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The Effects of Visual Experience and Training in Raised-Line Materials on the Mental Spatial Imagery of Blind Persons

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Abstract: Visual experience improved performances of blind adults in mental rotation and mental representation of the path of a spot. Congenitally blind participants with high expertise in graphic material performed better than two categories of nonexpert participants--those who became blind early in their lives versus those who became blind later in their lives--indicating that graphic expertise may compensate for the lack of visual representations. Implications for teaching are discussed.

Recent studies have shown that the mental imagery of people who are blind and those who are sighted share some of the same characteristics, for example, in the memory of concrete or abstract words, or the increase of response time in mental rotation tasks as a function of the angle of rotation (Cornoldi & Vecchi, 2003). However, some specific features of blind people's mental imagery have been noted (Arditi, Holtzman, & Kosslyn, 1988 ; Cornoldi & Vecchi, 2003) that probably result from the particular functioning of touch, including a small perceptual field, sequential processing, and specific exploratory procedures. These characteristics may overload attention and working memory, and it is assumed that a mental process of integration and synthesis is required to form a unitary image of objects (Revesz, 1950). Vecchi, Tinti, and Cornoldi (2004) observed that congenitally blind people were poorer at recalling more than a single pattern at a time.

More generally, blindness that occurs early in life impairs spatial representation, especially spatial displacement and the formation of cognitive maps; for comprehensive reviews, see Hatwell (2003), Heller (2000), Millar (1994), and Warren (1994). A number of studies have shown that adults who lost their sight early in life have a more limited capacity to generate mental spatial images than those who are sighted. Arditi et al. (1988) found that in adults who were congenitally blind, imagery capacities were disturbed by such aspects as perspective, which is typically visual and therefore unknown to congenitally blind persons. According to Cornoldi, Cortesi, and Preti (1991) and Cornoldi and Vecchi (2000, 2003), early visual experience has a facilitating effect on the generation and use of spatial mental imagery. These authors presented to blind and blindfolded sighted participants either two-dimensional (3 × 3 or 4 × 4) or three-dimensional (2 × 2 × 2 or 3 × 3 × 3) matrices made of wooden cubes. Participants were asked to follow mentally and memorize the starting position and path of a spot as it moved sequentially (both horizontally and vertically) through a series of adjacent cubes as described orally by the experimenter ("one step ahead, one step to the right," etc.), and then indicate the final position of the spot. Congenitally blind participants manifested more difficulties when they had to work fast and with the third dimension.

Gaunet and Thinus-Blanc (1996) studied the ability of blind and blindfolded sighted adults to localize objects in small- and large-scale spaces, and observed some limitation of the capacity for mental imagery in the blind participants. The place of one object was changed between presentation and test phases, and participants were asked to detect this change. Results showed that the exchange of places between two objects (topological change) was equally well detected by all participants, whereas the displacement of an object in centimeters (metrical change) was less well detected by those who were congenitally blind.

Kerr (1983) showed in a mental exploration task that a strong relationship existed between the duration of mental exploration of distances and the distance to be covered, for persons who were sighted as well as those who were blind; these durations, though, were longer for congenitally blind persons than for those who became blind later in their lives. It seemed, therefore, that blind persons could create and manipulate spatial representations just as could sighted ones, but that visual experience allowed faster generation and treatment of images. However, these results were questioned by Röder and Rösler (1998). These researchers presented a task of mental distance exploration to congenitally blind adults, together with a phase in which participants learned spatial representation through tactile exploration. No difference between the two groups was evident. In a mental rotation task, Marmor and Zaback (1976) observed that the response times of participants who became blind early in life, those who became blind later in life, and of blindfolded sighted ones improved linearly as a function of the angle of rotation. However, for the participants who became blind early in life, response times were longer and errors more frequent than for the other two groups. Similarly, Carpenter and Eisenberg (1978) found a linear improvement of response times as a function of rotation, with congenitally blind participants slower (59° per second) than those who became blind later in life (114° per second) or blindfolded sighted (233° per second) participants. But the error rate was not different for the three groups, a result confirmed by Dodds, Howarth, and Carter (1982). According to Thinus-

Blanc and Gaunet (1997), inconsistencies in the literature may be explained by variability in mental imagery capacities between individuals, which could result from such factors as education, age at onset of blindness, and type of schooling.

