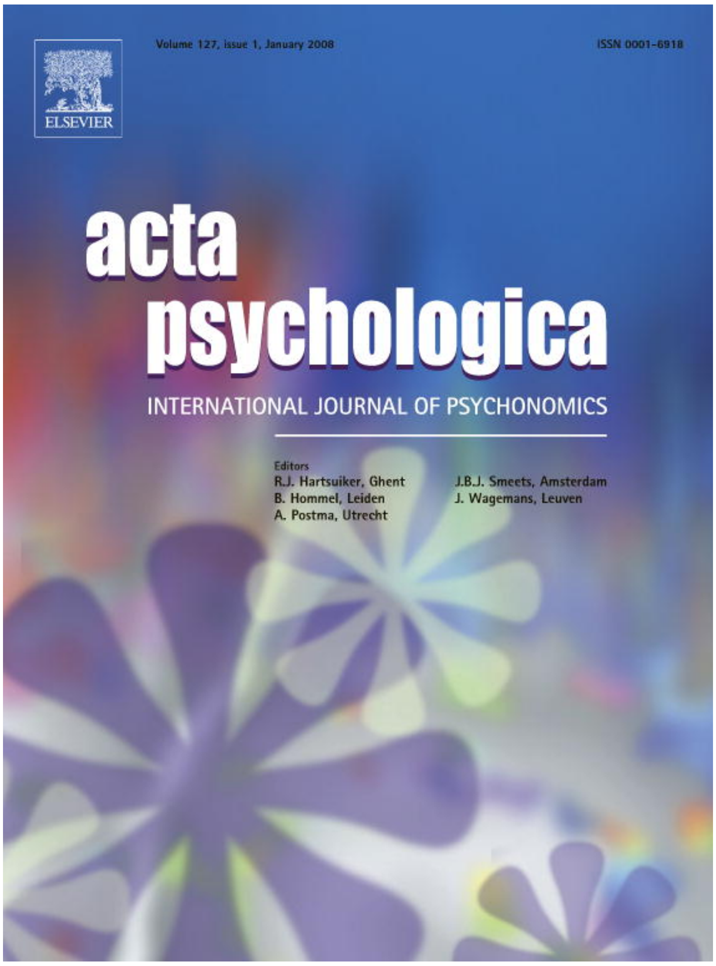
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Assessing the symbolic distance effect in mental images constructed from verbal descriptions: A study of individual differences in the mental comparison of distances

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Abstract

In two experiments, undergraduates processed a verbal description of a spatial configuration on the periphery of which six landmarks were located. The participants were then invited to generate visual images of the configuration, and to visualize the distances between pairs of landmarks. Their task consisted of deciding which of the two specified distances was longer. The results showed that as the magnitude of the differences in distance increased, the frequency of correct responses was higher, and response times were shorter. This pattern of results is characteristic of the symbolic distance effect, which is especially interesting in the present experiment where the images generated by the participants were constructed after processing a verbal description (rather than reconstructed from previous perceptual experience). In order to assess the role of visual imagery in the comparison of distances, the performance of participants with the highest scores on a visuo-spatial test (the Minnesota Paper Form Board) was compared to that of those with the lowest scores. High visuo-spatial imagers had higher frequencies of correct responses and shorter response times than the low imagers in the distance-comparison task. They outperformed their counterparts even more clearly on the items where the distance differences were the smallest, suggesting that visual imagery is especially important for items requiring the most attentive examination of a visual image. These data are interpreted as reflecting the fact that visual imagery mediates the process of mentally comparing distances, even when learning has been essentially based on verbal input. These findings support the view that a representation constructed from a verbal description may incorporate metric information about distances, and they offer evidence suggesting that visual images constructed from descriptive texts have genuine analog properties.

PsycINFO Classification: 2300; 2340

Keywords: Symbolic distance effect; Mental imagery; Verbal descriptions; Spatial configurations; Mental comparison of distances; Individual differences

1. Introduction

Among the properties that account for the effectiveness of images in human cognition, their *analog* character is the property that has received the most consideration (e.g., Denis & Kosslyn, 1999; Finke, 1989; Kosslyn, 1980; Kosslyn, 1994; Paivio, 1971; Paivio, 1986; Paivio, 1991; Richardson, 1999). Mental images are depictive representations of which internal structure is based on a *semantics of resemblance*. Not only do mental images contain information, but also this information is organized in meaningful patterns, and this organization is mapped onto the organization of information in the physical entities represented by the images. The structural isomorphism between images and objects or scenes is attested by the fact that they preserve topological relationships between parts of objects, and even detailed metric information, such as the relative distances between these parts. The theory of imagery most often adopted at the present time is based on the concept

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that images can preserve the Euclidean metrics of the objects perceived (Kosslyn, 1994). This concept lies at the core of most theoretical hypotheses regarding the architecture and function of the human cognitive system (e.g., Guenther, 1998; Kosslyn & Rosenberg, 2001; Shepard & Cooper, 1982). It is central to Barsalou's (1999) perceptual theory of knowledge, and the empirical work supporting the hypothesis that human cognition is grounded in perception (e.g., Zwaan & Radvansky, 1998; Zwaan & Taylor, 2006).

Empirical attempts to provide evidence of the analog character of mental images have been crucial in the development of knowledge about imagery processes. This was the objective that Stephen Kosslyn assigned to the image-scanning paradigm (Kosslyn, 1973; Kosslyn, Ball, & Reiser, 1978; Kosslyn, Margolis, Barrett, Goldknopf, & Daly, 1990; Pinker & Kosslyn, 1978). Scanning experiments have shown that when people are invited to scan mentally across the visual image of a spatial configuration, the greater the distance between two points in that configuration, the longer it takes them to scan the image. This chronometric consistency is viewed as evidence of the metric qualities of the mental representation to which the scanning process is applied, and taken as the empirical signature of the structural isomorphism between visual images and the configurations they represent (cf. Borst, Kosslyn, & Denis, 2006; Iachini & Giusberti, 2004; Mellet et al., 2000; Pinker, Choate, & Finke, 1984). A further value of the image-scanning paradigm, in this context, is that it applies not only to mental images of previously perceived objects, but also to the images constructed from verbal descriptions of configurations, that is, to the images constructed in the absence of any current or recent perceptual input (Chabanne, Péruch, Denis, & Thinus-Blanc, 2004; Denis & Cocude, 1989; Denis & Cocude, 1992; Denis & Cocude, 1997; Denis, Gonçalves, & Memmi, 1995; Mellet et al., 2002).

