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Comparing distances in mental images constructed from visual experience or verbal descriptions: The impact of survey versus route perspective

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Mental images constructed after visual examination of a spatial configuration or after processing a verbal description of that configuration have been shown to share similar properties, in particular the capacity to preserve metric information contained in the configuration represented. In the present study, we investigated the properties of mental images constructed under learning conditions resulting from the combination of a visual or a verbal mode of acquisition and a survey or route perspective. Participants memorized a virtual environment (a garden containing six objects) under one of four learning conditions: (a) viewing a map of the garden (visual–survey); (b) viewing a video presentation of a journey along the path around the garden (visual–route); (c) listening to a verbal description of the map of the garden (verbal–survey); and (d) listening to a verbal description of the journey around the garden (verbal–route). The participants were then invited to compare the distances separating objects in the garden mentally. Experiment 1, where the pairs of distances to be compared had a common starting point, revealed that the frequency of correct responses was higher, and response times were shorter when participants had learned about the environment visually rather than by a verbal description. The conditions involving a survey perspective resulted in a higher frequency of correct responses and shorter response times than those involving a route perspective. Lastly, a symbolic distance effect was obtained in the first three conditions, in that the greater the difference between the two distances being compared, the higher the frequency of correct responses, and the shorter the response times. Experiment 2, where the pairs of distances had different starting points, replicated these results, although longer response times revealed that the comparison process was more costly. Taken together, these findings support the view that mental spatial representations derived from different sources and adopting different perspectives contain genuine metric properties, except when the verbal modality and the route perspective are combined during learning.

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In large-scale spaces, people are frequently required to move toward unseen goals. To do this, they have to plan their movements on the basis of what they know about the environment beyond their perceptual reach. Such knowledge is generally assumed to take the form of mental spatial representations, or "cognitive maps" (cf. Bloom, Peterson, Nadel, & Garrett, 1996; Portugali, 1996). The informational value of these representations depends to a large extent on the degree of their isomorphism with the corresponding spatial layouts and in particular of how well they preserve the Euclidean properties of the layouts. For instance, the metric features of spatial representations may have important consequences for orienting behaviour that involves estimating and comparing distances. Whereas topological relationships are generally well preserved (Lynch, 1960), the metric features have been found to be fuzzy to a large extent (e.g., Giraudo & Pailhous, 1994; McNamara, 1986; Tversky & Schiano, 1989). This has been demonstrated using a variety of methods intended to assess the accuracy of spatial knowledge—for example, estimates of distances travelled and landmark sequencing (in the case of route knowledge), or Euclidean distances and direction estimates (in the case of survey knowledge).

In contrast, other sets of data derived from the field of mental imagery suggest that spatial representations sometimes contain quite precise metric information (cf. Denis & Kosslyn, 1999). The mental scanning paradigm, which was initially designed to assess the spatial properties of mental images (Kosslyn, 1973), revealed that when people move mentally over distances in imagined configurations, their scanning times increase with the distance scanned. This was found when the paradigm was applied to either two-dimensional images (Kosslyn, Ball, & Reiser, 1978) or three-dimensional images (Pinker & Kosslyn, 1978) and was taken to reflect the isomorphism between visual mental images and the corresponding physical spatial configurations.

Besides navigation, maps, photographs, videotapes, verbal descriptions, and virtual environments all provide spatial information likely to be processed and organized in the form of internal spatial representations. However, these various forms of information may not necessarily lead to the construction of similar representations. Indeed, how information is acquired (by a visual or verbal mode), on the one hand, and the perspective from which it is presented (survey or route), on the other, may affect the structure and accuracy of the mental representations.

Initially employed in experiments involving visual acquisition, the mental scanning paradigm has also been used as a way of assessing the properties of images constructed from verbal descriptions (Beech & Allport, 1978; Kosslyn, Reiser, Farah, & Fliegel, 1983). Using an adaptation of the material of Kosslyn et al. (1978), Denis and Cocude (1989) found the same scanning regularities following the verbal description of a spatial layout as after its visual examination, suggesting that the information was structured in a similar way in both cases. However, two main differences emerged from the data. First, the learning process was slower for verbal than for visual acquisition, which is consistent with the primary role of vision in the processing of spatial information (Thinus-Blanc & Gaunet, 1997). Second, in the case of verbal descriptions, the order in which items of information were provided affected the internal structure of the representations (Denis & Cocude, 1992; Denis & Denhière, 1990; Foos, 1980). The question of the equivalence between the mental representations constructed after visual or verbal acquisition therefore still merits further investigation.

Apart from how it is acquired (visual or verbal mode), the perspective from which a spatial layout is experienced (survey or route) may lead to differences in the nature of the resulting representations. For instance, the visual processing of a spatial layout seen from a survey perspective is quite different from integrating information sequentially as it becomes available while travelling along a route. In the former case, one is provided with a two-dimensional symbolic representation of the whole configuration that conveys direction and distance relationships, whereas travelling through a three-dimensional environment requires one to keep items of sequentially acquired information in the short-term memory in order to construct a two-dimensional mental representation. The possibility that spatial knowledge resulting from survey and route perspectives may reflect distinct properties has been investigated in several studies (Presson & Hazelrigg, 1984; Taylor, Naylor, & Chechile, 1999; Thorndyke & Hayes-Roth, 1982). For instance, Thorndyke and Hayes-Roth showed that route distance estimates were better than straight-line distance estimates after navigation (route knowledge), whereas straight-line distance estimates were better than route distance estimates after examining a map (survey knowledge).

Similarly, a text describing a spatial layout can be written in such a way that it prompts the reader to elaborate either a survey or a route representation. What emerges is that these different sorts of text have different effects on the computations that people perform later on their mental representations. Perrig and Kintsch (1985) found that constructing a mental representation took longer from a description based on a route perspective than from one based on a survey perspective. Noordzij and Postma (2005) reported that estimating distances was easier when spatial representations had been constructed from a survey rather than a route description of a complex spatial layout. However, Taylor and Tversky (1992) and Ferguson and Hegarty (1994) did not find any evidence for the effect of perspective on learning from descriptions. Lastly, the use of a verbal description has to cope with specific constraints. Since discourse has an inherently linear structure, a speaker must find the best way, if there is one, to describe an entity with two or more dimensions in a linear fashion, in order to place a listener in the best processing conditions to construct an internal representation. The effects of the structure of the descriptions on the structural properties of mental images have been assessed in several studies (Denis & Cocude, 1992; Denis, Gonçalves, & Memmi, 1995).

