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MENTAL MAJORIZATION OF FIGURES TACTILELY EXPLORED BY SIGHTED AND CONGENITALLY BLIND INDIVIDUALS

The study focused on the recognition of tactile figures by blind and sighted individuals. The findings allow the conclusion that, while visualizing shapes explored by touch, sighted individuals retain the size of the objects in their working memory and while comparing figures of various sizes they perform the process of mental scaling. By contrast, the size of objects does not seem to be of significance in mental representations created by blind individuals.

Keywords: blind vs. sighted individuals, imagery, mental scaling.

THEORETICAL INTRODUCTION

The present experiment was designed to compare the ways congenitally blind and sighted individuals perform the operation requiring an enlargement of mental representations, otherwise known as mental majorization or scaling. The study can be viewed in the context of the so-called imagery debate, in which the main opponents are Stephen Kosslyn and Zenon Pylyshyn (cf. e.g., Francuz, 2007; Pylyshyn, 2007). Its findings can be treated as another argument in the discussion concerning the nature of mental imagery, where, on the one hand, its

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analogue or spatial quality is assumed by Kosslyn, and on the other hand, in accordance with Pylyshyn's approach, mental imagery is viewed as an epiphenomenon, cognitively penetrable, that is, requiring the use of tacit knowledge.

A number of studies show that sighted and blind individuals have similar abilities to create mental representations based on haptic perception (research review: Cornoldi & Vecchi, 2003). Notably, however, individuals with no visual experience face specific difficulties while performing imagery operations. Using the terminology proposed by Cornoldi and Vecchi (2003), the passive component of visuo-spatial working memory, responsible for maintaining a mental representation, operates as efficiently in the blind as in sighted persons; on the other hand, the active component, involved in imagery processing, is more effective in sighted individuals than in the blind, especially if the spatial task is more complex (cf. Vecchi, 1998).

Vanlierde and Wanet-Defalque (2004) demonstrated empirically that tasks requiring the involvement of the active component of visuo-spatial working memory could be performed by blind and sighted individuals with similar accuracy, provided that the blind subjects were allowed to employ a preferred imagery strategy. The authors concluded that blind persons tend to use a sequential verbal strategy, while sighted individuals employ a visualization strategy. The subjects participating in Vecchi's experiment (1998) performed tasks where they were required to mentally follow a moving point (while maintaining the spatial pattern in memory); by contrast, Vanlierde and Wanet-Defalque (2004) asked subjects to perform the task of folding the imagined pattern in half. It is possible that during some mental operations the active component of visuo-spatial working memory functions equally effectively in sighted persons and in those with no visual experience; yet, there may also exist such operations during which the costs of loading the active component of visuo-spatial working memory are higher in the blind than in sighted individuals (yet, the differences in the results of the experiments may have been related to the fact that one of these experiments used a single task and the other applied a double task; cf. also: Aleman, van Lee, Mantione, Verkoijnen, & de Haan, 2001).

The mental operation referred to by Młodkowski (1998, p. 255) as majorization mainly involves "a relatively uniform increase in the entire image or only its central fragment." In English language publications the operation is called "scaling" (cf. Bennett & Warren, 2002; Larsen & Bundesen, 1978). Scaling is a more general term referring to a process of changing the size of mental images, including the operation of mental enlargement and mental reduction, the latter being called mental minorization.

The ability to enlarge or reduce objects mentally seems to be strongly linked with previous visual experience. What sighted individuals, experience in their visual perception on a daily basis is images of objects viewed from various distances getting larger or smaller (owing to the size constancy developed in infancy – cf. e.g., Slater, Mattock, Brown, 1990, sighted individuals treat physical dimensions of such objects as identical despite a change in angular size). What blind individuals learn from experience is that objects retain their dimensions regardless of their relative distance (e.g., a stone held in one's hand does not change its size when the arm is extended away from the body).

Studies that demonstrated limitations in the mental minorization process in individuals with no visual memories (congenitally blind or early blind) were conducted by Arditi, Holtzman, and Kosslyn (1988) as well as Vanlierde and Wanet-Defalque (2005). Arditi and colleagues (1988) designed an experiment where the subjects were asked to imagine objects at three increasing distances and to estimate their angular size by pointing to the location of their edges. The experimenters found out that the rules of perspective were ignored by the congenitally blind subjects; unlike the sighted subjects, they did not mentally scale down the receding objects. Comments made by the blind subjects suggested that they did not understand the task. They said, for instance, that the image was always the same, regardless of the distance, or that the receding objects became bigger because it was necessary to reach further out to get them. In a corresponding study carried out by Vanlierde and Wanet-Defalque (2005), as many as 40 per cent of the blind subjects with no visual memories made a comment that the experimental task did not make sense because an object's size was always the same. For comparison, objects mentally represented to be moving away from the observer were scaled down, following the rules of perspective, both by the sighted and the late blind subjects. On the other hand, case studies show that some individuals with no visual memories are able to accurately scale the size of imagined objects, which is manifested in their drawings (cf. e.g., Kennedy & Juricevic, 2006). Yet, it seems that in order to be able to draw pictures applying the rules of perspective a blind artist should be well-trained in creating tactile graphics.

