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THE MENTAL COMPARISON OF DISTANCES IN A VERBALLY DESCRIBED SPATIAL LAYOUT: EFFECTS OF VISUAL DEPRIVATION*

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ABSTRACT

In this study, we investigated the metric properties of spatial representations built from the verbal description of a spatial layout in early blind, late blind, and transiently visually deprived sighted participants. We adapted the verbal descriptions designed by Denis and Zimmer [1]. Participants had to mentally compare distances separating pairs of landmarks. The analysis of the frequency of correct responses suggests that visual experience does not play a crucial role in the preservation of the topology of a memorized spatial configuration. However, response times differed significantly among groups, with participants who experienced transient visual deprivation being overall faster than those suffering permanent loss of vision. Lastly, for all groups, the smaller the difference between two pairs of distances, the longer the response time, which attests to the presence of a symbolic distance effect. To conclude, if mental representations can be considered as reflecting described spatial layouts analogically, our data do not provide any strong evidence in favor of the visual character of these analog representations.

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INTRODUCTION

It is well established that verbal or perceptual learning of a spatial layout may induce the generation of mental representations endowed with metric properties that make them structurally isomorphic to the original spatial configurations [2, 3]. The main paradigms used to demonstrate this isomorphism are those based on mental scanning and the mental comparison of distances (for a review, see [4]). The mental scanning paradigm, originally devised by Kosslyn, Ball, and Reiser (1978) [5], consists in inviting participants to first memorize a spatial configuration, then to perform mental scanning between pairs of landmarks. The analysis of chronometric data typically shows that the greater the distance separating two points, the longer the corresponding scanning time, thus supporting the claim that a structural isomorphism exists between visual images and their physical counterparts (for a review, see [4-6]). The metric properties of visual images were also analysed in tasks where participants compare distances mentally. The results consistently showed a strong symbolic distance effect, that is, the time to process small differences between two given distances is longer than the time to process large differences [1, 7].

Both experimental paradigms have led the authors to postulate that participants construct a mental representation of the metric parameters of an object or an environment, whether these have been processed from visual or verbal information [3, 7]. These data strongly suggest the structural isomorphism between mental representations and described spatial layouts. As a consequence, mental representations can be thought to have a real visual component.

Studying the spatial mental representations of the blind from birth is an appropriate approach to assess the role of vision in shaping the visual properties of mental representations. A large number of studies suggest that early visual experience is not a pre-requisite for the acquisition of spatial concepts (for a review, see [8-10]). Indeed, blind people are able to mentally generate and correctly manipulate objects, even though an early experience of vision facilitates the generation and use of mental images [11-15].

Only few data have documented how visual experience influences the metric properties of mental representations of space. Kerr was the first author who collected such data with a mental scanning task [16]. She reported a strong positive correlation between scanning times and the length of mental travels, for both the sighted and the blind (from birth or later). Nevertheless, the time needed for the blind was significantly longer than for blindfolded persons. This result corroborates the finding that the blind as well as the sighted can generate and manipulate spatial representations, although with distinct time patterns. In contrast, Röder and Rösler showed that the chronometric performance did not differ in blind and blindfolded persons [17]. They used another mental scanning paradigm, involving haptic learning of the configuration. However, Kerr's [16] and Röder and Rösler's [17] results remain contradictory. The purpose of our experiment was to shed light on the effect of various degrees of visual deprivation on the metric properties of mental representations. We used the paradigm of mental comparison of distances [1], with a verbal description, adapted to persons suffering from a visual impairment, congenitally blind, late blind, and also blindfolded sighted participants.

MATERIALS AND METHODS

Participants

Twenty-seven participants were selected. All the participants had many hobbies and were active and autonomous. Each one belonged to one of three groups: congenitally blind (totally blind from birth, four due to glaucoma, two due to pigmentary retinite, one due to malnutrition, and two whose origin remains unknown), late blind (becoming blind between 6.5 and 30 years, mean: 17 years old), and blindfolded sighted. A matching was performed between the participants of the three groups, according to their gender, educational and socio-cultural levels, and age (at most 10 years of difference). Each group comprised five men and four women (from 23 to 63 years old).