From this brief overview of the literature, it appears that the domains of mental imagery and spatial cognition are becoming increasingly interconnected and make mutually helpful contributions. Indeed, it has been found that, like mental images, spatial representations may contain precise metric properties, which contrasts with the findings of earlier studies. Furthermore, as in the domain of imagery, there are good reasons to investigate whether survey representations acquired from the visual examination of a map and those acquired from processing a verbal description share similar analogue metric properties. In addition, in the domain of spatial cognition, it is acknowledged that the mode of acquisition (consulting a two-dimensional map or moving through a three-dimensional environment) may result in different functional organizations (Presson & Hazelrigg, 1984). However, no systematic studies have been conducted so far to compare the effects of the modality of acquisition (visual or verbal) and of the perspective (survey or route) on the accuracy of the metric properties of mental maps constructed within the same experiment.

The present study was intended to find out whether spatial representations constructed on the basis of navigation (i.e., from a route perspective) in a fictitious environment have the same metric properties as those of representations constructed after learning a symbolic map (i.e., from a survey perspective). The same question was also addressed with regard to representations derived from descriptions, either from a bird's eye perspective of a described environment, or from the route perspective used in the description of a visual journey. In a previous study, Chabanne, Péruch, Denis, and Thinus-Blanc (2004) used the mental scanning paradigm to examine the metric properties of mental spatial representations of a virtual environment constructed from visual depictions or verbal descriptions and presented from survey or route perspectives. The results revealed a significant relationship between scanning times and the distances scanned, suggesting that the mental scanning of a two-dimensional configuration reflects the fact that mental representations constructed from the visual inspection of the configuration and from the processing of its verbal description retain similar metric properties. Furthermore, when the configuration was originally learned as a three-dimensional environment by means of a video presentation or a verbal description (requiring the processing of a route perspective in both cases), the same regularities were confirmed, establishing that Euclidean distances are represented in route representations as they were already known to be represented in survey representations. However, the main difference that emerged was that an environment learned from a route perspective took longer to process by mental scanning. Longer absolute response times suggested that accessing the mental representation was more difficult after route than survey learning or, if the access time was not affected, that in any case the poorer quality of the representation made scanning more difficult.

Although the mental scanning paradigm used in the Chabanne et al. (2004) study provided quite encouraging indications, it was necessary to complement it with another paradigm also relevant to testing the metric properties of mental spatial representations, but involving additional methodological qualities. One problem with mental scanning lies in the difficulty of phrasing instructions to convey what is required of the participants. Furthermore, the responses provided by the participants only reflect their subjective feeling that the process of scanning has been completed, and, even though reliable regularities do appear, it nevertheless creates the need for a spatial task eliciting responses that can be evaluated against a standard—that is, that are objectively right or wrong. The task selected for use in the present study consisted of comparing distances between locations in the configuration learned by the participants. The comparison did not require responses in terms of absolute lengths, but simply deciding which of two distances was the longer.

The mental comparison of distances was used by Denis and Zimmer (1992) as a means of testing some of the properties of visuo-spatial knowledge acquired from the verbal description of a configuration. The processing of metric properties of the configuration (which were not made explicit in the description, but had to be inferred from the visuo-spatial representation constructed during the encoding of the description) appeared to be very similar to the situation where participants had learned the configuration visually. There was also clear evidence that response times were negatively correlated with the magnitude of the differences between the distances being compared (see also Afonso, Gaunet, & Denis, 2004). This "symbolic distance effect" (Moyer, 1973) provided grounds for the claim that representations constructed from verbal descriptions possess properties that are isomorphic with those of physical configurations, regardless of whether these are compared perceptually or from memory (cf. Marschark, 1983; Moyer, 1973; Moyer & Bayer, 1976; Paivio, 1975).

The new question introduced here was whether the chronometric regularities known to occur during the mental comparison of distances would occur in a similar way under the four conditions resulting from the combination of a visual or a verbal mode of acquisition and the survey or route perspective on the environment. In particular, our objective was to find out whether there was any evidence of the special difficulty that characterizes the processing of configurations or their descriptions from a route perspective when the participants have eventually to compare distances mentally.

In addition, on the basis of data from previous studies, we expected that learning from the visual modality would not only yield shorter response times in distance comparison tests, but would also lead to better performance than would verbal descriptions. Furthermore, distance comparisons were expected to be more accurate after examining a map than after route learning (Thorndyke & Hayes-Roth, 1982). Finally, we wanted to investigate whether these variables (modality and perspective) interacted, and whether the level of difficulty of distance comparisons was involved in these interactions. Previous experiments have shown that the smaller the differences between pairs of distances, the more difficult it is to compare them (Afonso et al., 2004; Denis & Zimmer, 1992), but in all of these experiments, the segments to be compared shared the same starting point. In the present study, besides an initial experiment that used the classic paradigm, a second experiment was designed in which the distances to be compared were disjointed, and some of the segments intersected, making the task more difficult to perform.

EXPERIMENT 1

The first experiment investigated the effect of how the information was acquired (visual or verbal modality) and of the perspective from which it was presented (survey or route) on the mental comparison of distances. In addition, the effect of the size of the difference between pairs of distances to be compared was investigated.

Method

Participants

The participants were 24 women and 24 men, all undergraduate and graduate students. They were between 18 and 34 years of age (mean = 24.0, *SD* = 3.4), with normal or corrected-to-normal vision. Each participant was randomly assigned to one of the four conditions described below, with equal numbers of men and women in each group. All participants were paid for participating in the study and were unaware of the purpose of the experiment.

Materials

The experiment comprised a learning phase and a test phase. Four learning conditions were designed, resulting from combinations of the modality of acquisition (visual or verbal) and the perspective of the presentation (survey or route). Specific materials were created for each condition.