In the case of sighted individuals, size is an important property not only of visual (cf. Ullman, 1989) but also of haptic representation of an object, which was demonstrated by Craddock and Lawson (2009) in a study of visual-to-visual, haptic-to-haptic, and crossmodal recognition. The task involved shape recognition, and the subjects' performance was poorer when the object changed its initial size than in the situation when the model and test stimuli were of the same

size. One of the first experiments focusing on mental size scaling was conducted by Larsen and Bundesen (1978). The subjects were shown a sequence of paired slides depicting flat figures and were asked to decide, as quickly as possible, whether the sequentially displayed figures were identical or different, regardless of their size. The reaction time, which increased with a growing difference between the sizes of the compared figures, constituted approximately a linear function of the size ratio of the displayed pairs of objects. Another experiment focusing on mental size scaling (Bennett & Warren, 2002) confirmed that the time needed for comparing stimuli increased with the growing size ratio of the viewed objects. Additionally, the response time is not as significantly impacted by retinal size as it is by environmental size, which is deduced based on retinal size and contextual information from the environment (in the above study the context was provided by a perspective drawing against which the compared objects were placed).

Longer recognition time in the case of objects with changed size confirms the so-called perceptual metaphor, according to which imagery is a process analogous to perception, as postulated by Kosslyn (cf. e.g., Kosslyn, Pinker, Smith, & Shwartz, 1979; Pylyshyn, 2007). Notably, however, the reviewed studies focusing on mental scaling were conducted with groups of sighted subjects who could apply tacit knowledge of optics while performing the tasks and who behaved in accordance with that knowledge. In order to see an object with changed dimensions, one must get closer to or further away from it (or wait for the object to get closer to or further away from the observer), and this requires time. Therefore, while solving the aforementioned experimental tasks subjects could operate only on a set of statements, and any images potentially occurring in their minds constituted a side effect of sentence processing. This would be consistent with the cognitive approach presented by Pylyshyn (2007) regarding the way imagery operates.

In the context of the debate on the nature of imagery it would be a good idea to examine the operation of people who have never had the ability to see. Many studies show that imagery processes occur in similar ways in blind and sighted individuals. For example, a task of finger tapping, imposing additional load on working memory and, consequently, constituting competition for an imagery task, makes it equally difficult for sighted and blind persons to perform an imagery task (Aleman et al., 2001). Marmor and Zaback (1976) demonstrated that in the case of both blind and sighted subjects the time necessary to compare pairs of tactile figures depended on the angle of rotation of the objects relative to each other. Furthermore, the experiment focusing on mental scanning carried out by

Kerr (1983) showed the effect of distance in the group of blind subjects – the length of time needed to mentally travel the way between objects spread over a small area increased with the growing distance between these objects. Therefore, the results of studies on scanning and rotation suggest that functional equivalence of imagery and perception processes is characteristic for blind individuals. Yet, it is unclear whether this equivalence is a result of the analogue nature of imagery or whether perhaps the above findings are an effect of using tacit knowledge. Will this kind of equivalence be identified if blind subjects are asked to perform a task which, by its design, requires mental scaling, that is, involves comparison of objects varied by size? Importantly, people with no visual experience, using the sense of touch in daily situations, may acquire knowledge related to the fact that rotating an object by a smaller angle requires less time than rotating it by a larger angle, and that the time needed to move one's hand from object to object depends on the distance between them; yet, they will not unwittingly acquire the knowledge of optics.

To sum up, the research findings reviewed above show that, while imagining an object sighted individuals retain, for example, information related to its size in their working memory. The recognition of an object that has changed its size requires more effort from them than the recognition of an object having the same size as the memorized model. This is because in the former case they must perform the operation of mental size scaling, which requires the involvement of the active component of visuo-spatial working memory. It is typical for blind individuals to concentrate on spatial relations between the components of a stimulus subject to mental representation rather than focus on its size. Therefore the following hypothesis was formulated: blind individuals recognize an enlarged figure as quickly as the original size figure, while sighted individuals need more time to recognize an enlarged figure than they do to recognize the same-size figure. The study was also designed to determine whether there is a difference in the accuracy with which blind and sighted individuals recognize shapes of greater size than the respective models and whether that is related to the complexity of the figure (task difficulty level).