Materials

The materials used in the experiment were adapted from those created by Denis and Zimmer [1]. In the training phase, a relief map of France (presented horizontally on a wood plank) was used. Six cities were located at its periphery (Brest, Dunkerque, Strasbourg, Nice, Marseille, and Bordeaux). After two practice trials, a list of four comparisons between two pairs of cities, where the first city named was common to the two pairs, was used for the purpose of training the participants.

In the main part of the experiment, a map of a circular island (iron-made disk presented vertically, 50 cm in diameter) was used. Six tags representing six geographical landmarks were fixed at the periphery of the disk. All distances between pairs of adjacent landmarks differed from each other. In the corresponding description of the island, the positions of the landmarks were described according to the conventional directions used in aerial navigation. The description 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 1:00, there is a lighthouse. At 2:00, there is a creek. Equidistant from 2:00 and 3:00, there is a hut. At 4:00, there is a beach. At 7:00, there is a cave.”

For the comparison task, the two distances of a pair had their first mentioned landmark in common (e.g., “harbor-beach”/“harbor-hut”). Two specific comparisons involving two equal distances were excluded (“hut-lighthouse”/“hut-beach” and “beach-cave”/“beach-lighthouse”). A list of 58 pairs of landmarks was constructed, including two possible formulations for each distance (e.g., “harbor-beach” and “beach-harbor”). The 58 items were arranged in a random sequence in order to create a first list (List 1), where each pair appeared only once. In List 2, the same items as in List 1 were proposed in the reverse order (e.g., “harbor-beach”/“harbor-hut” was replaced by “harbor-hut”/“harbor-beach”).

Procedure

In the training phase, the experimenter presented the relief map of France to the participants, and asked them to explore it haptically and to mentally create a representation as vivid and accurate as possible. The map was then removed and the participants had to perform mental comparison of distances between pairs of cities. Participants were invited to mentally focus on the distance separating two named cities. A few seconds later, they heard the name of two other cities. They were invited to compare this distance with the first one and to decide which one was the longest by pressing one of two buttons. After two practice trials, a list of four comparisons between two pairs of cities, where the first city named was common to the two pairs, was used. All the participants received the same list of items. This training phase was intended to ensure that the experimental task was well understood.

In the next phase of the experiment, participants heard a description of the map of a circular island, for which they had to create a mental representation as vivid and accurate as possible. The experimenter presented the disk that participants explored haptically for one minute. This was intended to provide a cue for the size of the mentally represented island. The disk was then removed. The description was presented using a pre-recorded voice, three successive times. Following each presentation, participants were required to focus on each geographical landmark in order to verify its exact location.

In the third phase of the experiment, participants had to perform the task of mentally comparing distances between pairs of landmarks. Participants heard the first pair of landmark names, and two seconds later, the second pair was presented. They were invited to create a mental representation of the two mentioned distances, to compare them to each other, and to decide which was the longest by pressing one of two buttons. The time interval between the completion of the second word of the second pair and the subsequent button press was recorded. This procedure was repeated until all test examples were presented. In this task, half of the participants received List 1 and half received List 2.

RESULTS AND DISCUSSION

The items were grouped into three subsets, depending upon the size of the difference between the two compared distances. The first set (Small differences, 17 items) included differences smaller than 8.6 cm. The second set (Medium differences, 21 items) included differences between 8.6 cm and 17.2 cm. The third set (Large differences, 20 items) involved differences larger than 17.2 cm. The smallest difference was that involved in comparing "cave-creek" and "cave-lighthouse" distances (2.0 cm); the largest one was for the comparison of "creek-cave" and "creek-hut" (43.5 cm).

Furthermore, when a participant's response time exceeded a given value (m + 1.5 sd), it was replaced in each category of difference size by the value of the mean response time plus 1.5 standard deviation (in average, between 4 and 5 changes on the 58 items, by group).