Learning. For the visual–survey condition, a map of a circular garden was constructed (15 cm diameter), with six objects represented by pictures (flowers, tree, bench, hedge, sandpit, well) located around the edge (see Figure 1a). The six objects were located in such a way that the distances between pairs of adjacent objects were all different. In French, the nouns designating the six objects were all one syllable long, and they all took the same length of time to pronounce when spoken aloud. For the visual–route condition, a video presentation of a tour following the path surrounding the garden at normal walking pace was displayed on a 17-in. flat monitor (see Figure 1b, which shows a specific view during the tour). The complete clockwise tour around the garden started from (and ended at) the flowers, and it lasted 45 s. For the verbal–survey condition, a text was written, describing the shape of the garden and the location of the six objects based on the clockface codes used in air navigation, and mentioned in the same order as that in the tour in the visual–route condition (e.g., "The flowers are at 11 o'clock. The tree is at 1 o'clock, etc."; as in Denis & Cocude, 1989). For the verbal–route condition, a verbal description of the circular tour was constructed in a similar way to the video presentation. The objects were named when the observer arrived at the position corresponding to each of them, so that the time intervals between the naming of successive objects was proportional to the distance between the objects in the video of the visual–route condition, and the journey time was the same.

Test. A list of all the distances between the pairs of objects was prepared, including the two possible formulations of the distance between each pair of objects (e.g., "flowers–bench" and "bench–flowers"). The comparison task involved 58 pairs of distances. Each pair of distances had the same starting point—that is, the first named object was the same for both distances (e.g., "flowers–bench"/"flowers–hedge"). The 58 items were arranged in random order to constitute List 1, but the same distance could not occur in three successive items, and no more than three items requiring the same response could occur consecutively. List 2 was constructed by reversing the order of the two distances in each pair (e.g., "flowers–bench"/"flowers–hedge" was replaced by "flowers–hedge"/"flowers–bench"). Half of the

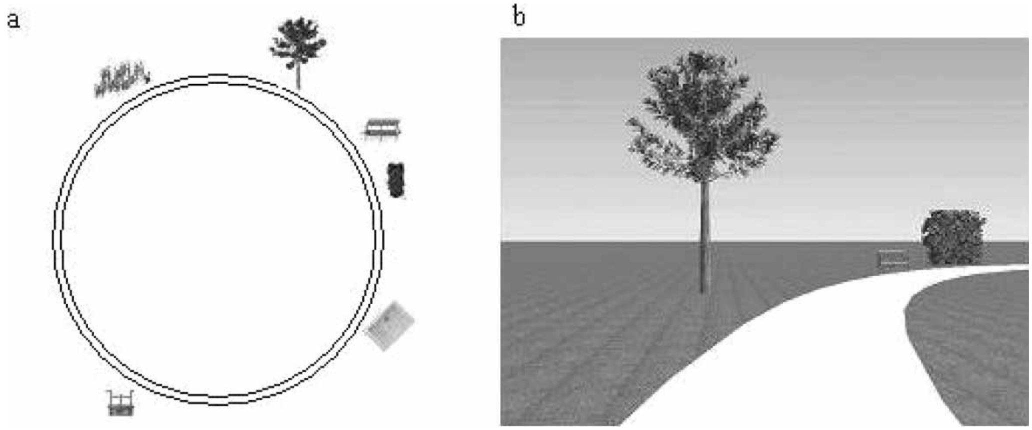

Figure 1. *(a) Map view of the circular garden with six objects, as shown to the participants in the visual–survey condition, and (b) perspective view taken along the video journey around the garden, as shown to the participants in the visual–route condition.*

participants in each condition received a tape-recorded version of List 1, and the other half received List 2. In each of the lists, the items were classified into three subsets, depending on the magnitude of the difference between the two distances to be compared (see Denis & Zimmer, 1992). The first set of items (small differences) comprised 17 items involving distance differences of less than 2.60 cm on the map of the garden. The second set (medium differences) included 21 items involving medium distance differences (between 2.60 cm and 5.20 cm). The third set (large differences) comprised 20 items involving distance differences of more than 5.20 cm.

Procedure

The participants received their instructions and carried out practice trials before the main experimental phase.

Learning. In the visual–survey condition, the participants were told the names of the six objects orally before studying the map for one minute. In the visual–route condition, the participants were also told the names of the objects and were shown the video of the tour around the garden; the video was shown three times. In the verbal–survey condition, the participants were given a description of the map of the garden; the text was read aloud by the experimenter three times. In the verbal–route condition, the participants listened to a tape recording of an oral description of the tour around the garden, which was played three times. Preliminary tests had revealed that three learning trials were necessary, except in the case of the visual–survey condition. For each learning condition, the participants were invited to create a visual image that was as vivid and accurate as possible.

Test. Following the learning phase, all the participants completed the same mental distance comparison task. They were told that each trial would consist first of hearing a tape giving the name of two objects. They would then have to form a visual image of the garden map, and then focus on the straight-line distance separating the two objects named. They would then hear the names of two objects defining another distance. They were invited to visualize the newly specified straight-line distance, and then to compare it with the first one. The participants were required to respond by pressing the "1" key on a response box if the first distance was longer and the "2" key if the second distance was longer. They were asked to use two fingers of their dominant hand to respond. The participants' responses were recorded via the computer.

Results

Preliminary analyses of variance (ANOVAs) of the frequency of correct responses and the times of the correct responses were performed with gender (men vs. women) and list (List 1 vs. List 2) as between-participant factors. Neither analysis revealed any significant main effect or interaction. Mixed ANOVAs were then performed with modality (visual vs. verbal) and perspective (survey vs. route) as between-participant factors, and magnitude of differences (small vs. medium vs. large) as within-participant factor.

Frequency of correct responses

Figure 2a shows the mean frequency of correct responses for each condition. The correct response rate was higher after visual (.83) than verbal (.78) learning, but the difference was not statistically significant. The analysis revealed a significant overall effect of perspective, $F(1, 44) = 4.86$, $p < .05$, with survey (.83) better than route (.77), and of magnitude of differences, $F(2, 88) = 69.77$, $p < .001$, with performance increasing as the difference between the distances compared increased (small differences, .72; medium differences, .81; large differences, .89). The frequency of correct responses was significantly smaller for small than for medium differences, $F(1, 44) = 37.04$, $p < .001$, and smaller for medium than for large differences, $F(1, 44) = 41.16$, $p < .001$. Planned comparisons showed that the effect of magnitude of differences was similar in each Modality × Perspective condition. Finally, there was no indication of any interaction among the various factors.

