

---

# The Role of Visual Experience in Changing the Size of Objects in Imagery Processing

Magdalena Szubielska and Bogusław Marek

---

**Structured abstract:** *Introduction:* This paper investigates the question of whether or not subjects who are congenitally blind experience greater difficulties mentally in resizing images of objects than those who have low vision or are adventitiously blind. *Methods:* Two experiments were conducted: one in which subjects were asked to mentally enlarge objects they previously explored manually, and one in which subjects were tested for the ability to demonstrate the change in the size of an object imagined to be moving away. Three groups of high school students with visual impairments took part in the experiment: congenitally blind, “late blind,” and those with low vision. *Results:* When showing the linear size of an object enlarged in their imagination, congenitally blind participants overestimated its size more frequently than those who were late blind. The degree of mental reduction of the size of an object imagined to be moving away was comparable for all groups. *Discussion:* The results suggest that the difficulties experienced by congenitally blind participants with the mental resizing of objects may be related to problems with performing mental scaling transformations. In the low vision group, the etiology of the subjects’ visual impairment was not taken into consideration. The group turned out to be heterogeneous with respect to imagery processes. *Implications for practitioners:* When using models for explaining new concepts, it is important to ensure that congenitally blind learners understand the change of scale.

---

The influence of visual experience on spatial imagery is still not fully under-

---

This work was supported by the Ministry of Science and Higher Education, Republic of Poland, grant no. N N106 279339. The authors would like to thank the anonymous reviewers for their detailed comments and helpful critical remarks on an earlier version of this article. Special thanks go to Professor John. M. Kennedy for drawing our attention to some important publications and for his helpful methodological advice. Last but not least, we would like to thank Robert Looby for lending his na-

stood. Although numerous experiments have been interpreted as showing considerable limitations in the functioning of imagery processes in people who are totally blind, especially those who were born blind or had early onset of blindness, there are studies suggesting that no significant differences in this area can be detected between blindfolded sighted and nonsighted individuals. There are claims

---

tive speaker’s intuition to make the language of this article more digestible.

---

that in some cases persons deprived of visual experience perform better than blindfolded sighted individuals (for a review, see Cattaneo et al., 2008). The differences in the results of the experiments reported in this and in other sources seem to follow from the specificity of the imagery task rather than from the imagery operation (mental imagery activity) being tested (see, for example, Cornoldi & Vecchi, 2003). Testing imagery scaling operations may serve as an example. Mental scaling transformation is an operation that involves changing the size of an image found, for example, when sighted persons compare objects (Larsen & Bundesen, 1978). The reaction time increased with the size ratio of objects (see also Bennett & Warren, 2002; Craddock & Lawson, 2009). Some research suggests that adults without prior visual experience do not understand that the size of an object imagined to be moving away must be reduced in accordance with the principle of perspective (Arditi, Holtzman, & Kosslyn, 1988; Vanlierde & Wanet-Defalque, 2005). There is, however, research providing evidence that it is unlikely that these difficulties result from an inability to perform the operation of mental scaling (Kennedy, 1993; Wnuczko & Kennedy, 2014).

For clarity of argumentation, it is important to distinguish between linear size (which can, for example, be measured in centimeters), and angular size. The linear size of a particular object is an objective property that does not change over time. The ability to evaluate the linear size can therefore be treated as an indication of conceptual knowledge related to typical sizes of objects encountered in the real world. These sizes may change only in fantasy (for example, in *Alice in Wonderland*). In visual perception, the angular

size—that is, the angle at which the observed object subtends at the eye—changes with the distance between the object and the observer. Angular size is usually measured in degrees of the arc, although in some research it was shown by pointing to the ends of the imagined object. In those cases the pointing span indicated the angular size (see, for example, Arditi et al., 1988).