In the present research, two of these factors were studied. We predicted that mental imagery capacities would be improved both by visual experience, as demonstrated previously (Heller 1989; Heller, Calcaterra, Tyler, & Burson, 1996), and by the level of expertise in the haptic exploration and perception of the raised Thermoformed shapes used in most studies. In their specialized schooling, children who are blind are now frequently presented with tactile drawings and diagrams, and familiarity with these displays may enhance their spatial imagery. We evaluated this expertise, acquired during previous learning, by a pretest and a questionnaire asking each participant to specify his or her training and interests in this area. The role of previous visual experience was studied by comparing a group of congenitally blind adults with a group of people who became blind earlier in life (whose blindness had occurred between the ages of 4 and 8 years) and a group of adults who became blind later in life (whose blindness had occurred after the age of 8). The purpose of the latter comparison was to evaluate the possible role of the amount and vividness of visual representations (which may depend on the duration of visual experience) in the mental imagery capacities of persons who are totally blind. Finally, we predicted that visual experience and expertise would interact, such that a low level of expertise in graphic materials might attenuate the positive effect of longer visual experience usually found in the spatial performances of persons who became blind early in life as compared to those who became blind later.

Two spatial imagery tasks were presented to the three groups of participants: a mental rotation task and a task of mental representation of the path of a spot. In the first one, participants were asked to explore haptically Thermoformed drawings of shapes and to imagine their rotations, whereas in the second task, participants stored in memory the path of an imagined moving spot and then reproduced this path through raised-line drawings. Both tasks have often been used in recent research on mental imagery.

General method

PARTICIPANTS

Of 55 adults tested, 24 who were completely blind (without light perception) were chosen to form three groups that varied by duration of visual experience: 8 were congenitally blind (CB); 8 were in the "early blind" group (EB), with onset of blindness between the ages of 4 and 8 years, and 8 were in the "late blind" group (LB), with onset of blindness after the age of 8. These were the 24 participants of the 55 tested who best met the criteria of between-group matching. They freely gave their informed consent to participate to this research according to French legislation (Hurriet laws), and they were autonomous in their everyday life and travel. The causes of blindness for CB group members were congenital glaucoma (4), retinopathy of prematurity (2), and atrophia of the optic nerve (2); for EB group members they were retinis pigmentosa (4), retinoblastoma (1), glaucoma (1), cataract (1) and accident (1); for LB group members they were retinis pigmentosa (6), cataract (1), and retinal detachment (1). The three groups were matched on gender, age (above 30 years was categorized as old, below 30 as young), social status (workers and students), school level (prebaccalaureat and postbaccalaureat, which are French grades corresponding to the U.S. secondary and post-secondary educational levels), and expertise in tactile graphic drawings (experts and nonexperts, as determined by a questionnaire and preliminary tests on production and exploration in relief drawings).

PROCEDURE

A questionnaire estimated the subjects' degree of autonomy (for example, "Do you go shopping on your own? Do you cook your own meals?"), their sociocultural level, the access they had to raised-line figurative representations during their training and their level of interest ("Have you drawn and worked with thermoraised shapes? Do you like drawing? Did you like geometry?"). Three tasks were then presented: a recognition task of Thermoraised drawings, creating a tactile drawing of the front view of a house, and solving a puzzle. "Expert" participants were defined as those who were competent in the activities proposed in the questionnaire and had high scores in these pretest tasks. The "nonexperts" were those with poor results in the questionnaire and low scores in these pretest tasks. Box 1 presents details of this evaluation.

The experimental tests, which lasted approximately 45 minutes, were performed in a quiet room where the participant and the experimenter sat facing each other. Participants were successively presented with two tasks in a counterbalanced order: mental rotations and mental spatial displacement of a spot.

Experiment 1: Mental rotation task

Participants haptically explored a geometrical Thermoformed shape model, and were then asked to indicate whether four rotated comparison shapes were the same or a mirror image of the model. Only the correctness of the response was considered, since this measure has led to contradictory results in the literature (as reported earlier).

METHOD

Material.

Four sheets of paper each contained four lines of five identical Thermo-formed rectangular shapes (the dimensions of all the rectangles were 4 × 3 cm). A small square (1.5 × 1.5 cm) was drawn in one corner of each rectangle, its position varying from one rectangle to another. On each line of drawings, the shape on the left represented the model. The four other shapes were either the same as the model (in the same orientation or rotated 90°, 180°, or 270°), or were mirror images (Figure 1). Each sheet had the same number of identical and mirror-image comparison shapes.