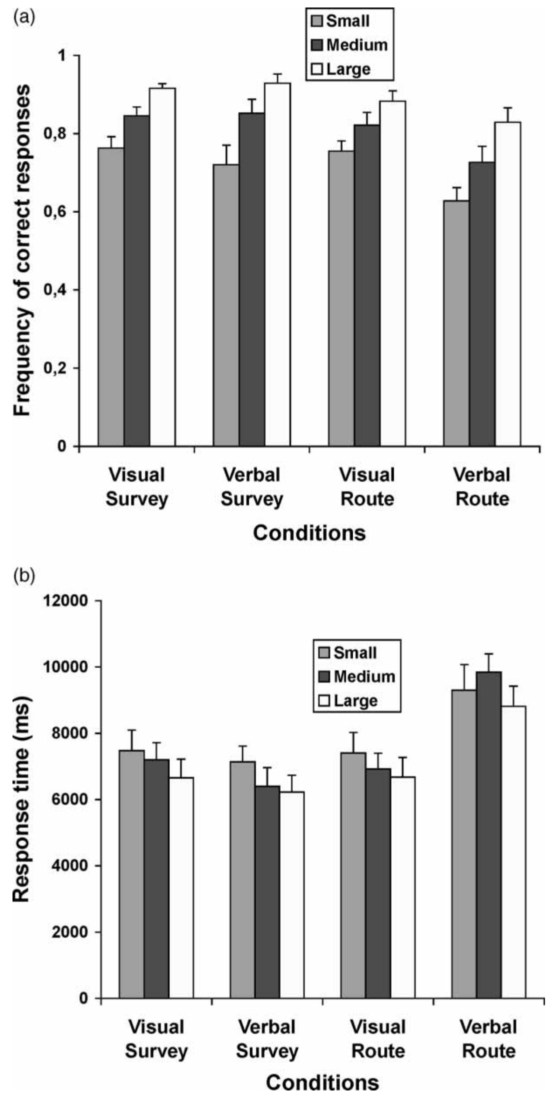

Figure 2. *(a) Mean frequency of correct responses and (b) mean response times (ms) as a function of conditions and magnitude of differences (small, medium, large) in Experiment 1. Error bars indicate* SE*s.*

Response times

Figure 2b shows the mean response times for each condition. An ANOVA revealed significant effects of modality, $F(1, 44) = 6.89$, $p < .01$, with more rapid responses after a visual (6,795 ms) than after a verbal (8,227 ms) presentation, of perspective, $F(1, 44) = 5.67$, $p < .05$, with more rapid responses after the survey (6,862 ms) than the route (8,161 ms) perspective, and of magnitude of differences, $F(2, 88) = 9.95$, $p < .001$, with times decreasing as the difference between the distances being compared increased (small differences, 7,839 ms; medium differences, 7,592 ms; large differences, 7,105 ms). Planned comparisons revealed that responses times for small differences did not differ significantly from those for medium differences, but that those for medium differences did differ from those for large differences, $F(1, 44) = 14.98$, $p < .001$. Moreover, the effect of the magnitude of differences varied for the different learning conditions. Under the survey conditions, response times were different only between the two extreme differences (i.e., small and large). Under the visual–route condition, magnitude of differences had no significant effect. Under the verbal–route condition, response times were different only between medium and large differences. Finally, there was no indication of any interaction among the factors.

Additional analyses

Further analyses of the response times were conducted in order to investigate the possible involvement of mental scanning in the process of distance comparison. To do this, we considered the subset of items involving the short and long distances only (all these data corresponded to the estimates of small distance differences). The aim was to find out to what extent response times were related to the absolute lengths (short or long) of the pairs of distances being processed. Table 1 shows the corresponding data. An ANOVA was conducted on response times with modality and perspective as between-participant factors, and distance length (short or long) as within-participant factor. No significant effect of modality or of distance length was demonstrated, but once again a perspective effect was observed, $F(1, 44) = 3.94$, $p < .05$, with the survey perspective (7,200 ms) resulting in faster responses than the route perspective (8,525 ms). Moreover, there was a significant interaction between modality and perspective, $F(1, 44) = 4.04$, $p < .05$. Post hoc tests (Tukey) revealed that for the route perspective, responses times were shorter after the visual than after the verbal modality, whereas no such difference was found for the survey perspective.

A second question was related to the possible effect of the angle between the two segments to be compared. In the case of a small angle between two slightly different distances, the ends of the segments are very close to each other, which could make it easier—and thus faster—to compare the distances. Conversely, when the angle between two distances is large, the comparison may be more difficult and may thus take longer. In order to check for this possible effect, times were averaged over participants in each condition, and the correlation between times and angles (ranging from 7° to 157°) was calculated from the data of each of the four groups. No significant correlations were found between response times and angles.

Discussion

Clearly, the distance comparison task yielded a more contrasting pattern of effects than did mental scanning (Chabanne et al., 2004). First, regardless of the modality of acquisition (visual or verbal), the survey conditions led to higher frequencies of correct responses than did the route conditions. Second, response times were

Table 1. *Mean response times[a] and standard errors for short and long distances under each condition in Experiments 1 and 2*

	Experiment			
	1		*2*	
	Short	*Long*	*Short*	*Long*
Visual–survey	7,019 ± 565	7,723 ± 1,051	9,228 ± 784	8,862 ± 607
Verbal–survey	7,973 ± 662	6,085 ± 434	9,967 ± 902	9,767 ± 746
Visual–route	7,510 ± 654	7,199 ± 857	10,007 ± 785	10,640 ± 723
Verbal–route	9,360 ± 760	10,030 ± 825	11,049 ± 942	10,287 ± 642

[a]In ms.

shorter in the visual than in the verbal groups, and those in the survey groups were shorter than those in the route groups. An overall effect of the magnitude of the differences to be estimated was found for both dependent variables. More errors and longer times were observed when small differences had to be processed, and fewer errors and shorter times were found for large differences. Taken together, these findings suggest that the representations resulting from all learning conditions contain the metric properties of the original configuration.

