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The paper tests the hypothesis that difficulties met by the blind in spatial processing are due to the simultaneous treatment of independent spatial representations. Results showed that lack of vision does not impede the ability to process and transform mental images; however, blind people are significantly poorer in the recall of more than a single spatial pattern at a time than in the recall of the corresponding material integrated into a single pattern. It is concluded that the simultaneous maintenance of different spatial information is affected by congenital blindness, while cognitive processes that may involve sequential manipulation are not. *NeuroReport* 15:2787–2790 © 2004 Lippincott Williams & Wilkins.

Key words: Blindness; Spatial memory; Working memory

INTRODUCTION

It is a common-sense assumption that the absence of visual experience, in congenitally and totally blind individuals, produces severe cognitive consequences and, in particular, the inability to produce visuo-spatial mental images. In fact it is assumed that the generation of mental images representing visuo-spatial features requires the availability of visuo-spatial experiences. This assumption is also based upon the consideration that visual perception and visual imagery may share similar neurological substrates. This assumption has not, however, received empirical support [1–3]. A large body of experimental evidence [4–6], has shown that blind individuals may have representations, which are functionally equivalent to the visuo-spatial mental images of sighted individuals. Blind people present a similar pattern of performance as the sighted in tasks requiring mental rotation of objects, the use of imagery mnemonics and memory for spatial configurations: the offered explanation is that, in both groups, mental images emerge from the treatment of information coming from different sources, such as vision, but also movement, tactual exploration and so on. The fact that, aside from vision, all the other sources of information are available to blind people makes it possible for them to generate certain types of spatial representations on a par with sighted individuals. Recent neuroimaging data highlighted that blind people may use mental images in association with sensory modalities other than vision, with the involvement of both visual and somatosensory areas [7–9]. It is also possible to hypothesize the use of compensatory mechanisms related to the absence of vision [10]. These mechanisms may involve different neural substrates, which, in turn, determine the involvement of different cognitive structures and strategies [11,12] in the processing of visuo-spatial mental imagery.

However, some differences between blind and sighted people in mental imagery tasks have been found, with a poor performance associated with blindness [6,13]. Three main limitations in blind peoples' mental images concern the lower speed of processing mental images [14], the difficulty in generating interactive images involving more than one place and one object [15] and a significant impairment of performance when movements must be imagined across 3D rather than 2D configurations [16]. This evidence has been referred back to the distinction between passive storage (i.e., recall information in the same format as it was previously memorised) and active processing (e.g., requiring manipulation, transformation or integration of information) within visuo-spatial working memory [17], the assumption being that blind people should meet difficulties in the active, but not in the passive tasks. Another possibility is that these three limitations are related to a common feature, i.e. a requirement to simultaneously treat and maintain different visuo-spatial representations, the difficulty of which would result in an impaired ability to rapidly process spatial information, to simultaneously maintain images of different objects and to represent a spatial array at the same time both on a horizontal and on a vertical plane.

In conclusion, the evidence so far collected shows that the blind can have visuo-spatial images, but that these are affected by a series of limitations evidently due to the absence of the visual experience, however we are still in search of the factor underlying these limitations. The aim of the present study was to examine whether this factor could be related with the simultaneous treatment of multiple configurations. Simultaneous spatial processes in working memory have already been considered in the literature in the context of a differentiation between sequential and simultaneous spatial processes [18,19], but they have never

been related to the role of the visual experience or the case of blind people. Movement and tactual exploration are necessarily sequential and can convey spatial information mainly in a sequential manner, whereas vision may offer the possibility of simultaneous information processing. The hypothesis of a specific deficit of spatial simultaneous processing in the blind could, at least partially, explain results from the literature. In fact, limited simultaneous processing can determine a difficulty in generating and maintaining multiple interactive images. At the same time, cognitive processes may be slower when simultaneous elaboration is required and 3D patterns may require generation and treatment of more than one single 2D representation at the same time.

In order to test the hypothesis that the absence of visual experience in the blind produces a difficulty in the simultaneous treatment of different configurations, but not a difficulty in the treatment of a single configuration, in this study, we administered to a group of congenitally and totally blind individuals three different visuo-spatial tasks, matched for the quantity of the to-be-remembered information. In a first preliminary phase we compared performance of blind and matched sighted people in a simple task requiring the memorization of positions in a single 5×5 matrix, in order to collect further evidence of blind people's ability in dealing with a passive task requiring memory of a single configuration. In a second phase we contrasted the performance of the two groups in two different task-conditions. In a first condition (multiple matrices) participants were presented with two-matrix configurations and were then invited to separately recall the configurations in two identical blank matrices. In the second condition (integration matrix) the presentation of material was the same as in the first condition, but the target positions had to be remembered on a single matrix, thus offering the possibility for integration of the two presented matrices into a single pattern. Both the second and third condition involved a simultaneous presentation of stimuli. However in the latter participants were required to integrate all available information, hence the condition comprised a greater active load but a reduced passive storage requirement. These tasks already proved their validity in testing blind and sighted people's ability of remembering and manipulating visuo-spatial information [20]; in addition, it has already been demonstrated that blind and sighted people use similar, non verbal, strategies while carrying out these tasks [16]. If the blind people's difficulty is related to the simultaneous maintenance of two representations, they should manifest errors in the multiple matrices condition, but perform flawlessly in the other condition, by integrating information in a single representation. Other predictions could be given if the blind people's deficit is related to the difficulty of tactually exploring multiple configurations (in this case they should have a similar degree of difficulty in both modalities) or if they have a particular problem in integrating visuo-spatial information. This last hypothesis could be coherent with the idea of an overall active processing impairment in blind people, affecting the process of combining and/or integrating different information.

