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# MENTAL ROTATION OF FIGURES EXPLORED BY TOUCH: A STUDY OF CONGENITALLY BLIND AND SIGHTED INDIVIDUALS

The form of mental images in congenitally blind people is intensely debated by researchers. In order to get a better insight into this topic, we conducted an experiment during which the task for congenitally blind individuals was to learn 2D tactile shapes and then mentally rotate them. The control group consisted of blindfolded sighted individuals. The visuo-spatial working memory model was treated as a theoretical framework for the theoretical debate. The aim of the study was to determine whether the accuracy of mental rotation is lower in congenitally blind than in sighted individuals and whether the difference in accuracy between the groups depends on the complexity of tactile figures. We also tested if the complexity of the figure and the background (grid or frame) influences the passive and active components of visuo-spatial working memory. Results show that congenitally blind subjects learned the shapes of figures by touch and rotated them faster than sighted subjects. It was established that the learning time depends on the complexity of figures and backgrounds. Figures presented on a complex background of a grid required more time to learn then figures in a frame. Moreover, sighted individuals required more time to learn complex figures than they did to learn simple ones. This was not the case with the congenitally blind. The rotation task was performed with greater accuracy for figures presented on a plain background compared to the complex background, and faster for figures drawn in a frame than for those on a grid. The study has shown that the active component of the visuo-spatial working memory engaged during

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mental rotation works with at least equal efficiency in congenitally blind individuals compared to sighted ones.

**Keywords:** mental rotation; congenitally blind individuals; blindfolded sighted individuals; stimulus complexity; tactile drawing; visuo-spatial working memory.

## THEORETICAL INTRODUCTION

According to Cornoldi and Vecci (2003), imagery processes can be analyzed in terms of the visuo-spatial system – so-called visuo-spatial working memory (Logie, 1995). The visual, tactile, and auditory modalities as well as long-term memory can all be sources of information for the memory system (Logie, 1995). Therefore, the functioning of visuo-spatial working memory can be analyzed for both sighted and blind individuals (e.g., Cornoldi, Cortesi, & Preti, 1991; Cornoldi & Vecchi, 2003; Vecchi, 1998, 2001). The issue of imagery format in individuals with no visual experience is still unresolved, and researchers cannot reach agreement on that matter (see e.g., Szubielska, 2010). In addition, in the majority of cases, the terms “imagery process” and “imagery” appear in studies associated with visual imagery. It is therefore “safer” to use the theoretical background of working memory than the selective concept of the visual, spatial, or visuo-spatial imagery when conducting research on imagery processes in blind individuals.

The use of active control in the performance of an imagery task being the distinguishing criterion, two independent components of the visuo-spatial working memory can be identified: passive[1] and active. The passive component is a limited-capacity repository where visuo-spatial information is stored temporarily. The passive repository is responsible for creating and maintaining mental representations in memory. The active component is involved in all kinds of transformations of visuo-spatial representations – that is, for imagery actions. Mental rotation is one of its tasks. The efficiency of the active component is more dependent on the existence of visual experience than the efficiency of the passive component (Cornoldi & Vecchi, 2000; Cornoldi & Vecchi, 2003; Vecchi, Monticellai, & Cornoldi, 1995). The agility of the passive repository is the same for congenitally blind and sighted individuals. On the other hand, tasks actively engaging the active component of the visuo-spatial working memory are performed with less accuracy by blind individuals than by sighted ones. This is

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[1] We are aware that the so-called passive component is associated with the information stored in memory and that it is therefore active in a certain way.

especially apparent in the case of more complex tasks (Cornoldi, Bertuccelli, Rocchi, & Sbrana, 1993; Vecchi, 1998, 2001).

The lack of visual experience makes it more difficult for blind individuals to create accurate imagery representations. However, in the case of a haptic study, extensive tactile experience (with tactile graphics interpretation, etc.) can compensate for the lack of visual memory (cf. Toroj & Szubielska, 2011). The encoding of tactile stimuli is supported by regular manual exploration, which is usually more developed in congenitally blind than in sighted individuals (D'Angiulli & Kennedy, 2001; Davidson, 1972). As a result, the perception of tactile stimuli is more time-consuming for the sighted than for the blind (Heller, 2006; Picard, Jouffrais, & Lebaz, 2011; Postma, Zuidhoek, Noordzij, & Kappers, 2007).