However, more detailed statistical analyses revealed that this general interpretation did not apply similarly to all conditions and for both dependent variables. Planned comparisons showed significant differences in response times between small and medium differences, on the one hand, and large differences, on the other hand. Detailed within-group analyses revealed that the distance effect was more clearly demonstrated in the frequency of correct responses than in the chronometric data. For this latter variable, no difference was found between the three categories of distances in the visual–route condition. In addition, the response times of the verbal–route group did not match the progressive decrease with the magnitude of differences observed in the other groups. Thus, it can be concluded that the representations in both route groups were less accurate than those of the survey groups, which is consistent with the overall effect of perspective. Moreover, although no interaction was found between modality and perspective, the present data, in particular the lack of difference between the two survey conditions, suggest that the statistically significant main effects of modality and perspective were predominantly attributable to the poor performance of the verbal–route group.

The additional analyses contrasting response times for short and long distances (within the category of slightly different pairs) confirmed the superiority of the survey over the route conditions. Furthermore, the modality of learning affected response times in the route conditions. This suggests that in the most difficult tests (those involving small distance differences), learning via the visual modality made it easier to process a representation constructed on the basis of route information. This interaction did not emerge from the analysis including the three categories of distance differences. Lastly, there was no indication of any involvement of the scanning process in the distance comparison task.

EXPERIMENT 2

In Experiment 1, the distances to be compared had the same starting points (cf. Denis & Zimmer, 1992). This may have facilitated the task by leading the participants to focus their attention on just one of the extremities of a given distance. In Experiment 2, the four locations defining the pairs of distances to be compared were totally distinct. Moreover, in some cases, the pairs of distances intersected. Increasing the difficulty of the task was expected to demonstrate the respective effects of the experimental variables more clearly. The contrast between the visual and the verbal conditions and the contrast between the survey and the route conditions could therefore be expected to be more marked than those in the previous experiment.

Method

Participants

A total of 40 new participants, 20 women and 20 men, all undergraduate and graduate students, were recruited for this experiment. They were between 18 and 30 years of age (mean = 22.4, *SD* = 3.3), with normal or corrected-to-normal vision. Each participant was randomly assigned to one of the four conditions used in Experiment 1, with equal numbers of men and women in each group. All participants were paid for participating in the study and were unaware of the purpose of the experiment.

Materials

The materials were the same as those used in Experiment 1: Two modalities of acquisition (visual and verbal) were crossed with two presentation perspectives (survey and route). For the tests, a list of all the distances between pairs of objects was prepared, including the two possible formulations of each distance (e.g., "flowers–bench" and "bench–flowers"). The comparison task consisted of 58 pairs of distances. Pairs were formed on the basis of different first-named objects (e.g., "flowers–bench"/"well–hedge"). The segments of 24 pairs intersected and those of the remaining 34 pairs did not. The 58 items were arranged in random order to constitute List 1, with the constraints that the same distance could not occur three times in three successive items and that no more than three items requiring the same response could occur consecutively. List 2 was constructed by reversing the order of the two distances in each pair (e.g., "flowers–bench"/"well–hedge" was replaced by "well–hedge"/"flowers–bench"). Half of the participants in each condition received List 1, and half received List 2. In each of the lists, the items were divided into three subsets, depending on the magnitude of the difference between the two distances to be compared. As in Experiment 1, the first set of items (small differences) comprised the 17 items involving the smallest distance differences. The second set (medium differences) included 21 items involving the medium distance differences. The third set (large differences) comprised the 20 items involving the largest distance differences. The proportion of pairs of distances that intersected was equivalent in each subset of items.

Procedure

The procedure was similar to that of Experiment 1. After the learning phase, participants in all four condition groups were given the same mental comparison task.

Results

Preliminary ANOVAs of the frequency of correct responses and the times of the correct responses were performed with gender (men vs. women) and list (List 1 vs. List 2) as between-participant factors. Neither analysis revealed any significant main effect or interaction. Mixed ANOVAs were then performed with modality (visual vs. verbal) and perspective (survey vs. route) as between-participant factors and magnitude of differences (small vs. medium vs. large) and intersection (intersecting vs. nonintersecting segments) as within-participant factors.

Frequency of correct responses

Figure 3a shows the mean frequency of correct responses for each condition. The analysis revealed a significant overall effect of modality, $F(1, 36) = 4.46$, $p < .01$, with better performance for visual (.73) than for verbal (.65), of perspective, $F(1, 36) = 8.96$, $p < .01$, with better performance for survey (.74) than for route (.63), and of magnitude of differences, $F(2, 72) = 18.41$, $p < .001$, with performance improving as the difference between the distances being compared increased (small differences, .59; medium differences, .72; large differences, .76). Planned comparisons revealed that the frequency of correct responses was lower for small than for medium differences, $F(1, 36) = 23.92$, $p < .001$, but the difference between medium and large differences was not significant. There was no difference between the frequency of correct responses for intersecting and nonintersecting segments (.68 and .69, respectively).

The effect of magnitude of differences varied depending on the learning condition. In the visual–survey condition, the frequency of correct responses was smaller for small than for medium differences, and smaller for medium than for large differences. In the verbal–survey and in the visual–route conditions, the frequency of correct responses was smaller for small than for medium or large differences. In the verbal–route condition, there was no effect of magnitude of differences: The frequency of correct responses was always close to random.

Two interactions were significant. The first one was the Modality × Perspective interaction, $F(1, 36) = 9.91$, $p < .01$. Post hoc tests (Tukey) revealed that in the route perspective the frequency of correct responses was higher for the visual than for the verbal modality, whereas it was equivalent for the two modalities in the survey perspective.