SUBJECTS AND METHODS

Participants: Sixteen congenitally and totally blind, 9 males and 7 females, aged between 18 and 62 years (mean age 28.5) and a control group of 16 sighted people, 7 males and 9 females, aged between 22 and 56 (mean age 33.7), matched for age and education. Visual handicap was never associated with a central neural disorder. Participants were totally blind and either congenital or with an early blindness, having appeared in the first months of life.

Materials and procedure: Participants were individually tested and sighted people were blindfolded in order to exclude any vision of the context and of the material. The test material was based on a 5×5 matrix made up of wooden cubes (4 cm/side). The interval between the cubes was $\sim$2 mm, such that the overall size of the matrix was 21×21 cm. Within each matrix different numbers of cubes were differentiated by covering them with sandpaper in order to allow them to be easily recognised by touch (target cubes). The participant had to give the responses by pointing to the target positions on similar matrices (blank matrices) where no position was covered with sandpaper.

The procedure consisted of two phases and involved also other tasks which are not presented here. Subjects were tested individually while seated in front of the experimenter. In the first phase, each participant was presented with single configurations with 4 target positions and single configurations with 6 target positions. Each configuration was presented for 10 s and both blind and blindfolded-sighted participants were asked to tactually explore the matrix in order to memorise the positions of the target cubes. Immediately after the presentation time, the participant was shown a blank matrix and was asked to tactually indicate the target cubes previously memorised (Fig. 1a).

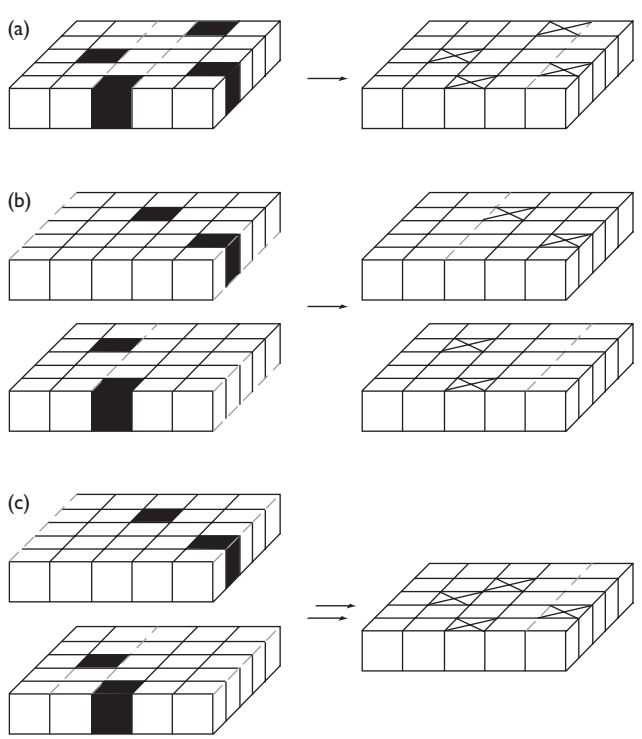

Fig. 1. Examples of tasks requiring the memorization and recall of single (**a**) and multiple (**b**) matrices or the integration of the targets in a single response matrix (**c**). Experimental stimuli may include four or six target positions either in a single matrix or divided into two matrices.

There were a total of 8 trials plus 2 practice trials and the session lasted ~10 min.

In the second phase (which followed the first phase, after a short interval), two task conditions were proposed. In the multiple matrices condition, the participant was presented with 2 configurations, each of them comprising 2 (4 trials) or 3 (4 trials) target cubes, and the participant was given 10 sec for exploring and memorising the target positions. Responses had to be given, at the end of the presentation, on two blank matrices, again by separately touching on the two matrices the positions previously occupied by the target cubes (Fig. 1b). In the integration matrix condition, the presentation was identical to the multiple matrix condition, but responses had to be given on a single blank matrix. Participants were explicitly required to integrate all target positions within a single matrix and then to tactually indicate them on a single blank response matrix (Fig. 1c). The order of presentation of these two conditions was counterbalanced, whereas all task trials with 4 target positions preceded trials with 6 positions. In the second phase, there were a total of 16 trials plus 4 practice runs and the session lasted ~20 min. Figure 1 shows a schematic example of the tasks.