Dependent variables were analyzed using a two-factor analysis of variance (ANOVA), with Groups (Congenitally Blind, Late Blind, and Blindfolded Sighted) and Magnitude of Differences (Small, Medium, and Large) as independent variables. Post hoc Scheffé-*F* test comparisons were used when necessary, with a probability of 0.05 as a significant difference.

Figure 1 shows the frequencies of correct responses as a function of groups and of magnitude of distance differences. The analysis of correct responses revealed a significant effect of the magnitude of differences, $F(2, 48) = 50.62$; $p < 0.0001$, with performance steadily increasing from comparisons involving small differences to those involving larger ones. Post hoc Scheffé-*F* test comparisons indicated a significant difference between small and medium ($p < 0.001$), small and large ($p < 0.0001$), and medium and large ($p < 0.01$) differences. These results provide the first evidence that the three types of differences were not treated similarly.

The statistical analysis did not indicate any significant effect of groups, suggesting that blindness, whether from birth, later in life, or transient, did not alter

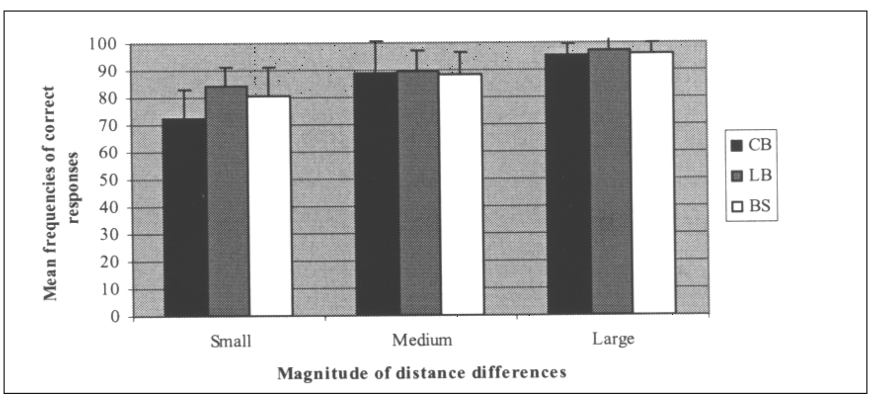

Figure 1. Mean frequencies of correct responses as a function of groups and magnitude of distance differences between pairs of landmarks.

the mental process of evaluating differences between pairs of distances. There was no significant interaction between groups and magnitude of differences.

Finally, the high level of performance of all groups, as well as the clear distance effect, provided arguments for the claim that the participants were able to generate a mental representation that genuinely incorporates metric information. This is an instantiation of the distance effect known to occur when representations derive from visual processing. The topological organization of the spatial layout described seems to be preserved in spite of blindness. These data suggest that visual experience may not have a crucial role in the ability to create a mental representation that preserves the topological organization of a spatial layout.

A further analysis was performed on the times needed by participants to perform the mental comparison of distances. This analysis involved only durations for correct decisions. Figure 2 shows the mean response times as a function of groups and of magnitude of differences. For the mean response times, the ANOVA revealed a significant effect of groups, $F(2, 24) = 3.49$; $p < 0.05$, and of magnitude of differences, $F(2, 48) = 34.35$; $p < 0.0001$. Post hoc Scheffé-*F* test comparisons revealed that the group effect was due to the difference between the late blind and blindfolded sighted ($p < 0.003$), and between blind from birth and blindfolded sighted ($p < 0.04$). There was no significant difference between the blind from birth and the late blind.

Moreover, a significant effect of the magnitude of differences was obtained. The results showed a significant difference between the processing time of small and medium ($p < 0.002$), small and large ($p < 0.0001$), and medium and large ($p < 0.01$) differences of distances. It thus appears that carrying out a mental comparison of distances where the difference between the two distances is small requires longer processing times than when differences are medium or large. The