METHOD

The group taken into account in the analyses consisted of 22 subjects (6 females), constituting two equal subgroups – congenitally blind persons and sighted persons – matched by gender, age (from 18 to 36 years), laterality (hand-

edness), and education level (at least secondary). The mean age of the sighted subjects was 24.18 ($SD = 5.49$), and the blind subjects were, on average, 24.27 years old ($SD = 5.41$).

The experiment was based on a repeated measures design that included a between-subject variable, namely vision-related characteristics of the subjects (congenitally blind vs. sighted subjects). The within-subject variables were: the complexity of the tactilely presented figures (simple vs. complex) and the surface of the test figure (unchanged in relation to the model vs. enlarged in relation to the model).

The research material comprised 40 tactile drawings depicting asymmetric and asemanic shapes (sample drawings are shown in Figure 1). Each drawing consisted of a frame with a side of 20 cm, inside which a single figure was located. The figures differed in terms of complexity. Simple figures had 10 angles, and those with 20 angles were defined as complex figures. The model figures had a surface of 40 cm² in the tasks where the surface of the test figure was unchanged in relation to the model and 10 cm² in the tasks where the test figure was enlarged. As regards their shape, some test figures were identical with and some differed from their respective models. In the latter case, the location of a single element in the test shape (a square with a side of 2 cm) was changed in relation to the model figure.

The sighted individuals were blindfolded during the trials. A single task involved the memorization of the model shape; no time limit was defined for that. Then, without delay, a test figure was presented. The subjects answered the question of whether the shape was identical with the model figure. Stopwatch was used for measuring the time needed for recognition (from the moment the subjects first touched the drawing to the moment they provided the answer). Performance accuracy was assessed by giving one point for both the correct recognition of a shape identical with the model and for the correct rejection of a shape differing from the model. The trials were conducted in two series, with 10 randomly displayed tasks in each (with equal proportion of simple and complex figures). The first series consisted of model and test figures with the same surface, and in the second series the test figures were enlarged in relation to the model.

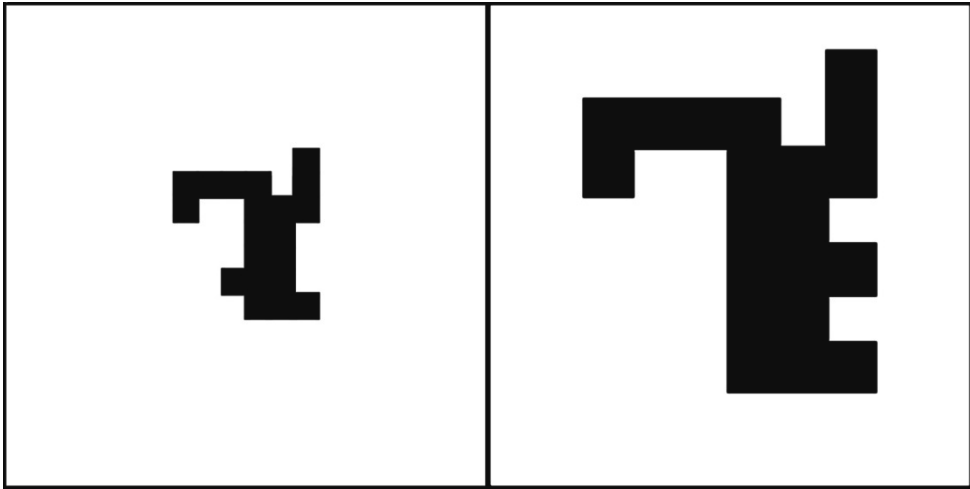


Figure 1. Sample figures of higher complexity. On the left there is a model figure and on the right there is the test figure, enlarged in relation to the model and differing in shape.