For blind people, mental rotation is a difficult imagery operation. Studies have shown that for blind children rotation is a more difficult task than maintaining information in working memory (Millar, 1975; Szubielska, 2010; Ungar, Blades, & Spencer, 1995). The results of an experiment conducted by Marmor and Zaback (1976) demonstrated that blind adults who had no visual memories rotated tactually learned figures with less accuracy that those who could visualize, i.e. the sighted or people who had lost sight. Millar (1976) observed greater difficulty with mental rotation in blind children than in their sighted peers. However, it should be noted that not all studies confirm that blind people perform imagery operations with worse results than sighted individuals. The lack of difference in the accuracy of imagery manipulation between blind and sighted people has been confirmed by experiments involving imagery operations such as folding along the axis of symmetry (Vanlierde & Wanet-Defalque, 2004; Szubielska, 2014), majorization (Szubielska, 2015), or rotation (Rösler, Röder, Heil, & Hennighausen, 1993). Unfortunately, the sources of discrepancies in the above-mentioned experiments cannot be clearly determined due to many differences in the experimental procedures applied. However, task complexity is one of the possible factors. As already mentioned, differences in the functioning of the active component of visuo-spatial working memory between the blind and the sighted are the most apparent when solving complex tasks with a higher level of difficulty (Cornoldi et al., 1993; Vecchi, 1998, 2001).

None of the experiments known to us involving mental rotation by the blind focused on the impact of task complexity on the accuracy of performance. Task complexity may result, among other things, from the complexity of the experimental stimuli. The complexity of two-dimensional spatial stimuli seems to be determined by two factors: shape complexity and background complexity. The number of angles is considered to be an indicator of complexity (Bałaj, 2015;

Cooper, 1975; Cooper & Podgorny, 1976). The complexity of the background can be defined by the number of lines in the background on which a figure is presented (cf. Heller, Wilson, Steffen, Yoneyama, & Brackett, 2003). Many researchers analyzing the functioning of visuo-spatial working memory used stimuli composed of squares placed on a grid (for a review, see: Cornoldi & Vecchi, 2003), but without the requirement that the experimental stimuli must also be presented on a simpler background, for example in an empty frame. In the study presented in this article, both the complexity of the figure and the background of exposition were considered.

It seems that the simultaneous comparison of two tactile stimuli of high complexity – additionally, one being rotated in relation to the other, as was the case in the experiment by Marmor and Zaback in 1976 – is an extremely difficult task, especially for the congenitally blind. Due to their general preference to use a self-centered point of reference (Postma et al., 2008; Pasqualotto & Proulx, 2012), these people may find it troublesome to simultaneously evaluate the shape of figures of which one is rotated in relation to the other (cf. Toroj & Szubielska, 2011). Egocentric representations are based on information coming from the body and movement. If a person prefers to use an egocentric representation, it will be hard for them to tactilely learn two different spatial stimuli and compare them. Therefore, in our own study, where rotation by congenitally blind and sighted individuals was compared, we decided to display the master and test stimuli one after the other within a single experimental trial (as Rösler et al., 1993).

Based on the literature on the subject addressed in this article, we formulated the following hypotheses and research questions relating to the functioning of visuo-spatial working memory.

H 1: The accuracy of mental rotation of figures depends on the interactive influence of “visual experience” and “figure complexity” factors. The interaction consists in sighted people rotating complex figures with greater accuracy than congenitally blind people, while the visual experience does not differentiate the accuracy of rotation of less complex figures.

H 2: The congenitally blind take less time to remember tactilely learned figures that the sighted.

Q 1: Does the complexity of the figure affect the functioning of the passive component of visuo-spatial working memory?

Q 2: Does the complexity of the background affect the functioning of the passive component of visuo-spatial working memory?