However, the image-scanning paradigm has been challenged on theoretical grounds, in particular because it was suspected of reflecting what people *know* about the relationships between time, speed, and distance, rather than being a genuine property of the images themselves (Pylyshyn, 1973; Pylyshyn, 2002; Richman, Mitchell, & Reznick, 1979). The argument of the "cognitive penetration" of images by knowledge and beliefs has been countered by further empirical data (e.g., Denis & Carfantan, 1985; Finke & Pinker, 1982; Kosslyn, Pinker, Smith, & Shwartz, 1979; Reed, Hock, & Lockhead, 1983). Nevertheless, several problems remain with this paradigm, which leaves data collected using this method open to criticism. One of these problems is the lack of consistency in how people interpret instructions about how to "scan" an image. Although the instructions are usually carefully compiled by the experimenters, they remain open to diverse interpretations by the participants, a situation that could clearly undermine the empirical value of data collected from participants who have differing perceptions of the task. Another problem with image-scanning experiments is that the participants' responses do not provide any measure of "performance". The participants are just asked to "declare" that they have completed an image-scanning trial, and the time that has elapsed when they make such declaration is taken to be the time they have actually devoted to scanning. This is a problem if a chronometric measure is conceived as a genuine reflection of a cognitive process. Interestingly, however, in spite of these problems, image-scanning experiments have provided quite consistent and dependable results, from which legitimate claims about the process of mental imagery have been generated, but we still need a behavioral measurement that would make it possible to assess the analog character of the mental representations constructed in mental imagery in an unambiguous fashion. To achieve maximum validity, such a measurement should be collected for a task where participants are invited to process a metric property of the imagined object, and which offers the experimenter a way of comparing their performance with an objective norm.

This condition would be met by a paradigm in which participants are required to form the visual image of a spatial configuration, and then assess a metric property of the configuration, for instance, comparing two distances and deciding which is the longer (or the shorter) of the two. Instead of requiring participants to perform absolute estimations of distances, the task now consists of comparing two distances, a task which is very easy to describe in the instructions, and unlikely to elicit diverse interpretations from the participants. Moyer (1973) found that when people are presented with simple physical stimuli, such as straight lines displayed side by side, the greater the difference between the two lengths, the easier the decision, and in particular, the shorter the time taken to respond (see Moyer, 1973; Moyer & Bayer, 1976). This phenomenon was labeled the "symbolic distance effect", and considered to reflect what Moyer called an "internal psychophysics". Subsequent experiments showed that this effect was maintained when participants compared the sizes of familiar objects from memory (e.g., Dean, Dewhurst, Morris, & Whittaker, 2005; Marschark, 1983; McGonigle & Chalmers, 1984; Paivio, 1975), or even performed novel, unfamiliar comparison tasks on familiar objects (such as comparing the angles formed by the two hands of clocks; see Paivio, 1978; Trojano et al., 2002; Trojano et al., 2000; Trojano et al., 2004). Such findings indicated that the consistencies and constraints that govern the processing of visual stimuli also apply to the corresponding internal representations. In other words, the internal representations exhibiting such consistencies and constraints meet the requirements that allow us to classify them as *analog* representations.

A further step in generalizing the symbolic distance effect consisted of searching for evidence collected when people mentally process novel objects (i.e., for which no pre-stored information is likely to facilitate mental comparisons), and specifically an object entirely constructed from verbal information. Denis and Zimmer (1992) reported an experiment (Expt. 2a) in which participants were invited to learn a spatial configuration either from a visual presentation of a map or from processing a description of it. The configuration included six geographical details that were positioned at its periphery at locations that the description made explicit by using the clock-face conventions of air navigation (e.g., "*At 11 o'clock, there is a harbor*"). After learning the map or the description, the participants were asked to construct an image of the configuration and to decide which of two designated distances (for instance, "*harbor–lighthouse*" and "*harbor–beach*") was longest. Not surprisingly, a distance effect was obtained after map learning, so that the mean frequency of correct responses increased as the magnitude of the difference being assessed increased. More interesting was the fact that a distance effect was also found for the participants who had constructed the mental representation from the verbal description. It is important for our argument that correct judgments about distances were produced (reflecting the chronometric regularities of the symbolic distance effect) even when the distances had not been experienced visually during learning, and had not even been made explicit in the description. Nevertheless, their metric values appeared to have been incorporated in the representation that the participants constructed while encoding the description. The fact that the same pattern was identified not only when distance judgments were based on physical stimuli, but also when they were based on their imaged counterparts (whether these images had been reconstructed from perception or constructed from a description), attests to the analog nature of visual images.

This finding was thought to be of special interest since this was the first time that distance effects had been obtained in a situation where the representation was not retrieved from long-term memory, but resulted from episodic construction. This was a clear indication that a representation constructed from a verbal description may incorporate metric information about distances, and offered evidence in favor of the analog properties of visual images constructed from descriptive texts. In a further experiment (Denis & Zimmer, 1992, Expt. 2b), which was restricted to the condition based on the learning of a verbal description, chronometric measures corroborated the previous findings. The time taken to produce correct responses decreased as the difference between the distances being compared increased. Further support was provided by experiments using variants of the distance-comparison paradigm (Afonso, Gaunet, & Denis, 2004; Péruch, Chabanne, Nesa, Thinus-Blanc, & Denis, 2006).

Recently, Noordzij and Postma (2005) broadened the perspective on the symbolic distance effect following learning of spatial descriptions by using more complex verbal materials than those of Denis and Zimmer (1992). The texts used in their experiment were spatial descriptions of realistic environments, such as a zoo or a shopping center. When invited to compare bird-flight distances between pairs of objects, the participants performed faster and better with increasing distance differences, which reflected the presence of a symbolic distance effect. An interesting addition to this experiment was the contrast between two modes of description, namely, survey and route descriptions. Regardless of the type of description that the participants had listened to, negative correlation coefficients were found between the metric distance differences and the comparison times. Finer analyses indicated that survey descriptions had a relative advantage, suggesting that they lead to mental spatial representations that pinpoint the location of the objects more accurately than route descriptions (see also Noordzij, Zuidhoek, & Postma, 2006; Péruch et al., 2006).[1]

However, the studies reported above left several questions unanswered, which the experiments reported below were designed to answer. The first question pertains to the assumption that *mental imagery* mediates the process of mentally comparing distances. The involvement of imagery in the mental comparison of objects is attested by the fact that performance declined in response to interference resulting from a secondary task making demands on the participants' visual working memory (cf. Dean et al., 2005). Evidence from other sources is also required. In particular, if mental imagery is the mediating process in the mental comparison of distances (even when the original source of information is verbal in nature), this should be reflected by differences in performance depending on individual imagery capacities. The experiments reported here were designed to establish whether such individual differences would predict performance in distance comparison. If high visuo-spatial imagers were to outperform low imagers, this would support the interpretation that distance comparisons are genuinely based on the process of visual imagery, even when the information that imagery provides has been constructed from verbal discourse. An individual differences approach was used by Paivio (1978) in a study of the symbolic distance effect, which involved the mental comparison of the sizes of angles, where high imagers did perform significantly faster than low imagers. No such evidence has been collected in the domain of distance comparisons, and this was the primary objective of the present study. Recording data in a distance-comparison task was worthwhile in that participants were invited to focus on exactly the same metric property as that considered in image-scanning studies, i.e., distances between points in a two-dimensional space.

A further objective of the present study reflects our interest in an unexplored facet of the issue under investigation.

