Transfer of Learning in People Who Are Blind: Enhancement of Spatial-Cognitive Abilities Through Drawing

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Structured abstract: *Introduction:* This study assessed whether basic spatial-cognitive abilities can be enhanced in people who are blind through transfer of learning from drawing training. *Methods:* Near-body spatial-cognitive performance was assessed through the Cognitive Test for the Blind (CTB), which assesses a wide range of basic spatial-cognitive skills. The CTB was administered to 21 participants who are blind in two behavioral testing sessions separated by five days. For participants in the "trained" group, these intervening days were occupied by the Cognitive-Kinesthetic Drawing Training method, during which participants learned how to draw freehand from memory. The "control" participants were not trained. *Results:* The results showed significantly increased overall CTB performance in the trained but not in the control group, indicating that the drawing training effectively enhanced spatial-cognitive abilities. A three- to six-month follow-up session with a subset of trained participants suggested that these training-induced spatial-cognitive improvements might persist over time, at least for some tasks. *Discussion:* These findings demonstrate that learning to draw from memory without vision over just five sessions can lead to enhancement of basic spatial-cognitive abilities beyond the drawing task. This study is the first to examine the transfer of learning of cognitive ability in blind individuals. *Implications for practitioners*: This study sheds light on the Cognitive-Kinesthetic Drawing Training as an effective wide-range rehabilitation technique that could be used to enhance basic spatial-cognitive abilities in those who are blind.

The ability to represent and remember objects and their spatial relationships is key to interacting with our immediate surroundings. For sighted individuals, vision is most often relied upon to process spatial-cognitive information, but for individuals who are blind, it might be thought that processing object and spatial information is more challenging given the loss of vision. Indeed, some evidence suggests that due to their absence of early visual experience, individuals with congenital blindness are impaired on spatial-cognitive tasks compared to sighted controls (Casey, 1978; Gaunet & Thinus-Blanc, 1996; Hatwell 2003; Millar, 1994; Rieser, Guth, & Hill, 1986; Worchel, 1951; for conflicting results, see Klatzky, Golledge, Loomis, Cicinelli, & Pellegrino, 1995; Tinti, Adenzato, Tamietto, &

Cornoldi, 2006), although their experience with relying on other senses may lead to enhanced performance relative to those with acquired blindness (Dulin & Hatwell, 2006; Passini, Proulx, & Rainville, 1990). Regardless of the degree of spatial-cognitive impairment in congenital vs. acquired blindness, any decline in spatial ability due to their visual impairment could negatively affect their daily lives (see Thinus-Blanc and Gaunet, 1997, for a review)—for instance, by making navigating through new environments more challenging. Thus, it is important to search for techniques to improve spatial cognition. According to the World Health Organization's classification of visual impairment, 20/500 (profound visual impairment) down to no light perception (total blindness) is characterized as the range where nonvisual information becomes particularly crucial for daily functioning. We therefore used this definition of *blindness* in the current study.

Our goal was to assess the training-based enhancement of basic spatial-cognitive abilities in individuals with blindness. We conceptualized "basic" abilities as those that are foundational to other tasks, such as the ability to perceive and remember object features, textures, spatial configurations, and patterns. To our best knowledge, the only research focused on interventions to enhance basic spatial-cognitive abilities in people with blindness has been that based on the cognitive-kinesthetic drawing training (see, for example, Likova, 2012, 2014, 2015), which has been shown to improve spatial memory and memory-guided spatio-motor coordination in drawing from memory. Although it is typically assumed that drawing is dependent on vision, previous work indicates that individuals with congenital blindness are able to learn to draw (Kennedy, 1993; Kennedy & Juricevic, 2006; Ponchillia, 2008)—a finding further supported by Likova's training method (Likova, 2012). Because drawing involves multiple spatial-cognitive abilities (Del Giudice et al., 2000; Eliot & Smith, 1983; Likova, 2012, 2013; Piaget & Inhelder, 1956), Likova hypothesized that the improvements from the Cognitive-Kinesthetic Training would transfer to a wide range of basic spatial-cognitive abilities well beyond the drawing task *per se*. The present study aimed to test this "transfer of learning" hypothesis in individuals with blindness by analyzing pre- and post-training behavioral performance.