In visual perception, identical objects placed at different distances from the observer create images on the retina that differ in size. It is also possible to determine the changing pointing span for these objects. The size differences are reflected in verbal descriptions: a lake observed from an airplane may be compared to a puddle, and a dog observed from a distance may seem as small as an ant. We get this impression despite being aware that the linear size of these objects does not change (this is the mechanism of size constancy). Visual angular size has its analogy in imagery. Kosslyn (1978) defines *angular size* as the visual angle of the mind's eye, and provides empirical evidence that sighted persons imagine objects as being a certain distance away from the mind's eye.

Sighted persons first experience size constancy in infancy (Slater, Mattock, & Brown, 1990). This constancy, functioning as automatic inference, makes it possible to assess the linear size of an object on the basis of its optical size and the distance. The accuracy of the inference involved in the process of visual perception improves gradually, and at early school age is not yet fully developed (Granrud & Schmechel, 2006). Developmental progress in understanding the relationship between angular and linear size can be observed in drawings made by sighted children. On reaching the

---

stage of visual realism around the age of eight or nine (Luquet, 1927), they apply the principle of perspective. At the visual realism stage in the development of drawing, children typically represent only what can be observed from a particular vantage point and show how it is perceived by the observer; for example, by using foreshortening (Luquet, 1927). More recent studies (Bremner & Batten, 1991; Cox, 1981) provide evidence that at the age of as early as five or six sighted children employ perspective and can show the depth relationship between objects.

Persons who are congenitally blind experience the change of angular size through touch. By extending their hands or arms, visually impaired persons can understand the principle of convergence to the horizon (see, for example, Kennedy, 1993; Kennedy & Juricevic, 2006c). Also, living in a “sighted world,” they gain declarative knowledge of the functioning of visual perception and use it in interactions with sighted persons (see Bigelow, 1988; Brambring, 2005). Understandably, although persons who are blind progress in their drawing abilities (with a delay, but otherwise similarly to sighted persons), the stage of visual realism is in most cases beyond their reach (D’Angiulli & Maggi, 2003; Heller, Calcaterra, Tyler, & Burson, 1996; Kennedy, 1993). There are, however, exceptional individuals—for example, Tracy, a totally blind adult woman who lost her sight before the age of two—whose drawings confirm full understanding of the principle of perspective. In Tracy’s drawing of three rows of tumblers, she showed depth: the glasses were smaller in rows more distant from the observer (Kennedy & Juricevic, 2003). Similarly, an untypical case is that of a 51-year-old man, totally blind since birth, who can not only make drawings of objects that are

easily recognized by sighted persons but who also uses the principle of convergence (Kennedy & Juricevic, 2006a, 2006b).

Some research suggests that persons who are blind tend to have problems with reducing the angular size of objects. Arditi et al. (1988) conducted an experiment in which congenitally blind and sighted adult subjects were asked to imagine three different objects at growing distances (3, 10, and 30 feet), and to evaluate the objects’ size by demonstrating the position of their edges with their hands: “to point to where the ends would be if the object were actually present and being seen as it appeared in the image” (p. 9). In the experiment, congenitally blind subjects correctly showed large pointing spans for large objects but failed to decrease the angles as the distance at which the objects were to be imagined was increased. They argued that the imagined objects were of the same size in all locations (or even that they got larger as they moved away because touching them required reaching out farther). The researchers interpreted this as “a fundamental lack of perspective” in congenitally blind subjects’ images (p. 9).

A similar procedure was adopted by Vanlierde and Wanet-Defalque (2005), who asked three groups of adults—“early blind” (those who experienced vision loss before age 3), “late blind,” and fully sighted subjects—to imagine an object at distances of 1, 3, and 9 meters. The task was to show the size of the object at each distance: “to point on a ruler (attached to the table in front of them) to the left and right sides of the object with their left and right index fingers” (p. 173). The authors of the article do not say which kind of size (linear or angular) was to be demonstrated by the

---

subjects. One can only speculate that the experimenters were interested in the angular size but no such definite statement is made (which suggests that the subjects may have had similar doubts about the task).