Q 3: Does the complexity of the figure affect the functioning of the active component of visuo-spatial working memory?

Q 4: Does the complexity of the background affect the functioning of the active component of visuo-spatial working memory?

We used the time spent on learning the master figure as a measure the performance of the passive component of visuo-spatial working memory. The performance of the active component was established based on the time needed to recognize the rotated figure and the accuracy of recognition.

## METHOD

### Participants

The sample consisted of 22 individuals (6 women), half of them congenitally blind and the other half normally sighted. In the first stage, congenitally blind subjects were paired with sighted subjects. The pairing process was based on the compatibility of gender, age, and education level. In both groups, the subjects' age ranged between 18 and 36 years. In the sighted group the mean age was *M* = 24.18 (*SD* = 5.49), and in the congenitally blind group it was *M* = 24.27 (*SD* = 5.41). Based on the subjects' statements, we established that all sighted participants were right-handed, while in the congenitally blind group one person declared themselves to be left-handed. All blind subjects could read Braille and had prior experience with tactile drawings. Five people were totally blind and six had a sense of light (including one in the left eye only). The causes of sight impairment were the following: retinoblastoma (two people), retinopathy of prematurity (five people), optic nerve atrophy (two people), and hypoplasia – underdevelopment of the optic nerve (two people).

### Materials

As the research material, we used 80 raised-line drawings (so-called tactile graphics), half of which were drawings of master figures used at the learning stage, and the other half were drawings of test figures presented at the stage of recognition. Each drawing consisted of a square frame with a side of 20 cm and a figure composed of 20 components, i.e. 2 cm squares. All figures were asymmetrical and asemantic. As a rule, the test figures were created by moving a single component of the master figure to another place. The research material was diversified in terms of figure and background complexity. The complexity of figures was defined in accordance with Szubielska's studies (2015). Figures with 10 right angles were classified as less complex and figures with 20 right angles – as more complex. A plain background was a square frame, and a complex background consisted of a 100-item grid (see Figure 1).

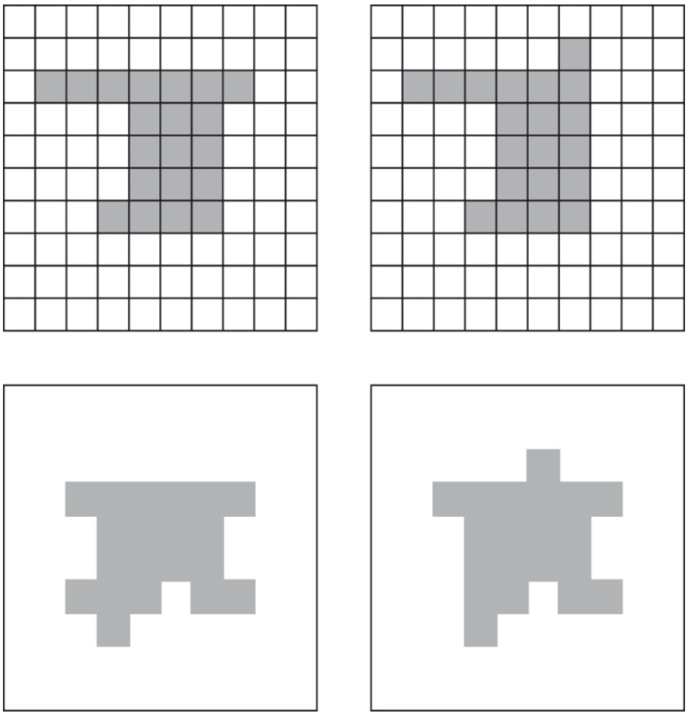

*Figure 1.* Examples of master (left) and test stimuli (right; a stimulus before the rotation). In the top row, there are less complex figures on a complex background. In the bottom row, there are more complex figures on a plain background.

All tactile drawings were prepared in collaboration with the Center for the Adaptation of Educational Materials for the Blind. The figures had a dotted structure, different from the structure of lines of the frame and the grid. The lines of figures were 0.5 mm high and those of the grid and the frame were 1 mm high. A preliminary study involving both blind and sighted people confirmed their ability to tactilely distinguish between the elements of these graphics.

