose cognitive systems are capable of generating representations that include accurate metric information demonstrate that their cognitive operations reflect the analog structure of their representations. This does not mean that the other subjects do not implement the same processes. They probably try to perform the task as specified by the instructions, but their limited capacity to generate and maintain images limits their subsequent cognitive operations. The limited capacity of their visual buffer (or visuo-spatial sketchpad, according to the working memory theory; cf. Logie, 1995) does not mean that they have no capacity for generating accurate analog representations, but that they require more processing than other subjects.

Manuscript received August 1996
Revised manuscript received November 1996

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