During the Cognitive-Kinesthetic Training (Likova, 2012, 2014, 2015, 2018), over five days, participants learned how to draw complex, recognizable pictures (faces and objects) guided solely by tactile memory. To do so, they first tactually explored raised-line drawings with one hand, and subsequently drew the picture from memory with their other hand. Importantly, this nonvisual drawing task requires extensive spatial-cognitive processing, including the assessment of the spatial layout of the raised-line drawings during exploration, detailed and stable memorization, followed by the precise recollection of those components during memory-guided drawing.

Previous studies have found that participants' drawings improve from before to after

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Cognitive-Kinesthetic Training (Likova, 2012), which may reflect enhanced spatial and memory abilities, at least on the drawing task. On a neural level, this training causes extensive cortical reorganization at both high and low levels in the brain (Cacciamani & Likova, 2016, 2017; Likova, 2012, 2013, 2014, 2015, 2017, 2018). In primary "visual" area V1, functional magnetic resonance imaging (fMRI) revealed that the response time course developed from erratic and random before training to strong and task dependent after training (Likova, 2012). Such training-induced cortical changes have also been found in higher-level "memory" structures such as the hippocampus (Likova, 2015) and perirhinal cortex (Cacciamani & Likova, 2016), as well as in brain connectivity (Cacciamani & Likova, 2017).

These previous studies have uncovered the effectiveness of this intervention at both the neural level and in the drawing performance level, but its effects beyond the trained drawing task (as proposed in Likova, 2014) have yet to be assessed. Here, we investigated whether the Cognitive-Kinesthetic Training causes learning that transfers beyond the trained drawing task to untrained basic spatial-cognitive skills.

Methods

Participants

The participants were 21 right-handed individuals with blindness (see Table 1). All participants gave informed consent for the experimental protocol, as approved by the Smith-Kettlewell Institutional Review Board. Participants were recruited from the local community through flyers, e-mail and online recruitment ads, and word-of-mouth, and were compensated for their time.

All participants had visual impairment below 20/500 down to no light perception, and relied on either a long cane or a dog guide for navigation. To determine participants' level of residual vision (if any), the Berkeley Rudimentary Vision Test (Bailey, Jackson, Minto, Greer, & Chu, 2012) was administered, consisting of a series of cards with black and white tumbling *E*s, gratings, and field projections. Based on their performance on this test, participants were labeled as either having severely low vision (n = 3), the ability to see hand motion (n = 2), light perception (n = 6), or no light perception (n = 10). Participants with any residual vision (low vision, hand motion, and light perception) were blindfolded during all aspects of the experiment to eliminate all possible visual input.

Measures

Cognitive Test for the Blind (CTB)

To measure spatial-cognitive abilities, we used the nonvisual performance scale of the tactile Cognitive Test for the Blind (CTB)—a component of the Comprehensive Vocational Evaluation System (CVES) developed and standardized specifically for individuals who are blind or have low vision (Dial, Chan, Mezger, & Parker, 1991). Importantly, this scale has been shown to have high test-retest reliability as a stand-alone measure (r = .95) (Dial et al., 1990; Nelson, Dial, & Joyce, 2002). The nonvisual performance CTB component of the CVES measures basic cognitive and spatial abilities via five subtests pertaining to learning, memory, and perception. Previous studies have used the CVES in clinical and vocational studies (Dial et al., 1991; Joyce, Dial, Nelson, & Hupp, 2000; Miller & Skillman, 2003; Nelson et al., 2002), but it has not yet been employed in a behavioral intervention.

Participants were randomly assigned to the trained condition (n = 13) or the control condition (n = 8); conditions were unequal because priority was given to obtaining sufficient power in the trained condition. Both trained and control participants completed two three-hour CTB testing sessions that we refer to as pretest and posttest. The CTB consisted of five subtests (described below, see Figure 1) administered in order. Each subtest

Table 1
Demographics of the participants.