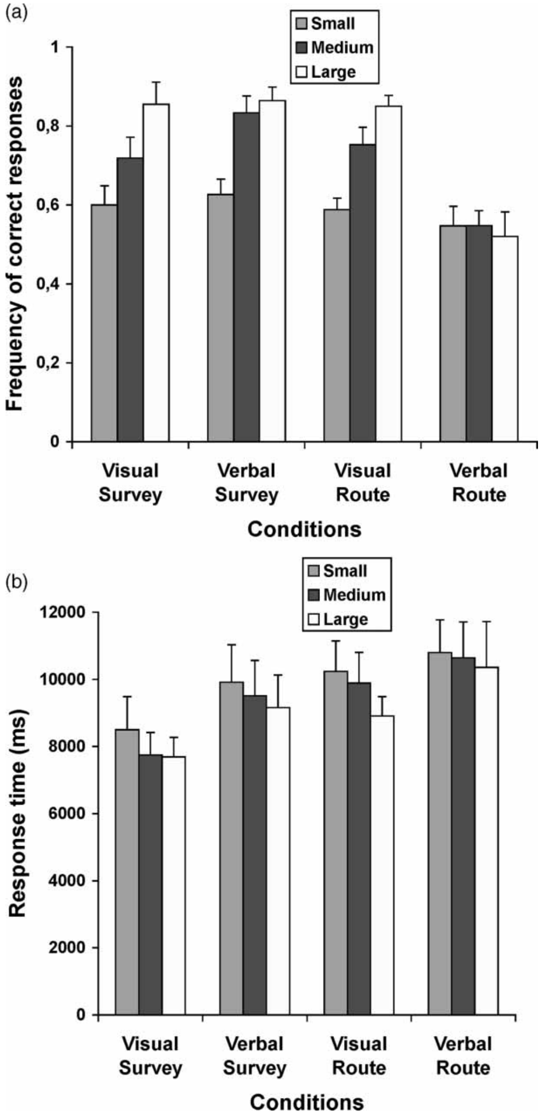

Figure 3. *(a) Mean frequency of correct responses and (b) mean response times (ms) as a function of conditions and magnitude of differences (small, medium, large) in Experiment 2. Error bars indicate* SE*s.*

The second significant interaction involved modality and magnitude of differences, $F(2, 72) = 6.07$, $p < .005$. Post hoc tests showed that the frequency of correct responses was higher for the visual than for the verbal modality for the large differences only.

Response times

Figure 3b shows the times taken to produce correct responses for each condition. The ANOVA revealed a main effect of only one factor—namely, magnitude of differences, $F(2, 72) = 3.14$, $p < .05$, with times decreasing as the difference between the distances being compared increased (small differences, 9,857 ms; medium differences, 9,456 ms; large differences, 9,038 ms). Planned comparisons showed a significant difference only between the two extremes (i.e., small vs. large), $F(1, 36) = 4.62$, $p < .05$. Finally, the Modality × Intersection interaction was significant, $F(1, 36) = 6.02$, $p < .02$. Tukey tests showed that response times were significantly shorter for the visual than for the verbal modality when segments intersected ($p < .001$), but that the two modalities did not differ from each other when the segments did not intersect.

Additional analyses

As in Experiment 1, additional analyses were conducted in order to find out whether mental scanning of the whole length of segments was involved in the distance comparison task. We considered only the set of items involving the estimates of differences between short or long pairs of distances (these data corresponded to small distance differences). Table 1 shows the corresponding data. An ANOVA was conducted on the response times with modality and perspective as between-participant factors and intersection and distance length (short or long) as within-participant factors. No significant main effects or interactions were found.

Comparison of Experiments 1 and 2

In order to examine the possible impact of having the same or different starting points for the pairs of distances to be compared (in Experiments 1 and 2, respectively), an ANOVA with modality (visual vs. verbal), perspective (survey vs. route), magnitude of differences (small vs. medium vs. large), and type of test (same vs. different starting points) as factors was performed on the two variables.

Table 2 shows the mean frequency of correct responses. As expected, significant effects were found for modality, $F(1, 80) = 6.81$, $p < .01$, with better performance after the visual presentation (.78) than after the verbal one (.72), and for perspective, $F(1, 80) = 16.07$, $p < .001$, with the survey perspective (.79) resulting in better performance than the route one (.70). There was an overall significant effect of magnitude of differences, $F(2, 160) = 86.13$, $p < .001$, with performance increasing as the difference between the distances being compared increased (small differences, .65; medium differences, .76; large differences, .83). The frequency of correct responses was significantly smaller for small than for medium differences, $F(1, 80) = 58.04$, $p < .001$, and smaller for medium than for large differences, $F(1, 80) = 34.47$, $p < .001$. Lastly, a significant effect was found for type of test, $F(1, 80) = 25.99$, $p < .001$, performance being better in Experiment 1 (same starting point, .80) than in Experiment 2 (different starting points, .69). There were three significant interactions. The first was the Modality × Perspective interaction, $F(1, 80) = 14.92$, $p < .001$. Post hoc tests (Tukey, $p < .05$) confirmed that performance in the verbal–route group was less good than that in the other three groups, which were all equivalent. Second, the Modality × Magnitude of Differences interaction was significant, $F(2, 160) = 3.66$, $p < .05$. Post hoc tests indicated that for the comparison involving small and medium differences, performance was similar in the visual and verbal groups, whereas the visual groups outperformed the verbal groups for the comparisons involving large differences. Third, the Perspective × Magnitude of Differences interaction was significant, $F(2, 160) = 3.71$, $p < .05$. Post hoc tests revealed that for the comparisons involving small and medium differences, the survey and route groups were equivalent, while the survey groups outperformed the route groups for the comparisons involving medium and large differences.

Table 2 shows the times for correct responses. As expected, an ANOVA of these data revealed significant effects of modality, $F(1, 80) = 8.04$, $p < .01$, with faster responses after visual (7,792 ms) than after verbal (9,211 ms) learning, and of perspective, $F(1, 80) = 8.38$, $p < .001$, with faster responses after the survey (7,777 ms) than after the route perspective (9,226 ms). There was an overall significant effect of the magnitude of differences, $F(2, 160) = 8.40$, $p < .001$, with times decreasing as the difference between the distances being compared increased (small differences, 8,834 ms; medium differences, 8,543 ms; large differences, 8,128 ms). Response times were longer for small than for medium differences, $F(1, 80) = 3.31$, $p < .07$, and also longer for medium than for large differences, $F(1, 80) = 6.48$, $p < .001$. Lastly, a significant effect was found for the type of test, $F(1, 80) = 15.67$, $p < .001$, with shorter response times for Experiment 1 (same starting point, 7,511 ms) than for Experiment 2 (different starting

Table 2. *Mean frequency of correct responses and mean response times*[a] *and standard errors under each condition in Experiments 1 and 2*

	Experiment			
	1		*2*	
	Frequency	*Response time*	*Frequency*	*Response time*
Visual–survey	.83 ± .02	6,589 ± 567	.72 ± .05	7,858 ± 744
Verbal–survey	.84 ± .04	7,135 ± 516	.77 ± .04	9,528 ± 1,045
Visual–route	.82 ± .03	7,002 ± 564	.73 ± .03	9,720 ± 796
Verbal–route	.73 ± .04	9,230 ± 645	.54 ± .05	10,860 ± 1,138

[a]In ms.

points, 9,491 ms). There was no interaction between these factors.