Late blind persons, retaining memories of visual experience and effectively using the *visualization strategy* (Vanlierde & Wanet-Defalque, 2004), which involves the creation of a visual image in the mind's eye (Pearson, 2010), perform image-building tasks in a way similar to that typical for sighted individuals. Both groups decreased the size of the image with increasing distance. No effect of distance change, however, was found in the group of early blind subjects. Moreover, 40% of early blind subjects were of the opinion that the task did not make sense, as objects do not change their size. These results may be an effect of ambiguous instructions or of literal interpretation of the instructions. It is possible that congenitally blind persons, who cannot observe the change of angular size, indicated the typical (linear) size of the object, while those participants who were late blind or sighted evaluated the angular size. Also, the constant distance marked by the location of the ruler may have biased the performance.

Kennedy's experiment (1993) shows that blind children understand that as distance increases objects appear to decrease in size. The experiment was performed as follows: initially, the children were moved from the central section of a 4.5-meter-long wall to one of the corners of the room, then back to the starting point, then to the other corner and again back to the central section. In the next part of the experiment, the children were asked to step away from the wall. The children were placed at two distances from the wall—first 1 meter and then 3.5 meters. Their task was to point to each end of the

wall using both hands. The procedure that was adopted for the experiment may help explain the differences in the results of this test and those obtained with adult subjects in the experiments described earlier (Arditi et al., 1988; Vanlierde & Wanet-Defalque, 2005). The angle between the arms depends on the imagined distance to the edges of the object being pointed at, which explains why the children in Kennedy's experiment reduced the angle between their arms when they tried to point to the edges of the whole wall from which they had stepped back. This finding, however, does not necessarily mean that they reduced the angular size of the image of the wall, although such a possibility cannot be excluded (see the concept of amodal spatial images, Loomis, Klatzky, & Giudice, 2013).

Kennedy (1993) examined two groups of blind children, one from Haiti and the other from the United States. All children evaluated the length of the wall as shorter when they pointed to it from a more distant location. The children from Haiti, aged from 9 to 18, were all adventitiously blind, with an average onset of blindness at the age of 8.5 years (some of the participants became blind before age 2, but it must be noted that although the age was declared by the participants themselves, not all of them were sure that the information they provided was correct). Their visual memory may have contributed to their success in performing the experimental task (Vanlierde & Wanet-Defalque, 2005). The American children (from Tucson) in Kennedy's (1993) experiment (who were congenitally blind and ranged in age from 5 to 14 years) had prior exposure to tactile graphics, which are believed to stimulate development of spatial imagery (Dulin & Hatwell, 2006). It is not known, however, if the adults taking part in

---

the experiments described earlier (Arditi et al., 1988; Vanlierde & Wanet-Defalque, 2005) had similar tactual experience. Another difference between the two studies that may have led to different results was the age of the subjects. Although the participants of the experiments conducted by Arditi et al. (1988) and by Vanlierde and Wanet-Defalque (2004) were all adults, the subjects studied by Kennedy (1993) were children.

Also, Wnuczko and Kennedy (2014) have empirically confirmed that blind persons have no problems reducing the angular size of distant objects. In their experiment, subjects were asked to point to different azimuths. The results obtained from blind participants did not differ significantly from those of sighted subjects. In both cases the azimuth decreased with growing distance. The study was similar to that described in Kennedy (1993) in that the subjects could touch the objects and were able to move within the space containing the objects. In the 2014 experiment, subjects guided by experimenters explored two paths of tactile circles, touching them with a one-meter-long stick. A limitation mentioned by the researchers was the small number of blind subjects (six) as well as the fact that the group was diverse. Only two subjects were blind since birth, including one with light perception in one eye.