## Procedure

The study was carried out individually. The sighted subjects performed the task blindfolded. The subjects were seated at the table and the tactile drawings were placed on the table. The subjects could explore the raised-line drawings in any way they chose.

The experiment consisted of 40 trials. Each trial began with a learning stage directly followed by a recognition stage. The learning stage consisted in memorizing the master figure with no time restriction. The subjects were instructed as follows: *There is a tactile drawing of a figure in front of you. Study the drawing and memorize it using touch. Take as much time as you think necessary. Once you feel you have memorized the shape of the figure, say "Ready."* At the recognition stage, test figures after 90° rotation in relation to master figures were presented. The figures were randomly rotated clockwise or counterclockwise, and the subjects were informed how the stimulus had been rotated. At this stage, the subjects were given the following task: *Decide whether the figure you are about to touch has the same shape as the one you have just studied, or different.*

The learning time was measured with a stopwatch from the moment the subject touched the master drawing until the moment they said "Ready." The accuracy of recognition was evaluated on a "yes" or "no" scale. One point was given both for a correct recognition of a match between the master figure and the test figure and for a correct rejection of a test figure not matching the master figure. The response time was measured from the moment the subject touched the drawing of a test figure until the moment they answered.

The test consisted of 40 trials in 4 series, in a random order. Each series was preceded by three test trials. The purpose of test trials was for the subjects to become familiar with the task and the conditions of stimuli presentation in each series. The following options of presentation were available: (1) learning stage: frame, recognition stage: frame; (2) learning stage: frame, recognition stage: grid; (3) learning stage: grid, recognition stage: frame; (4) learning stage: grid, recognition stage: grid. Each series consisted of 10 randomly presented trials, five for each of the two levels of complexity. For both complexity levels, the test figure was identical with the master figure in two trials and different from the master figure in three trials.

## RESULTS

The tables below show the descriptive statistics for the dependent variables of “correct recognition” (Table 1), “learning time” (Table 2) and “recognition time” (Table 3). A similar analysis of variance was performed for each of the dependent variables with the within-subject “visual experience” factor (sighted vs. blind) and the between-subject “figure complexity” factor (less vs. more complex), “master figure background complexity” (plain/frame vs. complex/grid) and “test figure background complexity” (plain/frame vs. complex/grid).

Table 1

*Accuracy of Rotated Figure Recognition in Each Test Condition – Descriptive Statistics: Mean (M), Standard Deviation (SD), Minimum Result (Min), and Maximum Result (Max)*

| | | *M* | *SD* | Min | Max |
|---|---|---|---|---|---|
| Learning: frame<br>Recognition: frame<br>Figures: less complex | Blind | 4.27 | 0.90 | 3.00 | 5.00 |
| | Sighted | 3.55 | 0.52 | 3.00 | 4.00 |
| Learning: frame<br>Recognition: grid<br>Figures: less complex | Blind | 3.64 | 1.03 | 2.00 | 5.00 |
| | Sighted | 4.00 | 0.77 | 3.00 | 5.00 |
| Learning: grid<br>Recognition: frame<br>Figures: less complex | Blind | 4.18 | 0.98 | 2.00 | 5.00 |
| | Sighted | 3.82 | 0.98 | 2.00 | 5.00 |
| Learning: grid<br>Recognition: grid<br>Figures: less complex | Blind | 4.18 | 1.08 | 2.00 | 5.00 |
| | Sighted | 3.55 | 1.13 | 2.00 | 5.00 |
| Learning: frame<br>Recognition: frame<br>Figures: more complex | Blind | 3.36 | 1.21 | 1.00 | 5.00 |
| | Sighted | 3.91 | 1.04 | 2.00 | 5.00 |
| Learning: frame<br>Recognition: grid<br>Figures: more complex | Blind | 3.36 | 1.12 | 2.00 | 5.00 |
| | Sighted | 3.36 | 1.03 | 2.00 | 5.00 |
| Learning: grid<br>Recognition: frame<br>Figures: more complex | Blind | 3.55 | 1.13 | 1.00 | 5.00 |
| | Sighted | 3.09 | 0.83 | 2.00 | 5.00 |
| Learning: grid<br>Recognition: grid<br>Figures: more complex | Blind | 3.36 | 1.03 | 1.00 | 5.00 |
| | Sighted | 3.82 | 0.87 | 2.00 | 5.00 |