Condition	Part. #	Gender	Age	Current visual status	Age of onset of current visual status	Visual status at birth	Diagnosis	Braille fluency
Trained	1	M	68	NLP	15	LP	Retinopathy of prematurity	High
	4	F	66	LP	< 1	LP	Retinopathy of prematurity	High
	7	F	57	LP	30	Tunnel vision	Retinitis pigmentosa	High
	10	M	76	LP	16	Full vision	Optic neuropathy	Moderate
	11	F	31	NLP	28	LP	Optic nerve hypoplasia	High
	17	F	66	NLP	16	Full vision	Glaucoma	Moderate
	19	F	37	HM	< 1	HM	Congenital optic neuropathy	High
	20	M	56	LP	47	Full vision	Glaucoma	None
	24	F	54	NLP	< 1	NLP	Retinoblastoma	High
	25	M	37	LV	30	Full vision	Optic nerve damage	Low
	27	F	75	LV	64	Full vision	Cataract/macular degeneration	None
	30	F	27	NLP	< 1	LP	Retinopathy of prematurity	High
	31	M	63	NLP	4	Full vision	Trauma	Moderate
Control	2	F	45	NLP	40	LP	Retinopathy of prematurity	High
	3	F	35	HM	< 1	HM	Maldeveloped optic nerve	High
	9	M	58	NLP	8	Full vision	Glaucoma	High
	12	F	65	NLP	12	LP	Retinopathy of prematurity	High
	14	F	31	LP	28	Full vision	Diabetic retinopathy	Moderate
	22	F	64	NLP	< 1	LP	Retinopathy of prematurity	High
	23	M	66	LV	60	Full vision	Diabetic retinopathy	None
	29	M	28	LP	< 1	LP	Leber's congenital amaurosis	High

Part. = participant; NLP = no light perception; LP = light perception; HM = hand motion; LV = low vision.