Persons who are blind create more accurate (that is, closer to linear size) representations of objects perceived by touch than do sighted persons. This finding was confirmed in experiments with adults (Smith, Franz, Joy, & Whitehead, 2005) who were asked to indicate with their index fingers the size of the image of various grocery items previously explored manually. The group included subjects who lost their vision in the first three

years of life (classified by the researchers as congenitally blind) and adventitiously blind persons. The results achieved were calculated for the group as a whole and not for each subgroup.

Persons who are blind are also more accurate at evaluating the real length, surface area, and volume of familiar objects, which was confirmed in experiments involving children aged nine to thirteen (Andreou & Kotsis, 2005). Both sighted and blind adults (congenitally, early, and late blind) and sighted children with severe vision loss were found to be more accurate in evaluating the real, typical size of common objects if they were allowed to apply subjective units of measurement (for instance, indicating the number of steps that needed to be made to cover a certain distance) than when asked to describe the size or a distance in centimeters or meters (Andreou & Kotsis, 2005; Dulin, 2008). This finding suggests that in order to avoid mistakes in the evaluation of blind persons' ability to estimate the size of objects, it is advisable to avoid using objective units of measurement and to not ask the subjects to give the estimated values in, for example, centimeters.

To sum up, persons who are blind since birth tend to find it difficult to evaluate the angular size of objects that they imagine to be moving away (although the findings described in various studies are not unanimous: Arditi et al., 1988; Vanlierde & Wanet-Defalque, 2005; vs. Kennedy, 1993; Kennedy & Juricevic, 2003, 2006a, 2006b; Wnuczko & Kennedy, 2014). These findings are why it is important to examine whether the difficulties that children born blind experience when evaluating the angular size of mental images of objects are the result of poor understanding

---

of the rules governing visual perception, or whether perhaps such difficulties may be related to the subjects' inability to modify the size of images of objects. Two hypotheses were proposed. Because they lack visual experience: (1) congenitally blind students are less accurate in enlarging images of objects previously explored manually (in the process of mental scaling), and (2) they are less likely to reduce the angular size of objects imagined to be moving away than are students with low vision or those who are late blind. As was shown earlier, in the sighted population the understanding of perspective develops by early school age. This development is why it is important to establish whether or not the ability to perform mental scaling by children with significant vision loss improves with age.

## Methods

The experiments reported in this article are part of a larger project approved by the Scientific Research Ethics Committee of the Institute of Psychology at the John Paul II Catholic University of Lublin.

## PARTICIPANTS

Thirty primary and junior high school students were examined in the experiment. The age of the participants ranged from 6 years and 11 months to 18 years, and the mean age was 13 years and 4 months ( $SD = 2$  years and 9 months). The group included 11 congenitally blind students (7 females and 4 males aged  $M = 12$  years and 9 months,  $SD = 3$  years); 8 late blind participants who lost their vision at the age of 3 or later and retained memory of visual representations (6 females and 2 males aged  $M = 15$  years,  $SD = 2$  years and 2 months); and 11 students with low vision (5 females and 6 males aged  $M = 12$

years and 8 months,  $SD = 2$  years and 6 months). Blind subjects had, at most, light perception. The participants came from two special schools for students with visual impairments in Poland. All blind students had prior exposure to tactile graphics (in geometry, in classes supporting braille literacy, and while reading books with tactile illustrations). Participants declared substantial experience with tactile graphics: 72.2% of the congenitally blind group and 37.5% of the adventitiously blind group.

## MATERIALS

A giraffe toy that was 10 centimeters (about 4 inches) tall from a LEGO Duplo set and a piece of string were used in the experiment.

## PROCEDURE

Subjects were asked, in a fixed order, to mentally enlarge an object (Experiment 1) and to estimate the angular size of an object moving away (Experiment 2). The independent variable in these experiments was the visual status of participants.

A toy giraffe was used in Experiment 1. Before performing the task, students explored the toy manually. They were free to choose the method of exploration and no time limit was set. The toy was then removed, and the subject's task was to imagine that the toy was growing like a balloon until it was four times as big as it was originally. Next, the subjects were asked to demonstrate the linear size of the enlarged giraffe on the piece of string. The experimenter then measured the relevant section of the string in centimeters.