Discussion

The objective of Experiment 2 was to introduce a variant likely to make comparing distances a more demanding task. This was done by having the two distances to be compared start at different points. The absence of a common starting point was expected to make the comparison process more costly. The lower frequencies of correct responses and the longer response times obtained attested that this was actually the case. This effect was found regardless of whether the distances to be compared intersected or not. The patterns obtained in Experiment 1 were confirmed overall, with performance increasing, and response times decreasing as the difference between the distances being compared increased. In addition, as expected, better performance for the survey rather than the route conditions was confirmed. Furthermore, a similar superiority of the visual over the verbal condition was observed in the route groups, but only when there were large differences between the distances to be compared. Finally, response times were shorter in the visual groups when the segments to be compared intersected.

Within-group analyses revealed some nuances in the above findings. First, the distance effect was clearly confirmed for the rate of correct responses for all conditions but one, the verbal–route condition. In this condition, not only were the scores similar for all three categories of distance differences (Figure 3a), but also the performance level was random (about 50% of correct responses). Second, although an effect of magnitude of differences appeared in all groups (Figure 3b) and was confirmed by the overall ANOVA, within-group analyses did not yield a statistically significant effect for any group taken individually. Lastly, the additional analyses did not provide any indication that mental scanning was involved in the distance comparison process.

Moreover, the comparison of Experiments 1 and 2 confirmed that when the segments to compare were disjointed, regardless of whether they intersected or not, the task was more difficult than when the segments shared the same starting point. Lastly, the statistical analysis of the combined data from the two experiments revealed main effects and interactions that did not emerge as clearly from separate analyses. In particular, a clear symbolic distance effect was found for the visual groups and for the survey groups, which confirms the special difficulty of participants in the verbal–route group to construct a representation conveying the precise metric features of the configuration.

GENERAL DISCUSSION

The mental scanning and mental distance comparison paradigms have been successfully used as tools for assessing the analogue features of mental images of visual configurations and their verbal descriptions (Denis & Kosslyn, 1999; Denis & Zimmer, 1992). In the present study, the mental comparison of distances was used in order to determine whether mental spatial representations constructed from the visual experience or from the description of a journey through a three-dimensional spatial layout have similar analogue metric properties as those resulting from the visual examination or the description of a two-dimensional physical map. To do this, four learning conditions were designed by combining two factors: the modality of acquisition (visual presentation or verbal description) and the perspective of presentation (survey or route). The two experiments used the same learning conditions, but the difficulty of the distance comparison test was greater in Experiment 2 than in Experiment 1. In Experiment 1, the conventional paradigm was used (where the two distances to be compared had the same starting point), whereas in Experiment 2, the two distances did not share the same starting point and, in some cases, intersected with each other.

Overall, the results of Experiment 1 showed that responses were related to the metric features involved in the comparison of distances. The frequency of correct responses was related to the magnitude of the differences between the distances to be compared. Though less marked, a consistent pattern of data was observed for the response times, which were longer when small differences had to be detected, and, conversely, shorter for large differences (reflecting the symbolic distance effect). As expected, the perspective from which participants had acquired their knowledge of the configuration had a strong impact on performance. First, the frequency of correct responses was higher, and response times were shorter, when the configuration was presented from a survey perspective than when participants visually travelled around it or listened to the description of that journey. Within-group analyses of the chronometric data revealed that in both route groups, the distance effect either was not significant (visual–route group) or did not share the same hierarchy as the other groups (verbal–route group). Second, visual acquisition elicited shorter response times than verbal descriptions (in particular for small differences under the route conditions), but the frequencies of correct responses were not significantly affected. These data are in agreement with previous studies showing that performance associated with the visual examination of a map is better than when a verbal description of that map is used (Denis & Cocude, 1989; Perrig & Kintsch, 1985). Visual experience makes it possible to create representations where metric information is more readily accessible than in representations constructed from verbal descriptions.

Similarly, the overall pattern of data from Experiment 2, in which the task was made more difficult by using pairs of distances that did not start from the same point and in some cases intersected, revealed a symbolic distance effect. The visual modality of acquisition and the survey perspective also had, independently, positive effects on the rate of correct responses. Statistically significant interactions revealed that the beneficial effect of visual learning was mainly related to the route condition of acquisition, in the case of large differences of distances. However, in contrast to Experiment 1, the visual or verbal modalities of acquisition did not significantly affect response times, except in one case for the visual modality, where response times were shorter when the segments to be compared intersected. Within-group analyses of the rate of correct responses revealed a symbolic distance effect for all learning situations except for the verbal–route condition.

The specific pattern of data of the verbal–route group in both experiments deserves further discussion. The increased difficulty of the task in Experiment 2 resulted in a level of performance close to random (which contrasted with Experiment 1), together with response times unrelated to the magnitude of distance differences. The error rate was close to random, even for large distance differences. Admittedly, in such cases, the need for a fine metric representation is not as imperative as for small and medium differences. In addition, in Experiment 2, the verbal–route group was the only one for which no symbolic distance effect was detected at all, whether in terms of the frequency of correct responses or in terms of response times. Consequently, we are entitled to conclude that mental images constructed in the verbal–route learning condition only retain approximate metric properties of the configuration. This explains the relatively poor performance of this group in Experiment 1 and the inability to perform the task when the situation was made more difficult in Experiment 2.