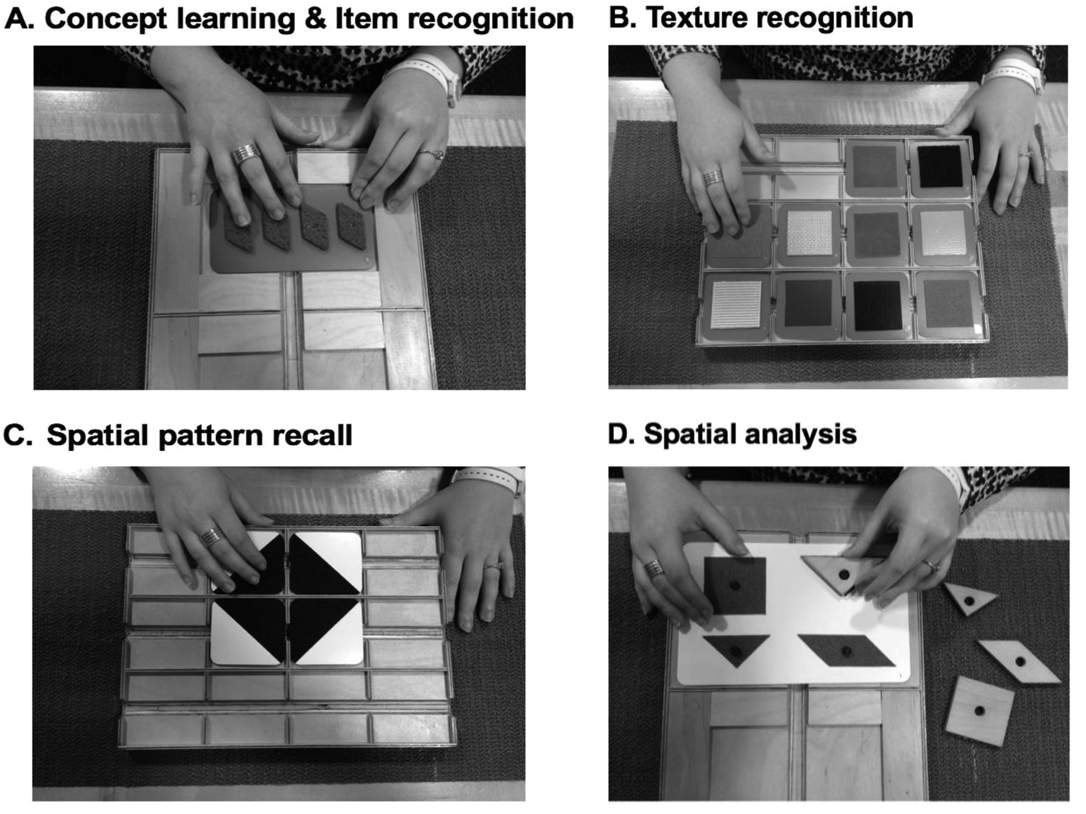

Figure 1. (A) Example trial in the concept learning subtest. Trial shown is from the "number" series (series A), on which the correct answer is 4. A subset of the concept learning cards was also used in the item recognition subtest. (B) Tiles being studied during the texture recognition subtest. On each tile is a different texture. (C) Example trial in the study phase of the spatial pattern recall subtest. The white and black regions are smooth and rough textures, respectively. (D) Example trial of the spatial analysis subtest. Shown here is a participant placing the wooden shapes onto the pegs.

utilized plastic cards with raised shapes or textures. The cards were held in place via a wooden board positioned on a nonslip mat on the table in front of the seated participant. For each trial, responses and reaction times were recorded by the experimenter. A total score for each subtest was automatically calculated and converted into a percentage correct. A composite score for the entire CTB was also calculated, which reflects participants' spatial-cognitive abilities across all subtests.

Concept learning subtest. Participants were presented with one 3″ × 5″ plastic card per trial (Figure 1A) and were told that each card represented a number between 1 and 4 based on an underlying concept that was consistent across a series of cards. Their task was to haptically explore the information on the card with their right hand and to verbally respond with a number from 1 to 4. In order to respond correctly, participants had to attempt to decipher the concept of that series as the trials progressed. There were 4 series, whose concepts became progressively more difficult. In series A (10 trials), the concept was the number of items. In series B (12 trials), the concept was the position of the odd-one-out item. In series C (15 trials), the concept was the quadrant number of the missing or odd-one-out information. In series D (15 trials), the concept was the proportion of the card that contained solid vs. dashed textured lines. From these 4 series, a total concept-learning score was calculated that reflected participants' ability to haptically learn new concepts. Participants were given feedback (correct or incorrect and, if incorrect, the correct answer was given) for the first 2 trials in each series.

Item recognition subtest. This subtest assessed participants' incidental memory of the cards explored in the previous concept-learning subtest. One card was presented per trial, and participants were instructed to haptically explore the card with their right hand and verbally respond "yes" if they remembered feeling that card during the previous subtest, or "no" if they did not. There were 16 trials in total (half "no," half "yes," intermixed). Participants were given feedback (correct or incorrect) on the first 2 trials only.

Texture recognition subtest. Participants were given one minute to memorize 10 different simultaneously presented 3″ × 3″ texture tiles using their right hand (Figure 1B). These 10 studied tiles were removed and shuffled with 10 new tiles. Participants were then presented with these 20 tiles one at a time and were asked to feel the texture of each tile with their right hand and respond "yes" or "no" as to whether or not they had felt that texture during the study phase. Participants were given feedback (correct or incorrect) for the first 2 trials only.