In Experiment 2, subjects were asked to imagine a spoon placed at three different distances (in a particular order): on the subject's lap, on the lap of a person sitting 10

**Table 1**  
**Assessment of size in experiments 1 (E1) and 2 (E2) by participants who are congenitally blind, “late blind,” or have low vision.**

Dependent variable	Congenitally blind			Late blind			Low vision		
	<i>M</i>	<i>Me</i>	<i>SD</i>	<i>M</i>	<i>Me</i>	<i>SD</i>	<i>M</i>	<i>Me</i>	<i>SD</i>
Linear size of the enlarged giraffe (E1)	59.00	57.00	13.91	47.75	46.00	15.95	47.36	44.00	17.39
Overestimation error (E1)	19.00	17.00	13.91	7.75	6.00	15.95	7.36	4.00	17.39
Pointing span of the spoon on the lap (E2)	24.09	18.00	20.65	22.00	22.00	5.66	20.00	19.00	2.79
Pointing span of the spoon 10 steps away (E2)	22.00	16.00	16.31	17.38	17.50	6.19	25.18	14.00	27.83
Pointing span of the spoon 20 steps away (E2)	21.82	10.00	22.90	16.00	13.50	14.38	28.45	8.00	49.23
The difference in the estimated size (pointing span) of the spoon between initial and final locations (E2)	2.27	7.00	17.83	6.00	7.50	11.56	-8.45	12.00	47.70

*M* = mean, *ME* = median, and *SD* = standard deviation.

steps away and then on the lap of a person sitting 20 steps away. Each time the same question was asked about the angular size of the mental image of the spoon: “How big does the spoon appear to you?” Subjects showed the size of the spoon by holding the string at two ends of a section corresponding to the length of their image of the spoon. The experimenter measured (in centimeters) the pointing span; that is, the length of the section of the string indicated by the subjects.

## Results

Because of the small number of subjects, non-parametric tests were used for comparing the results received for each group. The median test, that is, the analysis of k-between-group data, is based on contingency tables. For each group, the number of cases that fall above and below the median is established. The Mann-Whitney *U*-test, that is, the analysis of two-between-group data, tests the effects of differences in the location of the two trials to check how frequently results obtained for one group are higher (or lower) than in the second group.

## EXPERIMENT 1

The linear height of the correctly enlarged toy giraffe was 40 centimeters (about 16 inches). One congenitally blind and two low vision subjects correctly estimated the size of the giraffe enlarged in imagery. After calculating the mean value of the assessed size, it was confirmed that all groups had a tendency to exaggerate the size of the mentally enlarged toy (see Table 1). However, 23.3% of the subjects (including one congenitally blind, three late blind, and three participants with low vision) underestimated the size of the giraffe after mental enlarging.

The groups differed considerably in the extent of the overestimation error, understood as the difference between the evaluated size and the objective size of the enlarged toy,  $\chi^2 (2) = 7.23; p = .027$ . The error of overestimation was greater (on the border of statistical significance) in congenitally blind subjects than in subjects who were late blind ( $U = 20.50; p = .051$ ) (see Table 1). The differences between congenitally blind and low vision

---

subjects ( $U = 35.00$ ;  $p = .101$ ) and between late blind and low vision groups was not significant ( $U = 42.50$ ;  $p = .904$ ).

Correlations between age (measured in months) and the average overestimation error were not significant, both for the whole group ( $r = -.07$ ;  $p = .704$ ), and for the congenitally blind group ( $r = -.12$ ;  $p = .724$ ), the late blind group ( $r = -.05$ ;  $p = .905$ ), and students with low vision ( $r = .09$ ;  $p = .793$ ).