Procedure.

In a training phase, participants explored the first line of the first sheet and indicated whether each of the four comparison shapes was identical to the model or was a mirror image. They repeated the task until they had no errors. During the test phase, participants explored the model and each of the comparison shapes in each line and answered as quickly as possible. Each sheet could be explored during 45 minutes and each model during 5 seconds. No feedback was given. The total number of responses was 4 × 4 × 4 = 64.

Scoring.

The proportion of correct responses per sheet was calculated. Since there were 16 responses per sheet, each correct response was scored 1/16. The maximum score per sheet was therefore 1 and the maximum score for a task was 4.

RESULTS

An analysis of variance (ANOVA) on the independent factors: age (young vs. old) and gender did not show any effect or interaction (all $F < 1$) (*M* young = 2.71; *M* old = 2.78; *M* men = 2.99; *M* women = 2.49). Neither did another ANOVA concerning social status (workers vs. students) and school level (A+ level vs. A- level) show any effect or interaction (*M* workers = 2.75; *M* students = 2.74; *M* A+ level = 2.89; *M* A- level = 2.60). Therefore, the groups were collapsed across age, gender, social status, and school level.

A third ANOVA tested the hypotheses concerning the two independent factors: visual experience (CB, EB, and LB) and expertise (experts vs. nonexperts). Results are shown in Figure 2.

The significant effect of expertise, $F(1, 18) = 49.82$, $p = .00$, showed that experts were superior, $M = 4.23$, to nonexperts, $M = 2.62$, on the rotation task. There was no effect of visual experience, $F < 1$, but expertise and visual experience interacted, $F(2, 18) = 7.2$, $p = .00$. Partial tests showed that the effect of expertise was significant for the CB, $p = .00$, and the LB, $p = .00$, groups. The effect of visual experience was not significant for the experts, whereas among the nonexperts, the EB group had better results than did the CB group, $p = .01$, or the LB, $p = .01$. Finally, the expert CB group performed better than the nonexpert EB ($p = .01$) or LB ($p = .00$) groups, while the expert EB group performed better than the nonexpert LB group ($p = .00$).

DISCUSSION

The first result involved the interaction between expertise and visual experience. It revealed that the congenitally blind participants who were considered expert in tactile graphics performed better than nonexpert members of both the EB and LB groups. Similarly, experts in the EB group had better results than nonexperts in the LB one. Apparently, the advantage provided by expertise in graphic representations can surpass the advantage that duration (up to or over eight years) of visual experience generally brings to persons who become blind earlier or later in life. Of course, visual experience does not guarantee good performance in rotation tasks. In the present study, however, it was interesting that in the use of graphics in relief material only nonexperts (not experts) in the EB and LB groups performed less well than experts in the CB group.

Experiment 2: Mental spatial displacement of a spot

The aim of this phase of the study was to evaluate, in the same three groups of blind adults, the role of expertise in graphic material and of duration of visual experience in an imagery task widely used in contemporary research, namely, the representation of the path of a moving spot. This task tested participants' capacity to imagine and memorize the path of a spot undergoing linear vertical and horizontal displacements as specified orally by the experimenter, and then to reproduce this path graphically.

METHOD

Material.
The material used was a Swedish drawing kit comprising a piece of special transparent paper, a special ballpoint pen, and a special support on which the paper was laid.

Procedure.

Participants were asked to imagine and memorize the course of a spot (moving north, south, east, or west) according to the oral instructions of the experimenter until it formed a certain rectilinear geometrical shape. A direction was given every two seconds and was given only once. At the end of each item, the participant was asked to draw the whole course of the spot. No measure was given for the segments, though participants were asked to draw them to equal lengths. After a training test in which the spot formed a square, the main test was given. It was composed of five items of increasing difficulty: the first had 6 directions and the following items had 7, 8, 12, and 20 directions. See Figure 3 for examples.

Scoring.
While drawing, participants named aloud the directions they were tracing (for example, "I'm tracing a line toward the north, and another line toward the north. . ."). This helped in evaluating the number of lines drawn when the same direction was given twice. Since totally blind persons tend to draw poorly, a line was considered correct when it matched the oral direction given, and the length of each line was not taken into account. The scores were controlled by another experimenter. The dependent variable was the number of lines correctly drawn in each item, converted into a proportion. The maximum score per item was therefore 1, and the maximum score for the task was 5.