Table 2

*Master FigureLearning Time (in Seconds) in Each Test Condition – Descriptive Statistics: Mean (M), Standard Deviation (SD), Minimum Result (Min), Maximum Result (Max)*

| | | *M* | *SD* | Min. | Max. |
|---|---|---|---|---|---|
| Learning: frame<br>Recognition: frame<br>Figures: less complex | Blind | 18.47 | 12.01 | 7.16 | 50.93 |
| | Sighted | 61.64 | 30.36 | 23.58 | 122.14 |
| Learning: frame<br>Recognition: grid<br>Figures: less complex | Blind | 21.63 | 21.22 | 7.18 | 81.75 |
| | Sighted | 56.47 | 33.77 | 22.03 | 140.23 |
| Learning: grid<br>Recognition: frame<br>Figures: less complex | Blind | 26.99 | 16.94 | 8.72 | 63.32 |
| | Sighted | 111.94 | 54.41 | 32.90 | 240.40 |
| Learning: grid<br>Recognition: grid<br>Figures: less complex | Blind | 35.92 | 23.07 | 8.66 | 86.18 |
| | Sighted | 95.74 | 43.58 | 40.08 | 197.72 |
| Learning: frame<br>Recognition: frame<br>Figures: more complex | Blind | 31.69 | 26.00 | 7.31 | 85.42 |
| | Sighted | 80.05 | 44.88 | 23.93 | 179.40 |
| Learning: frame<br>Recognition: grid<br>Figures: more complex | Blind | 38.81 | 45.65 | 6.64 | 170.21 |
| | Sighted | 82.51 | 43.81 | 29.14 | 185.27 |
| Learning: grid<br>Recognition: frame<br>Figures: more complex | Blind | 37.39 | 25.47 | 10.18 | 85.10 |
| | Sighted | 136.30 | 71.58 | 33.28 | 276.84 |
| Learning: grid<br>Recognition: grid<br>Figures: more complex | Blind | 42.62 | 32.76 | 8.65 | 113.44 |
| | Sighted | 117.23 | 51.35 | 42.56 | 219.15 |

Table 3

*Rotated Figure Recognition Time (in Seconds) in Each Test Condition – Descriptive Statistics: Mean (M), Standard Deviation (SD), Minimum Result (Min), Maximum Result (Max)*

| | | *M* | *SD* | Min | Max |
|---|---|---|---|---|---|
| Learning: frame,<br>Recognition: frame,<br>figures: less complex | Blind | 10.15 | 4.86 | 4.33 | 20.64 |
| | Sighted | 31.60 | 17.90 | 8.76 | 74.46 |
| Learning: frame,<br>Recognition: grid,<br>figures: less complex | Blind | 22.61 | 19.28 | 5.58 | 64.52 |
| | Sighted | 49.14 | 23.56 | 22.90 | 112.34 |
| Learning: grid,<br>Recognition: frame,<br>figures: less complex | Blind | 12.83 | 10.46 | 3.14 | 38.13 |
| | Sighted | 35.89 | 18.32 | 7.51 | 65.98 |
| Learning: grid,<br>Recognition: grid,<br>figures: less complex | Blind | 16.78 | 7.67 | 5.49 | 31.79 |
| | Sighted | 44.90 | 16.30 | 18.76 | 74.00 |
| Learning: frame,<br>Recognition: frame,<br>figures: more complex | Blind | 14.88 | 10.04 | 4.02 | 33.77 |
| | Sighted | 34.85 | 13.19 | 12.12 | 57.07 |
| Learning: frame,<br>Recognition: grid,<br>figures: more complex | Blind | 23.56 | 18.47 | 5.48 | 62.35 |
| | Sighted | 54.96 | 23.44 | 23.63 | 111.10 |
| Learning: grid,<br>Recognition: frame,<br>figures: more complex | Blind | 15.46 | 12.23 | 4.58 | 40.31 |
| | Sighted | 42.65 | 21.78 | 13.75 | 92.89 |
| Learning: grid,<br>Recognition: grid,<br>figures: more complex | Blind | 20.64 | 17.63 | 6.43 | 68.32 |
| | Sighted | 48.64 | 24.88 | 11.89 | 83.45 |