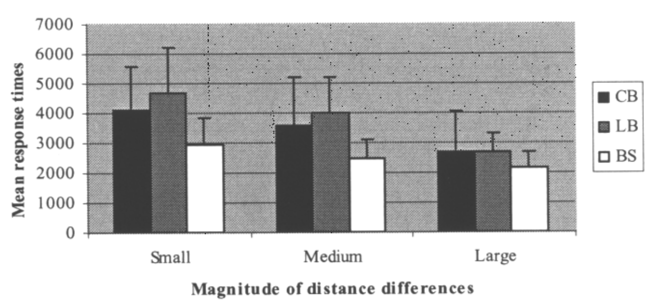

Figure 2. Mean response times in milliseconds as a function of groups and magnitude of distance differences between pairs of landmarks.

difference between blind (from birth and later) and the blindfolded tended to decrease steadily from small to large magnitude of differences, while a statistical analysis did not indicate any significant interaction between the groups and magnitude of distance differences. These results suggest that a visual experience may have a facilitating effect when the difference between two given distances is small, resulting in more difficulty to decide which one is the longest.

CONCLUSIONS

The main objective of the present work was to investigate the role of visual experience in the ability to mentally compare pairs of distances. The analysis of the frequencies of correct responses indicated that the topological organization and the metric relation between the objects composing a spatial layout were preserved in the mental representations constructed by the participants. The rates of correct responses ranged between 80% and 90% for each group of participants. This suggests that all participants built a correct representation of the described spatial layout. These data support the hypothesis that visual experience is not crucial to mentally represent the topology of an environment while preserving its metric properties. These results are consistent with a study by Carpenter and Eisenberg [8], who proposed a mental rotation task to blind people (from birth) and blindfolded sighted ones, and reached the same conclusions about the non-crucial role of the visual experience for preserving the topology of a spatial configuration. However, we may hypothesize that these results, having such high rates of correct responses, could be due to the fact that the task was not difficult enough, as such any possible differences were not discernable.

Lastly, our data offer clear evidence of a symbolic distance effect from the analysis of response times, and provide grounds for the claim that representations constructed by participants possess intrinsic properties that are isomorphic to those of physical spatial configurations. Moreover, the analysis indicates that the time to mentally process distances is longer for blind persons (from birth and later) than for the blindfolded ones, which suggests that definitive visual deprivation affects the way in which mental representations are processed.

Most of the studies on the mental representations of blind people have not provided evidence of strong differences between blind people (congenitally and late) and the blindfolded. Instead, studies usually indicate differences between the blind from birth, on the one hand, and people who have had sight (late blind or blindfolded), on the other hand [9, 18]. They suggest that sight in early stage of life is a crucial factor for evaluating distances. As regards the metric properties of mental representations, our data are in line with those of Kerr [16], who found, in a mental scanning task, that response times of the blind (from birth and later in life) significantly differed from those of the blindfolded. However, our results do not support the study by Röder and Rösler [17], who also used mental scanning, but in conjunction with haptic learning. Their study did not show any evidence of behavioral differences between the groups (congenitally blind or sighted), which suggests that visual experience is not essential for manipulating mental representations of spatial configurations.

We can also hypothesize that the modality under which an environment is learned affects the metric properties inferred by the participant about the spatial layout. In particular, if this modality happens to be more preferred by blind than by sighted participants, such as the haptic modality, the results obtained by Röder and Rösler [17] are easier to explain in comparison with our results and those of Kerr [16]. The fact that blind people are slower in our task may be accounted for by the hypothesis that sighted people directly access a visual representation of the spatial layout and thus only have to "look at" this representation in order to provide responses. In contrast, people without any visual experience have to translate the verbal information into a more informative (haptic) representation. This translation explains why congenitally blind participants need more time to perform the same task. Besides, our results are in line with those of several previous studies [1, 7]. They clearly indicate an effect of magnitude of differences, which confirms that mentally processing small differences in distance requires more cognitive effort than large differences. Our data also underscore that small differences of distances induce the highest frequencies of incorrect responses, but that such an effect is not related to differences in visual experience.

To summarize, the conclusions of studies that have interpreted the analog character of images as involving a visual component [1, 5, 19, 20] may need to be modulated. Our data show that the blind, and more specifically the blind from birth, can construct mental representations that preserve the metric properties of an environment, just as the blindfolded are able to do.

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