[1] Reference to the *metric* properties of mental images is common in the imagery literature. In the case of distance comparisons making use of imagery, there is no difficulty in recognizing that people have to use metric information. However, strictly speaking, the term "metric" implies the application of some numerical value combined with a unit of measurement. Admittedly, the comparison task can be executed accurately regardless of the scale of a participant's representation. It would therefore be more correct to refer to a notion of "relative metrics". The aspect of an internal representation endowed with metric properties that is relevant here is that the values reflecting the various distances are consistent with one another within the representation, even if there is no objective metric counterpart to these values in the outer world.

There is a strong presumption that imagery is involved in distance comparisons, but it is also likely to be involved at earlier steps, during the *construction* of the representation, that is, during the processing of the verbal description. If this is a valid assumption, participants with the highest visuo-spatial capacities should not only exhibit the benefits they enjoy from imagery while they are making the comparisons, but also during the earlier stage when they were constructing the representation. The objective of our second study was to collect fresh data about the visual imagery processes involved during the learning of spatial descriptions. Fine chronometric measurements can be expected to be affected by the participants' imagery capacities, with high visuo-spatial imagers displaying faster processing.

2. Experiment 1

Experiment 1 replicated the part of Denis and Zimmer's (1992) Experiment 2a involving the processing of a verbal description. After learning a description, the participants were invited to compare pairs of distances, and the frequency of their correct responses was calculated. The new data were expected to confirm an increase in the frequency of correct responses as the magnitude of the differences between the distances being compared increased. The new piece of evidence that this experiment was intended to provide was the superior performance of high visuo-spatial imagers. If this were to be observed, it would support the view that imagery effectively mediates the comparison process, since the participants who made the best use of their imagery capacities would outperform participants who were less prone to rely on images.

2.1. Method

2.1.1. Participants

The participants were 20 undergraduates from the Orsay campus. They were a subset of a larger sample of undergraduates ($N = 69$) who had been collectively tested using a set of five visuo-spatial tests and questionnaires one week earlier in a lecture room of the university. One of the tests was the Minnesota Paper Form Board (MPFB; Likert & Quasha, 1941), a visuo-spatial test widely used in imagery research (e.g., Denis & Cocude, 1997; Paivio, 1978; Pazzaglia & De Beni, 2001). In the present sample, the MPFB scores ranged from 10 to 30. The mean for the group was 18.3 (sd = 3.8) and the median was 18.5. From among the 69 participants, the 10 who had the lowest scores and the 10 who had the highest scores were invited to take part in the experiment described below. Care was taken to include equal numbers of male and female participants in the two groups (hereafter called MPFB− and MPFB+, respectively).[2]

[2] There were equal numbers of male and female participants in this and the next experiment. In fact, Gender was never significant, and has therefore been left out of the report of the analyses.

2.1.2. Materials

A text was written describing the map of a circular island on the periphery of which six geographical landmarks were located. The locations of these landmarks were defined in the terms of the air navigation clock-face convention. They were introduced in clockwise order, starting with the landmark situated at the 11 o'clock position. The six landmarks were located in such a way that the distances between pairs of adjacent items were all different. The text read as follows (original in French): "*The island is circular in shape. Six features are located at its periphery. At 11 o'clock, there is a harbor. At 1 o'clock, there is a lighthouse. At 2 o'clock, there is a creek. Midway between 2 and 3 o'clock, there is a hut. At 4 o'clock, there is a beach. At 7 o'clock, there is a cave.*" In French the names of the landmarks were all one-syllable words.

The list of all the distances between pairs of landmarks was established, including both of the possible formulations for every distance (e.g., "*harbor–beach*" and "*beach–harbor*"). The materials for the comparison task involved a subset of these pairs of distances. The pairs selected were those that used the first landmark in the two distances to be compared (e.g., "*harbor–beach*"/"*harbor–hut*"). Two comparisons involving equal distances were excluded ("*hut–lighthouse*"/"*hut–beach*", and "*beach–cave*"/"*beach–lighthouse*"). The 58 items were listed in random order. The constraints were that the same distance could not occur more than three times in successive items, and that no more than three items requiring the same response could occur in a row. A second list was constructed by reversing the order of the two distances in each pair (for instance, "*harbor–beach*"/"*harbor–hut*" was replaced by "*harbor–hut*"/"*harbor–beach*").

2.1.3. Procedure

2.1.3.1. Learning. The participants were informed that they would listen to a description of the map of an island, of which they were asked to create as vivid and accurate a visual image as possible. They were seated in front of a board placed 140 cm from them. On this board was a blank sheet of paper (75 × 75 cm), which was intended to provide a cue for the imaged size of the island. The board was then removed. The description was provided in auditory form as a tape recording played three times. Following each hearing, the participants were required to form a visual image of the map and to focus mentally on each of the geographical landmarks in turn and check the exact location of each.

2.1.3.2. Distance comparisons. The participants were given two pages listing pairs of distances written side by side (in the form of landmark names designating two distances to be compared). They were instructed to picture the entire map mentally, and then to visualize the two distances designated and compare them. The participants were then asked to respond by ticking the pair of landmark names that corresponded to the longer of the two distances. They were asked to respond as fast as possible, without impairing the accuracy of their responses. Half of the participants received the first list of pairs and half received the list of reversed pairs. At the end of the task, the participants were interviewed. Two participants who reported having followed the imagery instructions for less than 75% of the time during the task were excluded and replaced. In addition, the participants were asked whether before mentally comparing the distances they had either relied on the location of the landmarks depicted in their visual image or first revised the hour-coded location of the landmarks. None of the participants reported having used this latter procedure.

3. Results

The items were divided into three subsets, depending on the magnitude of the difference between the two distances to be compared. Differences were expressed in terms of the actual differences on the map used in the Denis and Zimmer (1992) experiments. The first set of items (D1) comprised 17 items involving distance differences of less than 10 cm. The second set (D2) included 21 items involving differences of between 10 cm and 20 cm. The third set (D3) comprised the remaining 20 items, all of which involved differences of more than 20 cm. If these values were re-expressed in terms of ratios to the diameter of the circular map, the D1 items involved distance differences comprised between 0.03 (i.e., the smallest distance difference, "*cave–creek*"/"*cave–lighthouse*") and 0.17; the D2 items involved differences comprised between 0.17 and 0.34; and the D3 items involved differences comprised between 0.34 and 0.83 (i.e., the largest distance difference, "*creek–cave*"/"*creek–hut*").

Fig. 1 shows the mean frequencies of correct responses in the distance-comparison task for each set of items and each imagery group. An analysis of variance (ANOVA) was conducted on the data, with Gender and Imagery Capacities as between-participant factors, and Magnitude of Distance Differences as within-participant factor. Overall performance was significantly lower for MPFB− than for MPFB+ participants, 0.85 (sd = 0.08) vs. 0.91 (sd = 0.04), respectively, $F(1,16) = 5.25$, $p < .05$. A significant effect of the magnitude of distance differences was found, $F(2,24) = 42.81$, $p < .001$. Tukey's post hoc tests showed that there were significantly fewer correct responses to D1 than to D2 items, and to D2 than to D3 items (in both cases, $p < .001$). Furthermore, there was a significant interaction between the two variables, $F(2,32) = 3.17$, $p = .05$. Inspection of the data revealed that performance was significantly lower in MPFB− than in MPFB+ participants for the D1 items (Tukey, $p < .005$), but that the difference remained below the level of significance for the D2 and D3 items.