RESULTS

An ANOVA on the independent factors of age (young vs. old) and gender did not show any effect or interaction, all $F < 1$ (M young = 3.42, M old= 3.73; M men = 3.54; M women = 3.62). Another ANOVA on social status (workers vs. students) and school level (A+ level vs. A- level) did not show any effect or interaction (M workers = 3.9; M students = 3.13; M A+ level = 3.38; M A- level = 3.77). Therefore, the groups were collapsed across age, gender, school status, and social status.

The principal ANOVA was on visual experience (congenitally, early, and late blind groups) and expertise (experts and nonexperts) (see Figure 4). There was a main effect of vision, F (2, 18) = 13.5, p = .00, showing that the LB group had better results (M = 4.6) than the EB group (M = 3.17) and the CB group (M = 2.96). No difference was evident between the EB and CB groups. The main effect of expertise, F (1, 18) = 19, 45, p = .00, was also significant, showing a superiority of experts (M = 4.49) to nonexperts (M = 2.96). The interaction between expertise and visual experience was not significant (p = .08).

In order to test our hypothesis comparing the performances of expert CB ($M = 4.03$) and nonexpert EB ($M = 2.7$) groups, a unilateral single Student's *t*-test was performed on the two groups. The difference was significant ($t = 2.97$, $p < .025$).

DISCUSSION

Duration of visual experience modified performance. A number of previous studies have shown that in the identification and production of relief drawings that symbolize real things (such as an object or a path), persons who are congenitally blind have more difficulties than do those who become blind later in life. It is likely that these difficulties result both from impaired visuospatial imagery and from less familiarity with the transcription rules of three-dimensional space into two-dimensional drawings (Millar, 1975, 1994; Heller et al., 1996). For a review, see Hatwell and Martinez-Sarocchi (2003). This could explain the main effect of vision obtained in the present study, since expert members of the LB group had better training in the use of drawings in addition to longer visual experience.

Another result showed higher performances by expert congenitally blind participants than by nonexpert early blind ones. As in the previous mental rotation task, expertise in graphic displays evidently reversed any beneficial effects of visual experience, restricted in this group to four to eight years.

General discussion

The hypothesis that previous visual experience enhances the mastery of mental spatial imagery in blind people was supported by the results of the study. More important, results also showed that capacity for mental imagery may vary according to level of expertise in the use of tactile drawings attained by congenitally blind people, and people who became blind early or late in life.

These results suggest that expertise in graphic displays should be controlled in all research using graphics in the evaluation of spatial imagery in blind persons, and that this factor may help explain some of the inconsistencies observed in the literature. With the small samples usual in studies of blind persons, the probability of sampling errors is high. Controlling for level of expertise in use of raised graphic representations is also important because results of this study suggest that the effect of this factor may be greater than the effect of duration of visual experience. Indeed, in both the mental rotation and in the mental spatial displacement tasks, expert members of the CB group had better performances than nonexpert EB group members. In the mental rotation task, the expert CB group members even had better performances than the nonexpert LB group members. Therefore, a high level of expertise in the congenitally blind population may compensate for the impairment in spatial representation that often results from lack of visual experience.

IMPLICATIONS FOR PRACTICE

In addition to offering a better understanding of the cognitive functioning of people who are blind, these results may be of practical interest. Today, the use of tactile graphic material tends to be widespread in the teaching and education of people who are visually impaired. The utility and pertinence of this practice is supported by our observations. The difficulty lies in finding methods of presentation of relief drawings that are compatible with constraints imposed by the slow development of haptic abilities in children, as well as the lack of representation in congenital blindness of what are the visual perceptual changes due to perspective. Nevertheless, training in the use of graphic materials may have positive effects on the spatial abilities of people who are blind and ought to be encouraged during schooling.

However, the interpretation of this study's results should be modulated by the question, still unresolved, of the origins of differences in drawing expertise among persons who are blind. It may well be that, because of previous general spatial aptitudes, some blind children and adolescents succeeded in the perception and identification of tactile drawings during their school years and therefore became interested in them. In contrast, others may have had more general difficulties in spatial representation and did not take advantage of graphic displays during schooling because they found them too difficult to process; consequently, they may have manifested no further interest in tactile drawings and diagrams. Clearly, general spatial competences and the effects of training with relief drawings are closely intertwined. Further research should try to isolate factors leading to the individual differences in expertise with graphic displays revealed in the present research.

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