For the correct recognition dependent variable, we found a main effect of master figure background complexity, $F(1,20) = 6.5$, $p = .018$; partial $\eta^2 = .25$; observed power = 0.69. Significantly more correct recognitions were made for master figures placed in a frame ($M = 3.90$), than for those placed on a grid ($M = 3.48$). The main effects of visual experience $F(1,20) = .23$, $p = .640$, figure complexity, $F(1,20) = .01$, $p = .936$, and background complexity, $F(1,20) = .18$, $p = .681$, were statistically non-significant.

For the master figure learning time dependent variable, the analysis showed three main effects: visual experience $F(1,20) = 17.50$, $p < .001$, partial $\eta^2 = .47$, observed power = .98; figure complexity, $F(1,20) = 34.52$, $p < .001$, partial $\eta^2 = .63$, observed power = .9999; and master figure background complexity, $F(1,20) = 27.15$, $p < .001$, partial $\eta^2 = .58$, observed power = .999. Blind individuals learned master figures significantly faster ($M = 31.69$) than sighted ones ($M = 91.74$). The learning of less complex figures took less time ($M = 48.91$) than the learning of more complex figures ($M = 75.52$). In the case of master figures presented in a frame learning was significantly faster ($M = 53.60$) than in the case of figures presented in a frame ($M = 70.83$). The main effect of test figure background complexity was statistically non-significant, $F(1, 20) = .18$, $p = .676$. We found significant interaction between the factors of visual experience and figure complexity, $F(1, 20) = 16.73$, $p < .001$, partial $\eta^2 = .46$, observed power = .97. We performed a post-hoc Tukey test for this interaction, and the result showed that sighted individuals required more time to learn more complex figures than the sighted needed to learn less complex figures ($p < .001$), more time than the blind needed to learn less complex figures ($p < .001$), and more time than the blind needed to learn more complex figures ($p <.001$). In addition, learning less complex figures took sighted subjects significantly more time than it took blind individuals ($p = .048$) (see Figure 2).

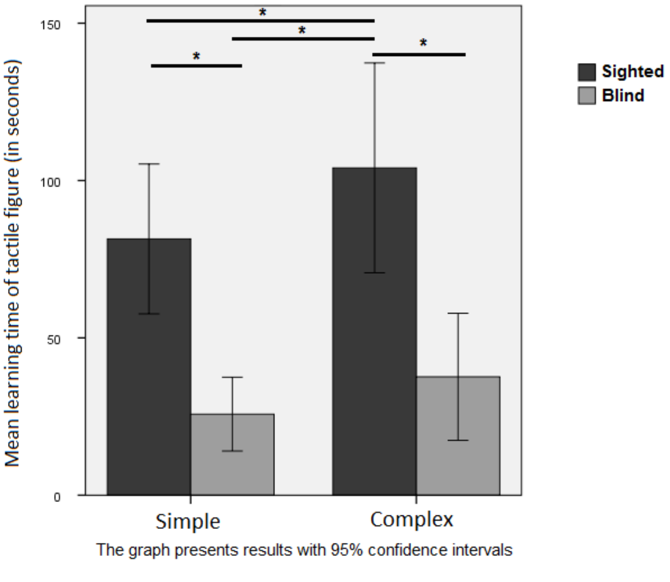

*Figure 2.* Interactive effect of figure complexity and visual experience on the learning time of master figures.