RESULTS

Analysis of variance was conducted for recognition times, with participants' visual status as between-subjects factor and figure complexity and test figure surface as within-subjects factors. Significant main effect was observed for the visual status variable, $F(1, 20) = 15.64$, $p < .001$, $\eta^2 = .44$ – the blind subjects took the decision significantly more rapidly, $M = 9.95$, $SE = 2.98$, than the sighted subjects, $M = 26.60$, $SE = 2.98$ – as well as for test figure surface, $F(1, 20) = 24.22$, $p < .001$, $\eta^2 = .55$ – the subjects needed more time for recognition when the test figure was enlarged in relation to the model, $M = 21.13$, $SE = 2.20$, in comparison to the condition where the surface of the test figure was equal to that of the model, $M = 15.42$, $SE = 2.17$. The findings also showed significant interaction of visual status and test figure surface factors, $F(1, 20) = 7.78$, $p = .011$, $\eta^2 = .28$. Post-hoc Scheffe's tests showed that only the sighted subjects needed more time to recognize enlarged figures in comparison to same-size figures ($p < .001$; see Figure 2), while the blind subjects needed a similar amount of time to recognize both types of test figures ($p = .531$). The main effect of figure complexity turned out to be statistically insignificant, $F(1, 20) = 0.27$, $p = .612$.

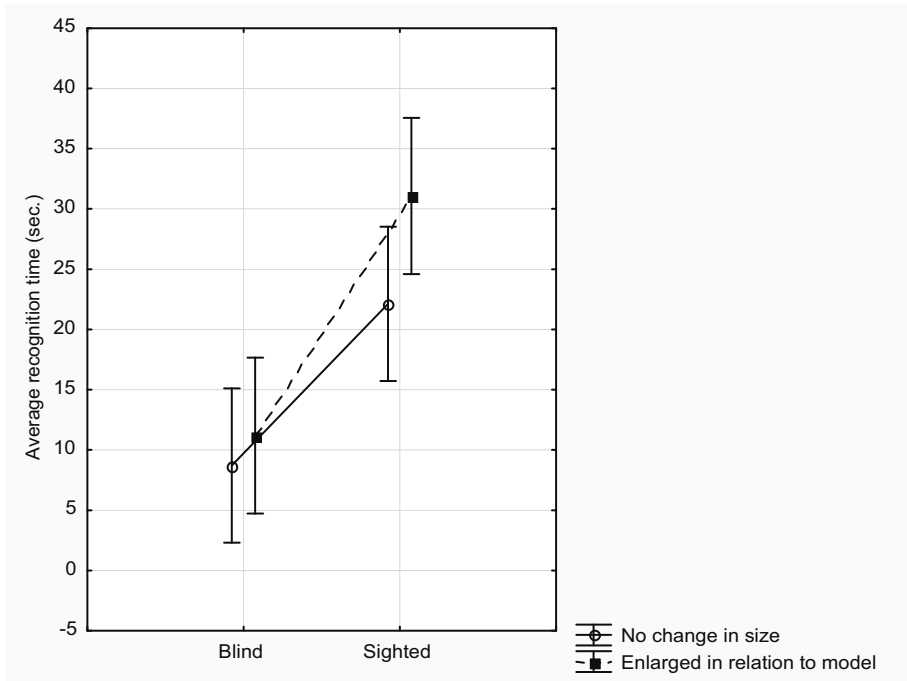


Figure 2. Interactive impact of the subjects' visual status and test figure surface on recognition time. The vertical bars represent 95% confidence intervals.

Analysis of variance assuming the same independent variables was performed for the dependent variable of response accuracy. The results showed neither significant main effect for the factors of visual status, $F(1, 20) = 3.07$, $p = .095$, size of test figure, $F(1, 20) = 3.55$, $p = .074$, and figure complexity, $F(1, 20) = 0.03$; $p = .865$, nor any interactions.

DISCUSSION

The research hypothesis was confirmed – the sighted subjects needed more time to recognize enlarged tactile figures than same-size ones, which was not observed in the group of blind subjects.

The experiment provides evidence supporting the claim that the size of an object is an important characteristic of mental representations invoked by sighted people (cf. Bennett & Warren, 2002; Craddock & Lawson, 2009; Larsen & Bundesen, 1978; Ullman, 1989). Yet, is this caused by the fact that sighted indi-

viduals visualize the stimuli they touch (cf. Vanlierde & Wanet-Defalque, 2004), and can see not only their shape but also the size with their “mind’s eye”? Not necessarily. It is also possible that they do not visualize tactily explored figures in any way but use tacit knowledge instead; if this is so, mental images may but do not have to appear because they are a side effect of operations performed on symbols (cf. Pylyshyn, 2007).