Spatial pattern recall subtest. Participants had to remember a textured pattern created by an arrangement of 3″ × 3″ tiles with half-rough (black) and half-smooth (white) surfaces (Figure 1C). In the study phase, they tactually explored the pattern emerging from the tile's arrangement for 30 seconds with their right hand. The tiles were then removed and shuffled. In the test phase, the participants were given the tiles and asked to place them in the exact spatial layout as was memorized during the study phase. The number of tiles placed correctly and the total time were recorded by the experimenter. There were 12 trials, which became progressively more challenging based on the number of tiles to be placed (progressing from 4 to 12). Feedback was given on the first trial only. On each trial, the participant needed to correctly place more than half of the tiles in order to "pass." After 2 consecutive failures (or after all 12 trials), the subtest ended.

Spatial analysis subtest. This subtest (Figure 1D) assessed participants' ability to tactually explore, spatially analyze, and match different shapes. On each trial, participants were presented with a 5″ × 7″ card on which from 2 to 5 raised pegs were arranged. On the table to the left were wooden block shapes with holes in the center. The participants' task was to use these holes to position the wooden shapes onto the pegs in order to create the appropriate pattern. The pattern was sometimes defined by rough textures on the card around the pegs that had to be matched with the wooden shapes; on other trials, as the subtest became more challenging, the pattern was defined by a raised border in which all of the wooden shapes would fit if positioned correctly ("like a puzzle"). Participants could use both hands and always feel the pattern, thus defining this subtest as a spatial analysis rather than as a memory task. They were given unrestricted time to explore the card and wooden shapes before the trial began, but upon beginning to position the first wooden shape a time limit (2 to 4 minutes, depending on the trial) was enforced. The trial ended when the time expired, or when participants placed all of the wooden shapes, whichever came first. There were 12 trials. On every third trial, all 9 wooden shapes were provided, and participants had to correctly select the shapes needed to create the pattern, thereby making the trial more challenging, as there was only one correct answer. On the other trials, only the shapes needed to create the pattern (between 2 and 5 shapes) were provided. The subtest ended when the 12 trials were completed, or when the participant failed to correctly position all of the shapes on 3 consecutive trials. No feedback was provided on any trials.

Computerized Recognizability Index (CR Index)

To quantify drawing performance, we used the Computerized Recognizability Index (CR Index), developed in the Likova Lab. The CR Index is based on an optimized spatial-correlation fit across the full spectrum of affine transformations (translation, rotation, scaling, and shear), and was applied to each recorded drawing, calculating the proportion of the image that contained contours that matched the original stimulus (with sparse-matrix correction for incomplete drawings). The total CR Index of pretest vs. posttest drawings was compared to quantify training-induced drawing improvement.

Cognitive-Kinesthetic Drawing Training

For trained participants, the days between the two CTB sessions included the Cognitive-Kinesthetic Training (Likova, 2012, 2013, 2014), wherein they learned how to draw guided solely by tactile memory. Two tasks were involved: Perceptual Exploration, where participants learned how to haptically explore, analyze, and memorize the spatial attributes of raised-line drawings; and Memory Drawing, during which they had to use the generated nonvisual memory to draw the same image freehand. Importantly, participants were not exploring the stimulus during the drawing task, and instead had to rely solely on their memory of that stimulus in order to guide the appropriate motor movements for drawing. This differentiates this memory-guided task from a simple copying task. Furthermore, exploration was done with the left hand and drawing with the right hand; by using different hands for the perceptual and drawing phases, participants learned to rely on tactile-spatial memory rather than muscle memory. The stimulus battery consisted of six raised-line drawings of faces and objects (see examples in Figure 2, left column), used in previous neuroimaging studies (Cacciamani & Likova, 2016; Likova, 2012, 2014, 2015, 2017, 2018) and designed to have complex local features.

The Cognitive-Kinesthetic Training is a highly complex, interactive, and personalized process incorporating a multifaceted system of cognitive and motor learning principles within a conceptual framework developed previously (Likova, 2012, 2014, 2015), which follows an elaborate algorithm evolving throughout the five sessions. Its complete description is beyond the scope of this paper. But, in short, one instructor worked separately with each participant, so that over the five two-hour training sessions participants learned how to analyze and memorize complex spatial structures, and replace the eye-hand coordination mechanism lost in blindness by memory-hand coordination (Likova, 2012), such that readily recognizable drawings were produced.