The time needed to recognize the figures significantly depended on: visual experience, $F(1,20) = 16.15$, $p < .001$, partial $\eta^2 = .45$, observed power = .97; master figure background complexity, $F(1,20) = 14.03$, $p = .001$, partial $\eta^2 = .41$; observed power = .95; and test figure background complexity, $F(1,20) = 63.74$, $p < .001$, partial $\eta^2 = .76$, observed power = 1.00. Blind individuals recognized figures faster ($M = 17.11$) than sighted individuals ($M = 42.83$). The recognition time of test figures was shorter for figures presented in a frame in the learning stage ($M = 27.99$) than for those presented on a grid ($M = 31.95$). Test figures were recognized faster when presented in a frame ($M = 24.79$) compared to those presented on a grid ($M = 35.15$). The complexity of figures had no effect on recognition time, $F(1,20) = .06$, $p = .811$.

## DISCUSSION

The purpose of this study was to determine the relation between figure and background complexity and the ability of sighted and congenitally blind individuals to mentally rotate a figure. We examined two components of visuo-spatial working memory: the passive component – by analyzing the time of tactilely learning master figures, and the active component – by analyzing the correctness and time of rotation.

The first hypothesis formulated for this study, under which the correctness of mental rotation depends on the interactive impact of figure complexity and visual experience, has not been confirmed. Thus, the results of previous studies where blind individuals performed worse than sighted ones in more difficult tasks involving the active component of visuo-spatial working memory (Cornoldi et al., 1993; Vecchi, 1998, 2001) have not been confirmed. Previous studies comparing mental rotation ability in congenitally blind and sighted individuals are ambiguous. The lack of difference in the accuracy of mental rotation between blind and sighted individuals found in this study confirms the results obtained by Rösler et al. (1993) and is contrary to the results of experiments conducted by Marmor and Zaback (1976) and Millar (1976). Our results may be associated with the test procedure applied. The figure was always rotated by 90º, while Millar (1976) found in her study of blind children that rotation by a right angle results in the highest accuracy of recognition in rotation tasks. On the one hand, it is possible that if other rotation angles were applied, more difficult for congenitally blind, the first hypothesis would more likely be confirmed. On the other hand, Rösler et al. (1993) did not find differences in the ability to mentally rotate between blind and sighted adults in any of the experimental conditions involving the recognition of tactile stimuli rotated by 60º, 120º, and 180º to the master. However, given that the mental rotation ability in blind people develops with age (Szubielska, 2010), it would be difficult to compare the results obtained by Millar (1976) and Rösler et al. (1993).

Probably, mental rotation ability found by Marmor and Zaback (1976) to be lower in blind adults than in sighted adults resulted from the test procedure adopted by the researchers. Firstly, the pairs of tactilely learned objects to be compared were presented simultaneously. This required working memory to perform sequential processes of haptic learning, creating a mental representation, and mentally rotating the figure. As previously mentioned, mental rotation requires the involvement of the active component of visuo-spatial working memory (cf. Cornoldi et al., 1993; Cornoldi & Vecchi, 2000, 2003; Vecchi, 1998, 2001; Vecchi et al., 1995) whose resources to perform such complicated tasks are very limited. Secondly, the rotated figures used in the test conducted by Marmor and Zaback (1976) did not vary in shape. Each pair consisted of a figure and its mirror image or of two identical figures. Blind individuals may have difficulties performing this task because they lack the visual experience of seeing objects reflected in a mirror and may find the concept of mirror image hard to grasp.

The second hypothesis has been confirmed in our study. We found that the congenitally blind individuals required less time to memorize figures presented on tactile graphics that the sighted. This confirms the results of previous studies where blind individuals performed equally well as sighted people in tasks engaging the passive component of visuo-spatial working memory (Cornoldi et al., 1993; Vecchi, 1998, 2001). Besides, the results indirectly confirm that the blind exceed the sighted in exploration efficiency (D’Angiulli & Kennedy, 2001; Davidson, 1972) and tactile perception (Heller, 2006; Picard, Jouffrais, & Lebaz, 2011; Postma et al., 2007), facts previously reported in the literature. We found that congenitally blind people could recognize a rotated figure on a drawing faster than the sighted.