## EXPERIMENT 2

No differences related to the type of impairment were found in the estimation of the pointing span of the spoon in the three experiment settings: the spoon placed on the subject's lap— $\chi^2(2) = 1.28$ ;  $p = .527$ —and the spoon on the lap of a person sitting 10 steps away— $\chi^2(2) = 1.28$ ;  $p = .527$ —and 20 steps away— $\chi^2(2) = 4.36$ ;  $p = .112$ . The difference between the sizes of the spoon estimated for its initial and the most distant locations was not significant ( $\chi^2 = 4.98$ ;  $p = .083$ ).

Correlations between age and the difference between the initial and the final setting turned out to be insignificant both for the whole group ( $r = .29$ ;  $p = .125$ ) and for the individual groups of students: congenitally blind ( $r = .07$ ;  $p = .832$ ), late blind ( $r = -.39$ ;  $p = .337$ ) and low vision ( $r = .50$ ;  $p = .116$ ).

Three congenitally blind, one late blind, and three students with low vision did not reduce the pointing span of an imagined spoon placed at a greater distance. The large standard deviations found within the low vision group for the distances of 10 and 20 steps (see Table 1) suggest that the low vision group consisted of two subgroups—those who correctly reduced the angular size of the spoon with growing distance

and those who considerably enlarged it instead.

## Discussion

Hypothesis 1, tested in Experiment 1, was partly confirmed. Congenitally blind students were less accurate in estimating the linear size of the mentally enlarged toy than the group of late blind participants. By applying a visualization strategy, late blind participants could “see” the object grow in their imagery. Visualization of objects is a strategy preferred by both late blind and sighted individuals in performing imagery tasks (Vanlierde & Wanet-Defalque, 2004). We therefore suspect that using the strategy allowed late blind participants to be more accurate in evaluating the size of the object enlarged in their imagery than were the congenitally blind group. The results obtained by low vision participants did not differ significantly from those found for the congenitally blind group. The question remains: why do individuals with low vision have statistically similar performance to persons with congenital blindness? Unfortunately, no information was available about the etiology of visual impairment in the persons with low vision, which is one of the weaknesses of this study. It is possible that only some of the individuals had visual memory and could use the visualization strategy; that is, could “see the object grow” in their imagery. The remaining low vision subjects may have never seen well enough to apply visualization and preferred different imagery strategies, used also by congenitally blind persons—hence, persons from both groups gave similar answers.

Hypothesis 2, tested in Experiment 2, was not confirmed. All students—congenitally



---

blind, late blind, and those with low vision—equally reduced the angular size of the spoon that they imagined to be moving away. Optimistically, this may be taken to mean that congenitally blind students did not have greater problems understanding perspective than students who had some visual experience. Those participants who were congenitally blind, like those in Kennedy's (1993) study, had prior exposure to tactile graphics. They received special instruction that was intended to compensate for the absence of visual experience. It is possible that this experience helped them gain some knowledge about such principles governing vision as perspective and depth. The results achieved by the American children in Kennedy's (1993) study mentioned earlier may therefore be related not only to the fact that these children stretched their arms to point at the edges of the wall located at some distance but that they could understand the rules governing vision and the phenomenon of changing angular size. The results of Experiment 2 are incompatible with those achieved in experiments involving congenitally and early blind adults (Arditi et al., 1988; Vanlierde & Wanet-Defalque, 2005), confirming their greater imagery ability to reduce the size of objects moving away.

In Experiment 2, evaluating the size of a spoon moving away, less variation in the results (smaller standard deviation) was found in the late blind group than in groups of congenitally blind and low vision participants, where the standard deviation was quite high. This finding may confirm the tendency to use the imagery visualization strategy by late blind subjects. A tendency to apply this strategy in tasks engaging visuospatial imagery was also found by Vanlierde & Wanet-Defalque (2004) in blind persons with visual memory. Subjects from

the congenitally blind group may have used a variety of strategies, both imagery and verbal (see Schmidt, Tinti, Fantino, Mammarella, & Cornoldi, 2013), which may have contributed to the variety of results obtained for this group.