The control participants did not undergo training, but instead simply participated in the two CTB sessions separated by five days.

Results

Drawing performance

As expected, the participants in the trained condition reported that the memory-guided drawing task seemed impossible initially. Before training, when participants explored the stimuli during perceptual exploration, they reported being unable to recognize the line drawings or understand their detailed spatial components. When trying to draw the images from memory during the memory drawing task, they lacked confidence, and, even if given unlimited time, they would produce drawings

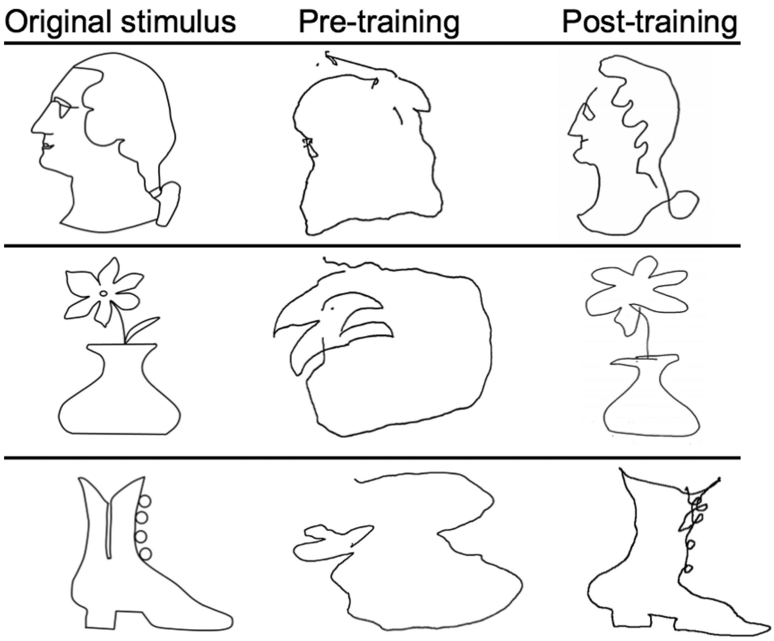

Figure 2. Sample line-drawing stimuli (left column). In the center and rightmost columns are examples of drawings from representative participants before vs. after training, respectively.

that were unrecognizable and unstructured (see Figure 2, middle column, for examples from a few representative participants).

After training, however, participants could confidently perceive, recognize, and memorize the detailed spatial components of each stimulus during exploration and could use that memory representation to draw it freehand within only 20 seconds.

Drawing success was assessed qualitatively and quantitatively. The qualitative assessment was based on resemblance to the original stimulus (that is, whether an outside observer could readily recognize the drawing). By the end of training, all participants produced drawings that were recognizable by outside observers (see Figure 2, right column). Quantitative assessment of drawing improvement showed that the CR Index (measuring drawing accuracy with respect to the original stimulus) increased significantly from pretest to posttest ($d = 4.15$, p .05). This memory-guided drawing improvement reflected an enhancement of spatial memory representations—at least on this task. Next, we investigated whether these enhancements transfer to untrained spatial-cognitive tasks.

CTB PERFORMANCE

A 2 × 2 mixed-design analysis of variance (ANOVA) was conducted on the composite CTB scores (in percentage correct) with factors of group (trained or control; between-subjects) and testing session (pretest or posttest; within-subjects) (see Figure 3). This

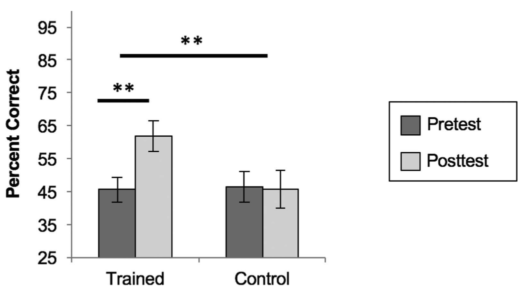

Figure 3. Composite scores (in percent correct) on the Cognitive Test for the Blind (CTB). Error bars represent standard error of the mean. ** p .01.