RESULTS

All participants were able to meet the tasks' requirements. For each task we considered the percentages of locations correctly remembered by each participant.

Data on the first phase showed that blind people were as able as the sighted to remember the locations presented on a single matrix. Mean performances of the two groups were comparable and the difference favouring blind people was not significant (61.9% *vs* 61.5%; s.d. 21.2 and 17.1 for blind and sighted people, respectively).

In the second phase (see Fig. 2 for an overview of the data) the two groups performed in a very different manner. A three-way ANOVA for mixed design, groups (blind *vs* sighted) × condition (multiple *vs* integration) × complexity (4 *vs* 6 targets) only revealed a significant main effect due to complexity, $F(1,30)=11.38$, $Mse=113.29$, $p<0.05$, caused by the greater difficulty of the 6 target configurations when compared with the 4 target configurations (45.1% *vs* 51.5%, respectively).

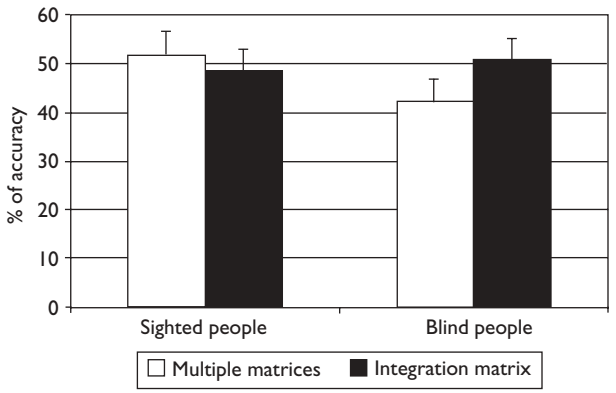

Fig. 2. Mean percentage correct performance and standard error rate as a function of response matrices (two matrices/multiple *vs* single matrix/integration) for sighted and blind participants.

Complexity did not interact with any other variable. There was a significant interaction between groups and conditions ($F(1,30)=5.92$, $Mse=183.55$, $p<0.05$). *Post-hoc* planned comparisons showed that blind people were significantly poorer in the multiple matrices condition than in the integration condition ($t(15)=2.89$, $p<0.05$), whereas the slight impairment in the opposite direction in the case of sighted people was not significant ($p=0.41$). Group differences were not significant.

DISCUSSION

The results of the present investigation confirm that blind people can be as good as the sighted in a visuo-spatial working memory task, but they also show that they may have specific limitations. Blind people were good at remembering a series of locations on a 5 × 5 tactually explored matrix. This result is in line with previous evidence showing a good performance by the blind in passive memory tasks [20]. Despite the fact that the material had to be tactually explored, the information to be recalled had a clear spatial nature suggesting that both blind and sighted individuals may retain material in a similar spatial-like format. When two matrices were presented rather than one, the two groups presented a clearly different pattern of performance. While the sighted had a similar, even slightly better, memory with the multiple matrices condition than with the integrated condition, the blind had an opposite pattern of performance, showing a significant memory decrease with the multiple matrices.

Obviously the integrated matrix task could be carried out in different ways. For example people could maintain two separate configurations and then sequentially recall the respective target locations on the single test matrix. However the instructions stressed the importance of generating a single representation and subjects reported being able to meet the task requirement. Furthermore, if, in the integration modality, the blind had maintained two different configurations, it would be difficult to explain why they performed significantly better than in the condition necessarily requiring the maintenance of two different configurations. The fact that performance on these two tasks was different shows that the blind used different processes. Furthermore the superiority of their performance in the multiple matrices condition shows that, in this case, they were able to overcome the difficulty met in the multiple matrices task. One difference between the multiple matrices and the integration condition was that in the former an active integration process in the visuo-spatial working memory was required [17]: this process did not prove difficult for blind people, showing that only some active VSWM tasks imply a difficulty for the blind. Although in the treatment of a single matrix, blind people are able to generate mental images functionally equivalent to the visuo-spatial images of sighted people and thus perform on a par, in the simultaneous and differentiated maintenance of locations in two different matrices, people who only experienced non-visual sensory modalities meet difficulties in adequately meeting the demands of the task. This highlights an important aspect of vision compared to other sensory modalities i.e. that whereas the simultaneous treatment of more than one visuo-spatial representation is typical of visual perception, it is largely absent in haptic exploration and auditory experience.

CONCLUSION

We show that congenitally blind people can process and transform mental images, but are poorer at recalling more than a single pattern at a time.

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