Further analyses were conducted after withdrawing some items from the data, in which the first distance designated was either the longest or the shortest of all possible distances. For these items, the response was indeed easy to predict. For instance, if the first mentioned distance was the longest of all ("*lighthouse–cave*"), a smart participant would not have to visualize the second distance to decide that it was shorter than the first one. Withdrawing these items reduced the number of items from 17 to 13 in D1, from 21 to 17 in D2, and from 20 to 12 in D3. However, after these corrections, the frequencies of correct responses remained remarkably similar to those computed in the first set of analyses, and the new set of ANOVAs simply confirmed the previous ones.

3.1. Discussion

The symbolic distance effect, which Denis and Zimmer (1992) initially reported to occur when people process episodic images constructed from descriptions of novel

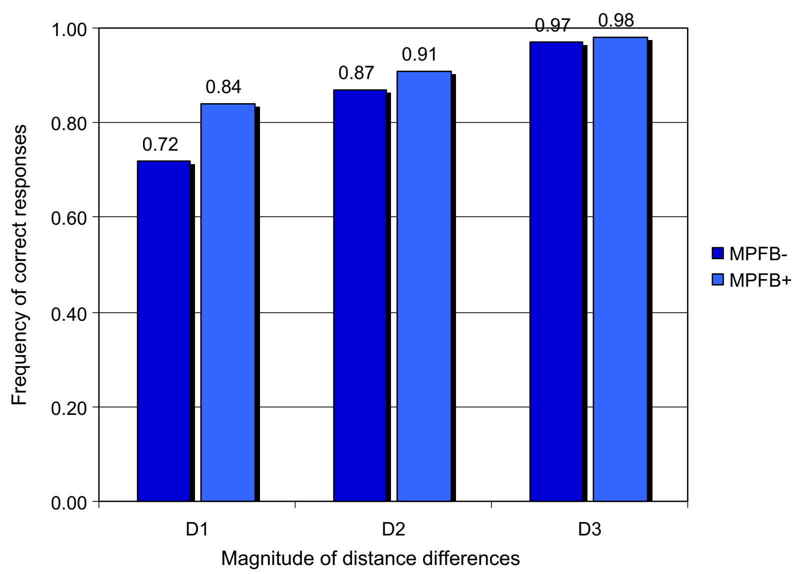

Fig. 1. Mean frequency of correct responses as a function of the magnitude of distance differences for MPFB− and MPFB+ participants (Experiment 1).

objects, was confirmed by the data of the present experiment. The clear hierarchy in the frequency of correct responses in a distance-comparison task as a function of increasingly demanding comparisons attests to the analog character of the representations used by the participants as the basis of their judgments, and this occurred despite the fact that no perceptual experience was at the origin of these representations. The representations constructed via mental imagery can therefore be conceived of as structural analogs of those that typically remain in the memory after perceptual episodes.

The second finding of interest is the evidence that individual imagery capacities had a measurable effect on performance in the distance-comparison task, where people who scored low on a visuo-spatial test were clearly outperformed by those with high imagery scores. This is the first time such an effect has been demonstrated in the distance-comparison task, which attests to the effectiveness of imagery in comparing distances constructed by imagination. The higher performance of high visuo-spatial imagers should not be interpreted as indicating that subjects classified as low imagers do not rely on visual imagery at all when trying to respond to the distance-comparison test. The latter group did in fact claim that they used imagery, as instructed, just as the former group did. What was presumably happening was that they had more difficulty in accessing and exploiting the analogical information provided by the imagery process. Low imagers were overall less often correct, which confirmed that they experienced greater difficulty in a task expected to call upon mental imagery.

A more subtle effect that merits consideration is the fact that high visuo-spatial imagers' superiority was not of the same magnitude for all items. Their superior performance was most marked for the most difficult items, those that involved narrow differences and were thus thought to require the most attentive scrutiny of the image. Not surprisingly, the participants who had the highest imagery capacities enjoyed a cognitive advantage, but this advantage was markedly lower for the items of medium difficulty, and not perceptible at all for the easiest items. This pattern of results is highly meaningful as it reveals that imagery capacities are exploited to a greater extent when distance differences are difficult to estimate. There was no difference in performance between the high and the low imagers for the items where the difference between the two distances being compared was very obvious from the image.

The metric accuracy of images constructed from descriptions, which is closely connected to their analog character, is a relevant feature in the present experimental context. High imagers are able to construct representations of which the geometrical properties are devoid of fuzziness. In the present task, their greater ability to process visual images is in line with the previous demonstration that in image scanning, people with the highest visuo-spatial capacities are those who display a typical pattern of image scanning (relatively short scanning times and significant time/distance correlations). Conversely, participants with poorer visuo-spatial capacities produce responses with chronometric characteristics that do not suggest that their images possess any stable, consistent structural properties (cf. Denis & Cocude, 1997).

Lastly, the absence of any consequence of withdrawing the responses to predictable items from the data analysis is a good indication that the participants did follow the imagery instructions to base their judgments on images, and did not attempt to perform computations of some other type. Had this been the case, the elimination of the items thought to be insensitive to the difficulty of the comparison would have had an impact on the data. The absence of any change therefore confirms that the participants did indeed deal with the entire set of comparisons using the same imagery process.

4. Experiment 2

Experiment 1 revealed distinct patterns of results for the participants identified as being particularly effective at generating and manipulating visual images, versus those who were less prone to engage in mental imagery. When both groups were invited to compare distances within a representation constructed from a verbal description, the former were shown to perform significantly better than the latter, but both groups displayed a similar significant symbolic distance effect. However, in addition to investigating the frequency of correct responses, we also needed to assess the distance effect by means of appropriate chronometric measures. This was the primary objective of Experiment 2.

Another objective of this experiment was to extend the measures made during the distance-comparison task to the earlier phase of constructing the images to be used in the comparison task. A number of experiments involving on-line chronometric measures have revealed the progressive nature of the construction process, and have confirmed that individual differences are highly likely to appear during the construction of the representation (Denis & Cocude, 1992; Denis et al., 1995). In particular, in the present situation, high imagers might prove to be especially efficient in *constructing* images, just as they are more efficient in *manipulating* them later (during the comparison task). The idea was therefore to record processing times during the *acquisition* of the description. To do this, the participants were invited to read the sentences describing the configuration, and their processing times were recorded, with the expectation that these might reflect the difficulties experienced during encoding, in particular by low imagers. The aim was to assess whether high imagers would perform better during encoding, as well as in the distance-comparison task.

Another way to test the differential capacities of participants during the encoding of the description is to expose them to versions of the descriptions that are more or less likely to assist them in constructing analog images. Previous experiments on image scanning and memorizing spatial descriptions have shown that distortions imposed on the structure of descriptions create cognitive difficulties at encoding and, as a result, impair the structural quality of the constructed images (Denis & Cocude, 1992; Denis & Denhière, 1990). One way to make image construction more difficult consists of delivering the information in a sequence that does not fit the readers' expectations, for instance by presenting pieces of information in a random order rather than in a systematic one (e.g., proceeding clockwise). In the present experiment, low imagers were expected to experience greater difficulty than their high imager counterparts in processing a poorly organized description.