Contrary to the original hypotheses, students with low vision performed imagery tasks with the same level of accuracy as those who were congenitally blind. The experiments did not take into consideration the type and age of onset of partial vision loss, which may be important for visuospatial mental abilities (Monegato, Cattaneo, Pece, & Vecchi, 2007). The results found in Experiment 2 revealed heterogeneity in the low vision group. This finding must be treated as a limitation of our study and suggests that in future experiments involving subjects with low vision, the variables connected with the etiology of the visual impairment must be more strictly controlled.

The age of the students in both experiments did not affect their performance in imagery tasks. It may be that declarative knowledge about vision is more important than the age variable for successful mental resizing. This hypothesis must be verified in future research.

Summing up the results of the two experiments and comparing them with the results of earlier research, it can be stated that the difficulties congenitally blind persons experience with the process of reducing and enlarging the size of imagined objects may result not only from a lack of understanding of perspective but may also be related to difficulties with applying the process of mental scaling. It is therefore important to give congenitally blind students more opportunities to develop the ability of reducing and enlarging images and help them

---

understand the concept of scale. Creating such opportunities is essential for conceptual development. Not all concepts are accessible through direct haptic exploration of specimens (one thinks here of a lion, for example). Some objects may be too large (a house) or too small (an ant). In such cases, models can be an aid and may be useful on condition that learners are able to accurately perform mental scaling transformations.

## References

- Andreou, Y., & Kotsis, K. T. (2005). The estimation of length, surface area, and volume by blind and sighted children. *International Congress Series, 1282*, 780–784.
- Arditi, A., Holtzman, J. D., & Kosslyn, S. M. (1988). Mental imagery and sensory experience in congenital blindness. *Neuropsychologia, 26*, 1–12.
- Bennett, D. J., & Warren, W. (2002). Size scaling: Retinal or environmental frame of reference? *Perception & Psychophysics, 64*, 462–477.
- Bigelow, A. (1988). Blind children's concepts of how people see. *Journal of Visual Impairment & Blindness, 82*, 65–68.
- Brambring, M. (2005). Perceptual perspective taking in children who are blind: The state of research and a single-case study. *British Journal of Visual Impairment, 23*, 122–127.
- Bremner, J. G., & Batten, A. (1991). Sensitivity to viewpoint in children's drawings of objects and relations between objects. *Journal of Experimental Child Psychology, 52*, 375–394.
- Cattaneo, Z., Vecchi, T., Cornoldi, C., Mammarella, I., Bonino, D., Riccardi, E., & Pietrini, P. (2008). Imagery and spatial processes in blindness and visual impairment. *Neuroscience and Biobehavioral Reviews, 32*, 1346–1360.
- Cornoldi, C., & Vecchi, T. (2003). *Visuo-spatial working memory and individual differences*. Hove/New York: Psychology Press Taylor & Francis Group.
- Cox, M. V. (1981). Spatial depth relationships in young children's drawings. *Educational Psychology, 1*, 275–287.
- Craddock, M., & Lawson, R. (2009). Size-sensitive perceptual representations underlie visual and haptic object recognition. *PLoS One, 4*, e8009.
- D'Angiulli, A., & Maggi, S. (2003). Development of drawing abilities in a distinct population: Depiction of perceptual principles by three children with congenital total blindness. *International Journal of Behavioral Development, 27*, 193–200.
- Dulin, D. (2008). Effects of prior experience in raised-line materials and prior visual experience in length estimations by blind people. *British Journal of Visual Impairment, 26*, 223–237.
- Dulin, D., & Hatwell, Y. (2006). The effects of visual experience and training in raised-line materials on the mental spatial imagery of blind persons. *Journal of Visual Impairment & Blindness, 100*, 414–424.
- Granrud, C. E., & Schmechel, T. T. N. (2006). Development of size constancy in children: A test of the proximal mode sensitivity hypothesis. *Perception & Psychophysics, 68*, 1372–1381.
- Heller, M. A., Calcaterra, J. A., Tyler, L. A., & Burson, L. L. (1996). Production and interpretation of perspective drawings by blind and sighted people. *Perception, 25*, 321–334.
- Kennedy, J. M. (1993). *Drawing and the blind: Pictures to touch*. New Haven, CT: Yale University Press.
- Kennedy, J. M., & Juricevic, I. (2003). Haptics and projection: Drawings by Tracy, a blind adult. *Perception, 32*, 1059–1071.
- Kennedy, J. M., & Juricevic, I. (2006a). Blind man draws using diminution in three dimensions. *Psychonomic Bulletin & Review, 13*, 506–509.
- Kennedy, J. M., & Juricevic, I. (2006b). Fore-shortening, convergence and drawings from a blind adult. *Perception, 35*, 847–851.
- Kennedy, J. M., & Juricevic, I. (2006c). Form, projection and pictures for the blind.