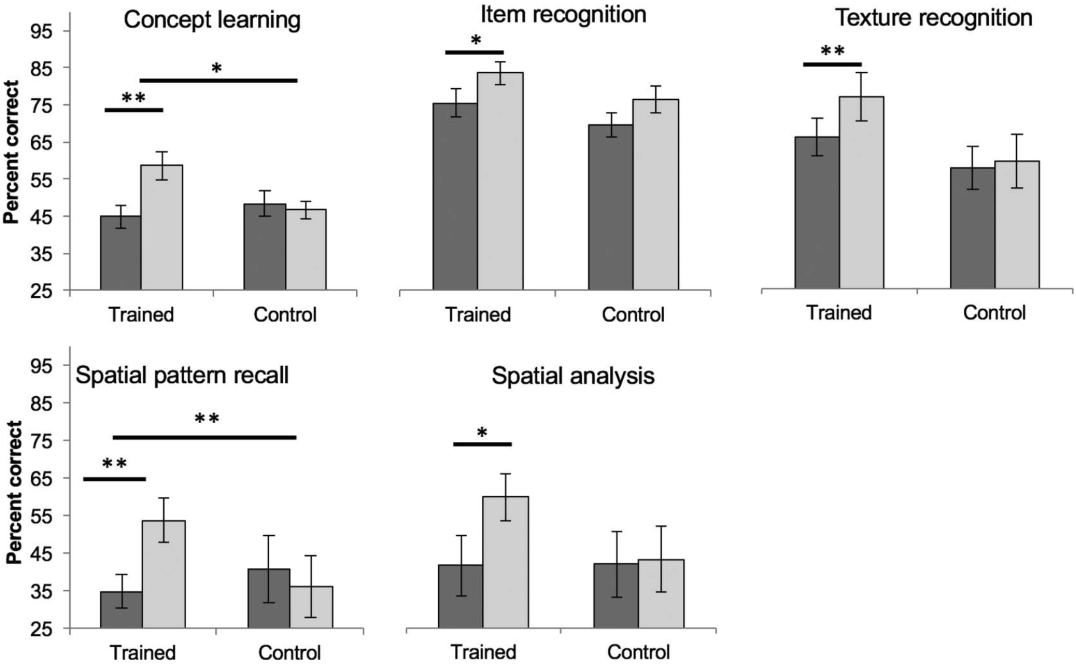

Figure 4. Cognitive test for the blind (CTB) scores on each subtest. Error bars represent standard error of the mean. * p .05, ** p 178 .01.

omnibus analysis revealed a significant group × session interaction, $F(1,19) = 14.28$, p .001, with a significantly greater difference in CTB performance between pretest and posttest for the trained vs. control group. Indeed, follow-up two-tailed paired-samples t-tests revealed that CTB scores significantly increased from pretest ($M = 45.6$, $SD = 13.0$) to posttest ($M = 61.9$, $SD = 16.8$) in the trained group—$t(12) = 4.08$, p .001, $d = 1.13$—but not in the control group ($M = 46.6$, $SD = 13.2$ pretest; $M = 45.6$, $SD = 16.1$ posttest; $p = .81$). In considering each session separately, two-tailed independent-samples t-tests showed that CTB performance between the trained and control groups did not differ at pretest ($p = .86$), indicating that the group effect cannot be attributed to baseline differences. This important finding supports the hypothesis that the Cognitive-Kinesthetic Drawing Training can lead to an overall improvement in basic spatial-cognitive abilities. Next, we analyzed each subtest individually (see Figure 4) in order to assess which cognitive skills are most affected by the training.