To summarize, the present experiment investigated the performance of high and low imagers during two phases, namely, during the reading of a spatial description (when the participants were engaged in the process of constructing a visuo-spatial representation of the described configuration) and subsequently during the distance-comparison task (when they were retrieving the corresponding information and making their comparisons). We expected that during encoding, difficulties would be more evident for low than for high imagers, and that difficulties would also be greater when the participants had to process a poorly structured description rather than a well-organized one. Later on, these difficulties would be expected to manifest themselves again when the participants were engaged in the comparison task. Lower frequencies of correct responses and longer response times for comparisons involving small distance differences would be expected to confirm the symbolic distance effect obtained in Experiment 1, and these effects should be more marked for low than for high imagers, given their special sensitivity to particularly demanding comparisons involving fine discrimination of lengths.

Finally, in order to monitor the process through the experimental session, processing times were recorded during successive learning trials, and the comparison task was performed twice: once after three learning trials, and once again after three further trials.

4.1. Method

4.1.1. Participants

The participants were 32 undergraduates from the Orsay campus, half of them male and half female. None of them had taken part in the previous experiment.

4.1.2. Materials

The text used in Experiment 1 was used again, but it was now presented in written form. This text will be referred to below as Text 1. This text was used to construct Text 2, in which the six geographical details were introduced in random order. Text 2 read as follows: "*The island is circular in shape. Six features are situated at its periphery. At 11 o'clock, there is a harbor. At 4 o'clock, there is a beach. At 1 o'clock, there is a lighthouse. At 7 o'clock, there is a cave. Midway between 2 and 3 o'clock, there is a hut. At 2 o'clock, there is a creek.*"

The materials for the comparison task involved a subset of the pairs of distances used in Experiment 1, namely, 10 D1, 10 D2, and 10 D3 pairs. The 30 pairs were arranged in random order to constitute List 1, following the same constraints as those used in Experiment1. For half of the pairs in List 1, the first distance designated was shorter than the second, whereas for the other half, the second distance designated was longer. List 2 was constructed by reversing the order of the two distances in each pair (for instance, "*harbor–cave*"/"*harbor–creek*" in List 1 was replaced by "*harbor–creek*"/"*harbor–cave*" in List 2). Furthermore, each of the two lists was arranged in two sequences, that is, from the first to the last item as in the original random listing (Order A) or in the reverse order, from the last to the first item (Order B). A tape recording was made to present the distance-comparison test. For each trial, the first two names of landmarks designating a given distance were recorded, followed 2 s later by the two names designating the other distance that was to be compared to the first one. Presentation of the last name started a clock. The whole procedure was driven by a computer program designed specifically for the purpose of the experiment.

Equal numbers of male and female participants (2 males, 2 females) were allocated to the eight conditions resulting from the combination of the two versions of the description (Texts 1 and 2), the two lists of items used during the comparison task (Lists 1 and 2), and the two orders of presentation of these items (Orders A and B).

4.1.3. Procedure

The participants were invited to read one version of the description three times in immediate succession. After reviewing the learned configuration mentally, they performed the distance-comparison task. The whole procedure was repeated, with three more readings of the description, followed by a mental review and the distance-comparison task. The procedure was thus basically the same as in Experiment 1, except that the description of the island was presented in written form in the learning phase, and the materials were presented in auditory form in the distance-comparison task.

4.1.3.1. Learning. At the beginning of the first learning phase, the participants were told that they were to read a description of the map of an island. They were told that they would be required to create as vivid and accurate a visual image of the map as possible. They were seated in front of a computer screen on which the description would be displayed sentence by sentence. They were invited to press the space bar when they wanted to go on to the next sentence. They were told that there would be no way of rereading any previous sentence. They were therefore invited to take as long as they felt necessary in reading each sentence before going on to the next one. The time taken to process each sentence was recorded, but the participants were not aware of this. At the end of the first reading episode (R1), two more readings (R2 and R3) were carried out under the same conditions. In the second half of the experiment, three further reading episodes (R4–R6) took place with the same instructions and the same procedure.

4.1.3.2. Mental review. After the third reading of the description, the participants were asked to review the constructed representation mentally, that is, to situate each landmark at its specific location in their mental image. The participants were invited to signal to the experimenter as soon as they had completed this reviewing process and were ready to go on to do the distance-comparison test. The time taken to review the description mentally was recorded. In the second half of the experiment, the same mental review of the description took place after the last reading episode.

4.1.3.3. Distance comparisons. After mentally reviewing the configuration, the participants were introduced to the comparison task. They were told that each trial would consist of hearing the names of two landmarks on the map from a tape. They were to picture the entire map mentally, and then focus on the straight-line distance between the two landmarks designated. This distance was to be used as the standard against which a second distance would be compared. After an interval of 2 s, the names of two landmarks defining another distance were presented. The participants were to visualize this distance while keeping the first one clearly in their minds, and had to decide whether the second distance was longer than the first. Presentation of the first name of the second distance started a clock. The participants were provided with two buttons. They were to press one of these buttons if the answer was "yes" (i.e., if the second distance was longer than the first one), and the other button if the answer was "no" (i.e., if the second distance was shorter). The clock was stopped when either button was pressed, and response time was recorded. The participants were asked to respond as quickly as possible, but without impairing the accuracy of their responses. Half of them were required to use their dominant hand for positive responses, and the other hand for negative responses. The opposite assignment of hands to positive and negative responses was required from the other half of the participants. For each participant, equal numbers of items were expected to elicit Yes and No responses. The participants' responses were recorded via the computer. Two participants who reported having followed the imagery instructions for less than 75% of the time during the task were excluded and replaced. None of the participants said that they had revised the hour-coded locations of the landmarks before mentally comparing the distances.

4.1.3.4. Visuo-spatial imagery test. At the end of the experimental session, the participants completed the MPFB. The scores on this test ranged from 9 to 27. The mean was 21.0 (sd = 4.1) and the median was 21.1.

4.2. Results

4.2.1. Learning

Processing times for each sentence during each of the six reading episodes were computed. Below, we only consider the times for sentences stating landmarks' positions (thus excluding the two introductory sentences). Any individual times that were more than 2.5 sd above the mean time for the corresponding group in a given reading episode were replaced by that limit value ($m + 2.5$ sd). Only three such replacements were carried out (for one participant in the third reading episode, and for another in the fourth and the fifth reading episodes). Such cases corresponded to only 1.6% of the total number of individual processing times.

An ANOVA was performed on the processing times, with Gender and Text as between-participant factors, and Reading Episode as within-participant factor. Text 1 took less time to read than Text 2, 6.30 s (sd = 1.88) vs. 6.76 s (sd = 2.00), respectively, but this difference was not significant. A significant effect of the rank of the reading episode was found, $F(5,140) = 21.36$, $p < .001$. On average, the first three reading episodes took longer to process than the last three, 7.89 s (sd = 2.16) vs. 5.17 s (sd = 2.72), respectively, $F(1,28) = 23.47$, $p < .001$. Tukey's post hoc tests showed that processing times were longer for R1 than for any of the other reading episodes ($p < .001$), and that the only other significant differences were those between R2 and both R5 ($p < .02$) and R6 ($p < .005$). There were no significant interactions among the main variables.