The significantly longer time needed for recognizing an enlarged figure than a same-size one showed that the operation of majorization (mental size scaling) was performed if the model was smaller than the test figure. The results obtained for haptic stimuli are consistent with evidence acquired in earlier experiments, where the stimuli – asemantic drawings – were presented visually (Bennett & Warren, 2002; Larsen & Bundesen, 1978), and correspond with the findings reported by Craddock and Lawson (2009), who investigated the process of learning followed by recognition of semantic three-dimensional models in haptic conditions. At the same time, the evidence acquired by the present study contributes new information to the existing knowledge. Functional equivalence of imagery and perception during mental scaling operations was demonstrated for a new type of haptic stimuli, namely for abstract flat figures. Furthermore, contrary to the experiment described by Craddock and Lawson (2009), the present study did not show a decrease in recognition accuracy in the case of enlarged figures in comparison to same-size figures. In order to identify the factors responsible for the divergent findings reported by these studies, it would be a good idea to conduct an experiment manipulating both the semantic property of the haptic stimuli and the number of their dimensions (3D vs. 2D).

The obtained results suggest that size does not constitute a significant characteristic of mental representations in the case of congenitally blind people, which was earlier demonstrated by studies involving individuals with no visual memories (Arditi, Holtzman & Kosslyn, 1988; Vanlierde & Wanet-Defalque, 2005). Because of their preference for verbal imagery strategies (cf. Vanlierde, Wanet-Defalque, 2004) the blind subjects may have memorized the spatial stimuli taking into account their descriptions reflecting the relations between their constituents. Consequently, they did not need to scale up the mental picture when the test stimulus was larger than the model. Whether or not a test figure was larger than the model, in order to compare their shapes it was enough for them to simply examine the constituents of the two figures.

The findings suggest a negative answer to the formulated research questions. Recognition accuracy did not differentiate the blind and the sighted subjects and it did not depend on the complexity of the explored figure.

The blind subjects recognized enlarged and same-size figures as accurately as the sighted subjects. It was sufficient to engage the passive component of visuo-spatial working memory in the process of recognizing figures having the same size as their models; therefore, the lack of differences is understandable in the context of earlier studies (cf.: Cornoldi, Vecchi, 2003; Vecchi, 1998). On the other hand, the task of recognizing figures with enlarged surfaces probably involved a process of scaling up their mental representations; in other words, it required the engagement of the active component of visuo-spatial working memory, but only in the case of the sighted subjects, whereas the blind subjects used the passive component of visuo-spatial working memory during the task of recognizing an enlarged shape, which means the task required fewer resources from them.

In order to explain why the accuracy of the responses was not affected by the complexity of the figures, it is necessary to remember that, in accordance with the experiment's design, the subjects could take as much time as they needed to tactilely explore and memorize the model figures. It is possible that an alternative procedure, with a fixed time allowed for learning the models, would yield different results. Yet, such procedure would be disadvantageous for the sighted subjects, who are not experienced in exploring embossed pictures (this is reflected by the results of the present study: the blind subjects recognized haptic figures significantly more quickly than the sighted participants).

Possible limitations of the present study include the fact that the scores achieved by the sighted subjects may have been impacted by a lack of tactile training, and those achieved by the blind participants may have been confounded by their varied experience in using tactile graphics (this variable was not controlled in the study). For this reason, further studies could include a training procedure for sighted participants, designed to familiarize them with the use of touch but unrelated to the recognition of same-size and enlarged shapes. Future studies could also attempt to control the variable of experience in using tactile graphics in the group of blind subjects.

Going back to the purpose of the study – it was impossible to determine whether the mental majorization operation occurs in different ways in blind and sighted individuals, because the sighted subjects probably did not perform the process of mental size scaling while solving the experimental tasks. Therefore, it seems that in order to continue the investigation of the problem it is necessary to design experimental tasks that will explicitly relate to comparing the size of tactilely explored figures.

It is extremely likely that while performing the task of comparing same-size and enlarged tactile stimuli both the blind and the sighted subjects applied tacit knowledge, which significantly differs in the two populations (sighted people have tacit knowledge of optics), and due to this mental representations were subject to these specific transformations in the two groups. Therefore, in the context of the imagery debate, the findings of the present study provide support for the propositional approach postulated by Pylyshyn. He questions Kosslyn's assumption about the "spatial" nature of imagery and argues that mental images do not have size or length but only represent these measures. Thus, according to him, size is a quality of represented objects rather than a characteristic of representations of these objects (e.g., Pylyshyn, 2007).

The acquired findings can be applied in practice, for example in spatial orientation learning. In the process of exploring new areas blind individuals frequently use tactile miniature models or drawings. The obtained results suggest that the use of such scale models should not make it more difficult for the blind to learn new routes.

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