Unexpectedly, although the visual and the survey conditions had been shown independently to enhance performance, their combination never yielded especially high scores or low response times. In fact, the visual learning conditions had a beneficial effect when the tests were most difficult. This was the case in both route groups with regard to the rate of correct responses in Experiment 2. This was also the case for small differences with regard to the response times in Experiment 1. The beneficial effect of the visual condition was also evidenced when segments intersected with regard to the response times in Experiment 2. In the latter experiment, a similar effect (in terms of correct responses) was found in all four groups, but this was the case when the task was easiest—that is, for large differences.

There was no indication of any facilitating effect of the survey condition interacting with any other factor.

We were interested in the possible commonality of processing required by the scanning and the distance comparison paradigms. We reasoned that if distance comparison implied some form of scanning of the distances to be compared, then the greater their size, the longer the response times could be expected to be, regardless of the magnitude of the differences between them. The analysis conducted on the pairs of short versus long distances failed to indicate any effect of the absolute size of the items to be processed. Similarly, the distance between the ends of the segments did not appear to have any impact, since the angle formed by the two segments was not found to have any effect (Experiment 1). This suggests that although scanning and distance comparison both reflect metric properties of representations, they may not necessarily share the same mechanisms.

The paradigm of distance comparison appears to be a more discriminating tool for detecting the distinct effects of the learning conditions than the scanning experiment of Chabanne et al. (2004), in which the main finding was longer scanning times following route learning. In the present study, not only did the route perspective result in poorer performance in both experiments, but also this was true for the verbal modality of acquisition in Experiment 2, which also elicited longer response times than Experiment 1. The comparison of the two experiments revealed the difficulty of processing pairs of disjointed distances. In contrast, when the distances to be compared shared the same starting point, this had a facilitating effect on both the frequency of correct responses and the response times.

A noticeable advantage of the distance comparison paradigm over mental scanning is that one measure—the frequency of correct responses—reflects another interesting aspect of the processing. Traditionally, the demonstration of a symbolic distance effect is based on chronometric measures, with the frequency of correct responses being considered to be closely associated with these measures. The present data suggest that the performance level also reflects a symbolic distance effect. For instance, in Experiment 1, the chronometric data indicated that all three factors had an effect, whereas the positive effect of visual learning was not reflected in the frequency of correct responses. A different pattern emerged in Experiment 2, where the effect of the magnitude of differences was found significant only for response times, whereas the frequency of correct responses indicated that all three factors had an effect. Only under one of the experimental conditions of Experiment 2, the verbal–route condition, did within-group analyses of both correct responses and chronometric data fail to reveal any effect of the size of the distance differences. This strongly suggests that participants of this group had failed to construct an accurate representation of the configuration. Conversely, for the two survey groups in Experiment 1, the rates of correct responses and response times were found to be similarly affected by the two learning modalities. Such a result may be specifically due to a strong effect of the survey presentation that overshadowed the more subtle influence of the learning modalities.

An alternative possibility would be that the verbal–survey condition does not necessarily require the storage in the memory of a mental image of a circular garden with embedded objects. A simpler strategy would be to remember the clock face locations and just remember, for instance, that "the tree is at 1 o'clock". This would imply that at the time of retrieval, the verbal information is employed to construct a mental image of the garden, and distances are compared on the basis of this reconstruction. The fact that there was no difference between the visual–survey and verbal–survey conditions in either experiment supports this hypothesis. However, if such was the case, response times should have been longer in the verbal–survey condition (due to the additional time required to generate the image of the garden) than in the visual–survey condition. In fact, in Experiment 1, the significant main effect of modality on response times was due to the longer times in the verbal–route condition, but was not related to the survey conditions. In Experiment 2, modality had no effect on response times. Thus, the present data fail to confirm this alternative hypothesis.

The fact that the two variables (frequency of correct responses and response times) yielded different patterns of results in some cases may help to elucidate the cognitive processes implemented during the comparison task. Whilst the rate of correct responses reflects the metric accuracy of the representations, the chronometric measure is likely to reflect the time required both to access the representations and to perform the comparison task. The latter process is partly reflected by the hierarchy related to the magnitude of differences of the distances to be compared. In contrast, the former process is best reflected by the absolute durations. The metric accuracy of represented information may vary considerably depending on the nature of the learning situation. In the present study, visual mental representations originating from a visual input (as in the visual–survey condition) were easier to generate than representations based on verbal descriptions, given the similarities between the initial and final formats. In contrast, the generation of images from verbal descriptions (verbal–survey condition) or from travelling in a three-dimensional environment (visual–route condition) required the transformation of the original stimuli into an analogue visual format. The visuo-spatial working-memory literature has documented the capacity of the cognitive system to implement such interformat translations (e.g., Baddeley & Hitch, 1974; Deyzac, Logie, & Denis, in press; Logie, 1995; Pazzaglia & Cornoldi, 1999; Pearson, 2001), and imagery research has provided evidence that these translations may result in functionally equivalent representations, but with a cost which is generally reflected by extra learning time (cf. Denis & Cocude, 1992; Denis et al., 1995).

When a symbolic distance effect on both the rate of correct responses and response durations is detected, it can reasonably be concluded that the mental representation conveys the metric properties of the actual situation. On the other hand, when the error rate is close to that of random, response times may not be meaningfully related to any metric representation of the distances or the assessment of their metric properties (as in the verbal–route condition, Experiment 2). However, if the frequency of correct responses alone reflects the hierarchy of the magnitude of differences (as in Experiment 2, for the visual–survey, verbal–survey, and visual–route conditions), it can be argued that a variable measuring the accuracy of the representation is more reliable than the time necessary to generate and process the corresponding visual mental image.

In conclusion, the main finding of the present study is that representations constructed through various modalities and perspectives contain genuine metric properties, except when the verbal modality and the route perspective are combined in the acquisition phase. In the other three conditions examined here, spatial information can be embodied in visual images that have the specific property of representing metric distances, which in turn affects the chronometric characteristics of the processing of these images. The more the learning situation departs from a visual experience, and the more it implies a route perspective, the more difficult it is to construct a representation including accurate metric information and to access that information within the representation. Future research should investigate why the particular task demands resulting from the verbal–route context make Euclidean representations so hard to maintain and/or to access.

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