The sample of participants was then considered as a whole set from which two subgroups with contrasting imagery capacities were composed. To do this, we withdrew from the analysis the participants whose scores fell in the region of the median of the MPFB scores. We only retained those participants with MPFB scores equal to or lower than 20 (MPFB−, $N = 13$, average score: 17.2) and those with MPFB scores equal to or higher than 23 (MPFB+, $N = 12$, average score: 24.9). An ANOVA was conducted with Text and Imagery Capacities as between-participant factors, and Reading Episode as within-participant factor. This analysis did not reveal any significant difference between low and high imagers' processing times, 6.49 s (sd = 1.66) vs. 6.53 s (sd = 2.01), respectively.

4.2.2. Mental review

The times taken by the participants to mentally review the configuration were recorded after the third reading episode (Review 1) and the sixth one (Review 2). An ANOVA of the reviewing times was conducted, with Gender and Text as between-participant factors, and Review as within-participant factor. Overall, the representation constructed from Text 1 took less time to review than that constructed from Text 2, 16.84 s (sd = 11.24) vs. 25.18 s (sd = 13.55), respectively, $F(1,28) = 3.65$, $p < .07$, and Review 1 took longer than Review 2, 30.28 s (sd = 18.65) vs. 11.74 s (sd = 13.53), respectively, $F(1,28) = 35.12$,

$p < .001$. There was a significant interaction between Text and Review, $F(1,28) = 6.01$, $p < .05$. Post hoc tests revealed that reviewing times were significantly shorter for Text 1 than for Text 2 during Review 1 only, 22.28 s (sd = 15.46) vs. 38.28 s (sd = 18.52), respectively ($p < .01$), but that they did not differ from each other during Review 2.

The next analysis contrasted MPFB− and MPFB+ participants, following the same procedure as had been used to analyze the processing times. An ANOVA with Text and Imagery Capacities as between-participant factors, and Review as within-participant factor, revealed that reviewing times were overall longer for low than for high visuo-spatial imagers, 26.64 s (sd = 11.20) vs. 14.08 s (sd = 11.01), respectively, $F(1,21) = 12.30$, $p < .005$. There was no significant interaction between Imagery Capacities and any of the other variables.

4.2.3. Distance comparisons

4.2.3.1. Frequency of correct responses. Fig. 2 shows the mean frequencies of correct responses in the distance-comparison task for each set of items. An ANOVA was carried out with Gender and Text as between-participant factors, and Magnitude of Distance Differences, Test, and Response Type as within-participant factors. Text had no significant effect on the frequency of correct responses. A significant effect of the magnitude of distance differences was found, $F(2,56) = 25.52$, $p < .001$. Tukey's post hoc tests showed that there were significantly fewer correct responses to D1 than to D2 items ($p < .001$) and to D2 than to D3 items ($p < .001$). The frequency also differed between Test 1 and Test 2, 0.82 (sd = 0.14) vs. 0.91 (sd = 0.10), respectively, $F(1,28) = 14.94$, $p < .001$. Lastly, the frequency of correct Yes responses did not differ from that of correct No responses.

The next step consisted of testing the impact of imagery capacities. The ANOVA took into account Text and Imagery Capacities as between-participant factors, and Magnitude of Distance Differences and Test as within-participant factors. Overall performance was lower for MPFB− than for MPFB+ participants, 0.83 (sd = 0.10) vs. 0.89 (sd = 0.08), $F(1,21) = 3.61$, $p = .07$. In addition, MPFB− participants appeared to be more obviously outstripped by MPFB+ participants for D1 than for D2 and D3 items. The interaction between Imagery Capacities and Magnitude of Distance Differences was significant, $F(2,42) = 4.18$, $p < .05$. Fig. 3 displays this interaction pattern. Inspection of the data revealed that performance was significantly lower in MPFB− than in MPFB+ participants for the D1 items (Tukey, $p < .001$), but that the difference was not significant for the D2 or D3 items.

4.2.3.2. Response times. The response times for each item were recorded. Only the times of correct responses were taken into account in the analyses reported below. Individual times which were above the mean time of the individual's group by more than 2.5 sd in one of the two comparison tests, for one of the subset of items (D1, D2, D3) eliciting either Yes or No responses, were replaced by that extreme value ($m + 2.5$ sd). Such cases only accounted for 1.6% of the total number of individual response times.

Fig. 4 shows the mean response times in the distance-comparison task for each set of items. The same steps were followed for the analysis of the response times as for the analysis of the frequency of correct responses. The first ANOVA involved Gender and Text as between-participant factors, and Magnitude of Distance Differences, Test, and Response Type as within-participant factors. Responses tended to be faster after processing of Text 1 than Text 2, 2840 ms (sd = 920) vs. 3121 ms (sd = 767), but the effect remained below the level of significance. A significant effect of the magnitude of distance differences was found,

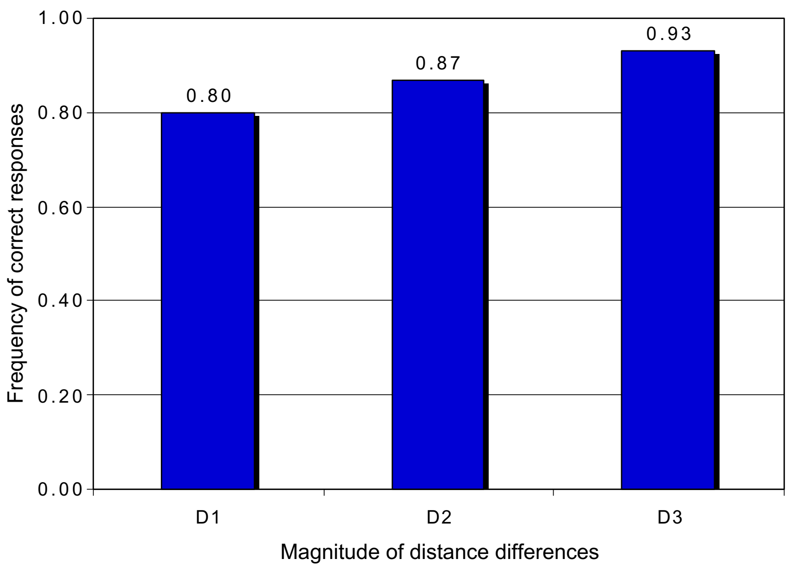

Fig. 2. Mean frequency of correct responses as a function of the magnitude of distance differences (Experiment 2).