The differences in learning and recognition times for two-dimensional tactile figures may stem from the more effective strategies used by blind people to study raised-line drawings. Unfortunately, those strategies were not the subject of our interests in this study; however, in the course of the experiment certain regularities were observed for each of the test groups. The majority of congenitally blind individuals could expertly recognize drawings by touch, often directly with their whole hand or using a couple of fingers at the same time and then proceeding to more detailed exploration of a selected part of the drawing only. The sighted, by contrast, tended to touch the drawing with one finger and study it piece by piece, often touching the same spots several times. The literature (Perkins & Gardiner, 2003; Russier, 1999; Symmons & Richardson, 2000) contains similar descriptions of raised-line drawing exploration strategies applied by blind and sighted people.

In addition, this study revealed that the learning of less complex figures takes less time than the learning of more complex figures, while the accuracy and time of the recognition of rotated figures do not depend on their complexity. The results showed an interesting effect of the interaction between figure complexity and visual experience on the time of mental image creation. Only sighted people needed less time to learn less complex figures than they did to learn more complex ones, while the time spent on learning by the congenitally blind was the same for less complex and more complex figures. This shows that if a sighted person spends more time memorizing a more complex figure explored by touch, then they are consequently able to rotate it in the mind as quickly and correctly as a less complex figure. Sighted people required more time to learn a more complex figure from a tactile drawing, which may be associated with the fact that the more complex the stimulus, the more difficult it is to visualize it in a clear and detailed manner (Kosslyn, 1975). Visualization is one of the most often chosen strategies in sighted people, while blind individuals prefer sequential (verbal or other) strategies of memorizing spatial stimuli (Millar, 1975; Szubielska, 2014; Vanlierde & Wanet-Defalque, 2004). It is noteworthy that in our study, both less and more complex figures were composed of an equal number of components (20 squares each), which is why the sequential analysis of the components by congenitally blind subjects should take a similar amount of time regardless of figure complexity.

Other results of the study focused on the impact of the complexity of the background for figures on the functioning of the passive and active components of visuo-spatial working memory. We found that the learning time of figures presented in a frame was significantly shorter than for figures presented on a grid. This confirms the findings reported by Heller et al. (2003) that the more complex the background, the more difficult it is to recognize the shape of a drawing. In other words, the grid turned out to be a distracting factor in the learning process. It has been found, moreover, that mental rotation accuracy depends on master figure background complexity. Regardless of visual experience, the subjects performed mental rotation with greater accuracy for figures presented in a frame that for those presented on a grid. The creation of an accurate mental representation of a stimulus to be rotated in the mind seems to be the basic requirement for accurate rotation, making it even more difficult when a figure is presented on a more complex background (cf. Heller et al., 2003). We found that rotation was performed faster for test figures in a frame that for figures on a grid. Moreover, the task was completed faster for master figures presented in a frame than for those presented on a grid. While the first result concerning rotation time is not surprising and probably stems from the fact that grid made it more difficult to extract the shape of a test figure from its background (Heller et al., 2003), the second result is far more intriguing. In order to complete the rotation task, the subject had to memorize the shape of the master figure, then learn the shape of the test figure, and finally compare the two. It seems that the imagery representations of master figures presented on a more complex background were less available than the representations of figures presented on a plain background, making the comparison of the master and test shapes longer.

In conclusion, we recognize the great potential of congenitally blind people to create and handle spatial representations. Our experiment shows that these people can use the active component of the visuo-spatial working memory equally well (in terms of the accuracy of mental rotation) or even better than the sighted (when we consider the time of the mental rotation process). This brings us to practical conclusions, very important in the context of the spatial orientation ability of people without visual experience. The research reported in the present paper suggests that when walking around with a raised-line map a blind person should not find it more difficult than a sighted person to compare the spatial relations shown on the map with the actual spatial relations in the location, even after a rotation of the map – providing, obviously, that the congenitally blind person understands the concept of size scale and can accurately perform mental majorization and minorization as well as a sighted person (cf. Szubielska & Marek, 2015a, 2015b).

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