- In M. A. Heller & S. Ballesteros (Eds.), *Touch and blindness. Psychology and neuroscience* (pp. 73–93). Mahwah, New Jersey: Lawrence Erlbaum Associates.
- Kosslyn, S. M. (1978). Measuring the visual angle of the mind's eye. *Cognitive Psychology, 10*, 356–389.
- Larsen, A., & Bundesen, C. (1978). Size scaling in human pattern recognition. *Journal of Experimental Psychology: Human Perception & Performance, 4*, 1–20.
- Loomis, J. M., Klatzky, R. L., & Giudice, N. A. (2013). Representing 3D space in working memory: Spatial images from vision, touch, hearing, and language. In S. Lacey & R. Lawson (Eds.), *Multisensory imagery: Theory & applications* (pp. 131–156). New York: Springer.
- Luquet, G. H. (1927). *Le Dessin Enfantin*. Paris: Alcan.
- Monegato, M., Cattaneo, Z., Pece, A., & Vecchi, T. (2007). Comparing the effects of congenital and late visual impairments on visuospatial mental abilities. *Journal of Visual Impairment & Blindness, 101*, 278–295.
- Pearson, J. (2010). Inner vision: Seeing the mind's eye. *Psyche, 16*, 1–8.
- Schmidt, S., Tinti, C., Fantino, M., Mammarella, I. C., & Cornoldi, C. (2013). Spatial representations in blind people: The role of strategies and mobility skills. *Acta Psychologica, 142*, 43–50.
- Slater, A., Mattock, A., & Brown, E. (1990). Size constancy at birth: Newborn infants' responses to retinal and real size. *Journal of Experimental Child Psychology, 49*, 314–322.
- Smith, M., Franz, E. A., Joy, S. M., & Whitehead, K. (2005). Superior performance of blind compared with sighted individuals on bimanual estimations of object size. *Psychological Science, 16*, 11–14.
- Vanlierde, A., & Wanet-Defalque, M.-C. (2004). Abilities and strategies of blind and sighted subjects in visuo-spatial imagery. *Acta Psychologica, 116*, 205–222.
- Vanlierde, A., & Wanet-Defalque, M.-C. (2005). The role of visual experience in mental imagery. *Journal of Visual Impairment & Blindness, 3*, 165–178.
- Wnuczko, M., & Kennedy, J. M. (2014). Pointing to azimuths and elevations of targets: Blind and blindfolded-sighted. *Perception, 43*, 117–128.

---

**Magdalena Szubielska, Ph.D.**, assistant professor, Institute of Psychology, The John Paul II Catholic University of Lublin, Al. Raclawickie 14, 20-950 Lublin, Poland; e-mail: <magdasz@kul.pl>. **Bogusław Marek, prof. KUL, Ph.D., OBE**, chair, Department of ELT Typhlology and Alternative Communication, The John Paul II Catholic University of Lublin, Poland; e-mail: <bmarek@kul.pl>.