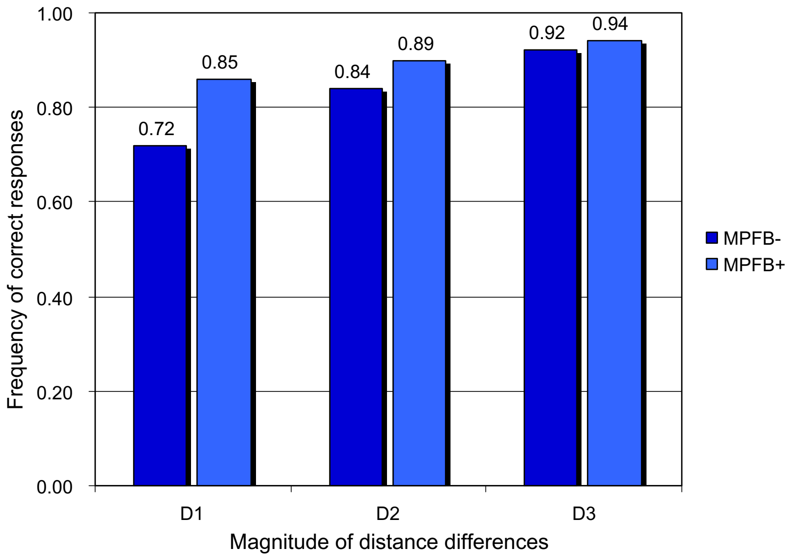

Fig. 3. Mean frequency of correct responses as a function of the magnitude of distance differences for MPFB− and MPFB+ participants (Experiment 2).

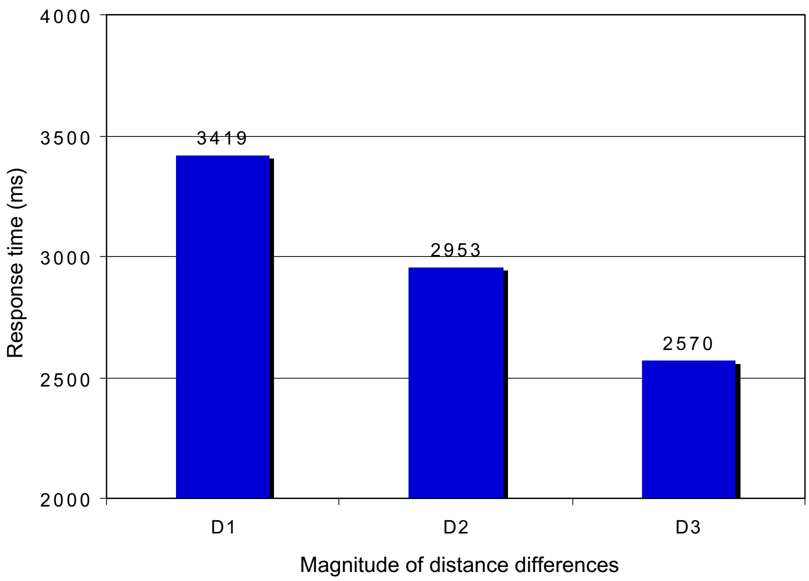

Fig. 4. Mean response times (ms) as a function of the magnitude of distance differences (Experiment 2).

$F(2,56) = 40.33$, $p < .001$. Tukey's post hoc tests showed that response times were significantly shorter for D1 than for D2 items, and for D2 than for D3 items (in both cases, $p < .001$). Response times also differed for Test 1 and Test 2, 3248 ms (sd = 868) vs. 2714 ms (sd = 896), $F(1,28) = 33.20$, $p < .001$. Lastly, times were systematically shorter for Yes than for No responses, 2867 ms (sd = 895) vs. 3095 ms (sd = 889), $F(1,28) = 5.28$, $p < .05$.

The next analysis tested the impact of imagery capacities. The ANOVA took into account Text and Imagery Capacities as between-participant factors, and Magnitude of Distance Differences, Test, and Response Type as within-participant factors. Fig. 5 shows the mean response times for each set of items and each group of participants. Overall, response times were significantly longer for MPFB− than for MPFB+ participants, 3473 ms (sd = 798) vs. 2750 ms (sd = 856), $F(1,21) = 6.26$, $p < .05$. There was no significant interaction between Imagery Capacities and Magnitude of Distance Differences. The same pattern of results was obtained when the so-called predictable items were withdrawn from the analysis.

4.3. Discussion

The first major finding of Experiment 2 was to provide a further demonstration of the symbolic distance effect during the processing of visual images, in the special case where these images have been generated from a verbal description

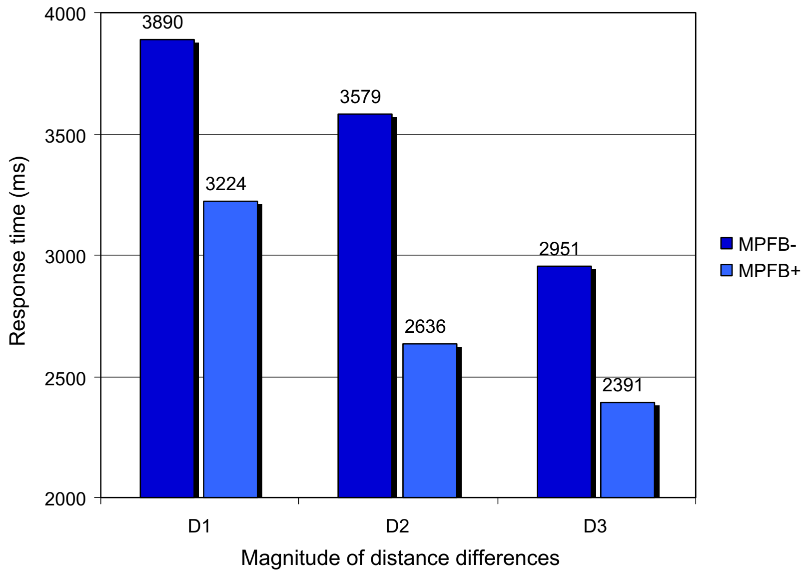

Fig. 5. Mean response times (ms) as a function of the magnitude of distance differences for MPFB− and MPFB+ participants (Experiment 2).

rather than being reconstructed from long-term memory (as was the case in Paivio's and Marschark's pioneering studies). The results of Experiment 1 were confirmed in a new, slightly different experimental context, including (a) longer periods of time devoted to learning the configuration, (b) variations in the text describing the configuration, and (c) repeated distance-comparison tests. As well as confirming the symbolic distance effect, Experiment 2 provided a second major confirmation, that of the effect of individual imagery capacities on distance comparisons. More specifically, we obtained a further demonstration of the special difficulty experienced by low visuo-spatial imagers in processing the most subtle distance differences.

The new feature of Experiment 2 was that it provided information about the time required to perform mental comparisons of distances. As the distance differences increased, not only did the frequency of correct responses increased, but response times also systematically decreased, contributing to the signature of the symbolic distance effect in our study (cf. Noordzij & Postma, 2005). Furthermore, response times were shown to be affected by individual imagery capacities. People with the highest imagery capacities had shorter response times than low imagers, which suggested that they found it easier to access the metric information contained in their mental images. Presumably, their images contained more accurate information, which increased the likelihood that they would produce correct responses, and produce them in shorter times. However, the chronometric measures did not corroborate any special difficulty of low imagers in processing the smallest differences. Only the measures of performance revealed this difficulty (as was the case in Experiment 1), and chronometric measures did not detect any such limitation of their capacities. Response times for the three levels of difficulty were ranked similarly in the two groups, and low imagers systematically took longer to respond than high imagers.

Other effects of interest were also demonstrated by this experiment. First, we carried out two distance-comparison tests during the experimental session, something that does not seem to have been done in previous experiments on the symbolic distance effect. Not surprisingly, performance increased and response times decreased from the first to the second test, but the major points noted here were as follows: (a) the typical pattern of symbolic distance effect was unaffected, a result which speaks in favor of the robustness of the phenomenon, and (b) the effect was not qualified by the level of individual imagery capacities. Second, we did not obtain any evidence that items requiring No responses would elicit performance patterns that differed from those requiring Yes responses. No difference emerged in terms of the frequency of correct responses. However, a clear effect was found for response times. It took longer to produce a negative response than a positive one. This effect was consistent, and did not interact with other variables of interest, notably with the magnitude of distance differences or the participants' imagery capacities.

The newest feature of the present study was to include measures related to the acquisition of the representation on which the symbolic distance effect would later be tested. In particular, the objective was to establish whether imagery capacities, which are known to impact on distance comparisons, would also play a role earlier in the process. The construction of visuo-spatial representations from the descriptive texts has been amply documented in previous research, which has established that people are able to create images with properties similar to those derived from visual perception (Denis et al., 1995; Mellet et al., 2002; Péruch et al., 2006). The descriptions used in Experiment 2 are the same as those used to demonstrate their impact on the generation and scanning of images (Denis & Cocude, 1992). It was expected that greater difficulty in building coherent images would occur when reading these texts, where information was presented in an unexpected (random) order (Denis & Cocude, 1997; Denis & Denhière, 1990). In the present experiment, during the processing of the texts, a minor effect was detected, reflecting that the random text did indeed take longer to process than the well-structured one, but the effect remained below the level of significance. Furthermore, high and low visuo-spatial imagers did not display differing processing strategies, at least in terms of reading times.[3]

The task where the impact of individual differences was quite obvious was the mental revision of the representation under construction. It always took longer to reconstruct and review the image of a configuration that had not been described in a regularly organized fashion (clockwise). When the participants could no longer read the description, the cognitive cost of reconstructing the configuration on the basis of a memorized poorly structured text became evident. Furthermore, imagery capacities had a significant impact, with high imagers being better able than their counterparts to reinstate and review the image that they had constructed based on a description.

Lastly, no significant effect of text structure was detected in distance comparisons. The representation was constructed under more difficult conditions from the poorly structured text, but once it had been achieved, the representation resulting from the processing of Text 2 was available to inspection in the same way as that derived from Text 1. The dominating factor was the individuals' imagery capacities, the impact of which was the most clearly assessed during distance comparisons. Most of the differences between high and low imagers did not result from the difficulties experienced when constructing the representation, but reflected the greater difficulty experienced by the latter group to access the metric information available in their mental images.

5. General discussion

People's ability to construct images from verbal information is a well-established capacity. Not only can such images be constructed and contain information, but, more importantly for our discussion, they can also provide accurate metric information. This has been clearly shown with the help of the image-scanning paradigm. A relevant additional piece of information is provided by the demonstration of the symbolic distance effect in the present study. By examining distance-comparison performance in representations derived from the processing of a map or a description, Denis and Zimmer (1992) had already shown that a basic psychophysical phenomenon such as the symbolic distance effect occurs regardless of whether the origin of the image is perceptual or verbal. In the present study, using an approach similar to that of Noordzij and Postma (2005), we took another step in this direction. By focusing on images constructed from text descriptions, we confirmed the presence of the symbolic distance effect, while also testing the hypothesis of the imaginal substrate of the comparison task through the impact of individual imagery differences on this task, a novel piece of information in the symbolic distance literature that pertains to distance comparisons.

The existence of the symbolic distance effect is compatible with the idea of an analogical representational substrate, although it does not in itself provide a definite demonstration that mental imagery is used in distance comparisons. By contrasting high and low imagers' performance, we have provided a more valid approach to this question. In the two experiments reported here, we have shown that when distance comparison is applied to a representation that has been constructed from verbal information, high imagers consistently perform better, and their response times are always shorter than those of low imagers. This finding supports the claim that visual images underlie the distance-comparison process. It is important to note that the symbolic distance effect is demonstrated by both groups of participants (see also Paivio, 1978), which suggests that low imagers (who are not "non-imagers") do indeed attempt to perform comparisons on the basis of an imaginal representation, but that they have more limited resources for generating, manipulating, and executing computations on these images than high imagers. Another relevant finding is that the magnitude of the difference in performance of high and low imagers is greatest for the most difficult items, those which involve subtle differences and therefore require more scrutiny. However, in addition to the differences between the two groups of participants, it should be noted that based on a text, an analog representation can be constructed that contains metric information that was not explicit in the text used to construct it.[4]

The data collected here are highly compatible with an imagery-based explanation for performance in size com-

[3] An original aspect of the study is its combined approach to the processes of encoding and those involved in the comparison task. A covariate approach would be sound if there were a definite, motivated expectation that text-processing times would be predictive of comparison times. Although this approach is legitimate in principle, the present study was not carried out to test any such hypothesis. We do, of course, know that imagery capacities have an impact on the time needed to process a descriptive text, and so time can be taken to reflect the cost (in terms of cognitive resources) of constructing a representation. On the other hand, imagery capacities can also be expected to have an impact on the comparison process, but probably by tapping into resources of a different nature. The resources involved in translating language into a representation are presumably distinct from those involved in visually inspecting the representation. In an attempt to assess the validity of this assumption, we tentatively calculated the correlation between the two sets of response times (text processing and distance comparisons) for the whole set of participants. No correlation was found between the two time measures.

[4] These conclusions are in line with those of the studies documenting the role of visuo-spatial working memory during the processing of more complex spatial texts (cf. De Beni, Pazzaglia, Gyselinck, & Meneghetti, 2005; Deyzac, Logie, & Denis, 2006; Gyselinck, De Beni, Pazzaglia, Meneghetti, & Mondoloni, 2007).

parisons (Dean et al., 2005). We must certainly consider the possibility that the representations built by low imagers result from impaired learning, which would explain why they take longer to *reconstruct* the representation during the distance-comparison task. If the representation is of poor quality and not sharp enough, thus resulting in fuzzy representations of distances, then no symbolic distance effect should in fact be expected. The fact that both groups displayed the symbolic distance effect indicates that the representations they used were functionally equivalent. The difference reflected by low imagers' longer comparison times is due to their difficulty in performing the relevant computations on analog representations.

These conclusions are similar in some ways to those obtained from scanning studies, but a difference between the two sets of findings should be pointed out. In scanning, high and low imagers differ in terms of their absolute response times, and only high imagers actually display the scanning effect. In contrast, in distance comparisons, high and low imagers also differ from each other in terms of absolute times, but both produce the *same pattern* of results, i.e., all participants display the symbolic distance effect. Subtle distance differences are harder for low imagers to detect (thus resulting in a specific interaction), but the overall pattern is the same. This finding supports the notion that low imagers use the same type of representational resources as high imagers, but that the difference between them resides in the differing amounts of computational resources available to process these representations.

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