Concept learning subtest

A 2 × 2 mixed-design ANOVA was conducted on the concept-learning scores with factors of group (trained or control) and testing session (pretest or posttest). This analysis revealed a significant group × session interaction—$F(1,19) = 4.87$, $p = .01$—with participants in the trained group performing significantly better from pretest ($M = 44.8$, $SD = 11.2$) to posttest—$M = 58.7$, $SD = 13.8$, $t(12) = 3.47$, $p = .004$, $d = 1.15$—suggesting that the training improved participants' cognitive ability to learn new concepts. The control group did not change ($M = 48.3$, $SD = 9.7$ pretest; $M = 46.6$, $SD = 6.2$ posttest; $p = .61$).

Item recognition subtest

The same 2 × 2 ANOVA performed on item recognition scores revealed no significant group x session interaction (p = .85). Although the lack of interaction significance precludes us from drawing conclusions with respect to group differences in performance improvements, it is still insightful to assess changes within each group (trained or control) so long as caution is taken in interpreting the results. In the trained group, the increase from pretest (M = 75.5, SD = 13.8) to posttest (M = 83.6, SD = 10.9) was significant—$t(12)$ = 2.04, p = .04, d = .68—suggesting an improvement in incidental memory performance. No improvement was observed in the controls (M = 69.5, SD = 9.11 pretest; M = 76.5, SD = 10.4 posttest, p = .18).

Texture recognition subtest

The analysis of texture recognition scores across both groups and sessions revealed no significant interaction (p = .16). However, a paired-samples *t*-test on just the trained group showed a significant increase in performance from pretest (M = 66.5, SD = 18.5) to posttest (M = 77.7, SD = 24.4): $t(12)$ = 2.79, p = .006, d = .54. The control group showed no significant change from pretest (M = 58.1, SD = 16.9) to posttest (M = 60.0, SD = 20.7, p = .76).

Spatial pattern recall subtest

Results showed a significant group × session interaction, $F(1,19)$ = 10.92, p = .001, with trained participants performing significantly better at posttest (M = 53.8, SD = 21.2) vs. pretest (M = 34.9, SD = 15.9)—$t(12)$ = 4.71, p .001, d = 1.05—than controls (M = 40.7, SD = 25.1 pretest; M = 36.1, SD = 23.7 posttest, p = .38). This important finding supports the hypothesis that the training led to enhanced spatial memory abilities beyond the drawing task.

Spatial analysis subtest

The results showed no significant group × session interaction (p = .14). However, a paired-samples *t*-test on the trained group revealed a significant increase in performance from pretest (M = 41.6, SD = 28.8) to posttest (M = 59.8, SD = 22.7)—$t(12)$ = 4.55, p = .02, d = .73—indicative of a similar pattern of improvement observed in the other subtests.

Correlation with demographic factors

A post hoc correlation analysis revealed that no demographic factor—including current age, age of onset, years in current condition, current visual status, or braille fluency (see Table 1)—significantly correlated with the overall change in CTB performance between the testing sessions ($ps > .23$). This finding indicates that these individual differences were not underlying the pretest-posttest change in performance that we observed.

Persistence of performance improvements

To assess whether the training-induced CTB enhancements persisted over time, seven of the original 13 trained participants returned three to six months after the immediate posttest (posttest-1) for a second CTB posttest session (posttest-2); the remaining participants were unable to return. A within-subjects analysis on these seven participants showed that overall CTB performance at posttest-2 (M = 53.3, SD = 13.6) was still significantly higher than at pretest (M = 45.0, SD = 9.9)—$t(6)$ = 2.83, p = .03, d = .69—and not significantly different from the posttest-1 (M = 58.6, SD = 15.2, p = .10). This finding suggests that the training-induced improvements on the CTB overall were not some short-term boost, but seem to be sustained over at least several months.

The same analysis was performed on each subtest. On the concept-learning subtest in this reduced participant group, like the overall CTB analysis, the difference between posttest-1 (M = 53.0, SD = 13.4) and posttest-2 (M = 60.9, SD = 8.0) was not significant (p = .21), while the difference between pretest (M = 43.4,

$SD = 9.9$) and posttest-2 was: $t(6) = 5.26$, $p = .002$, $d = 2.10$. These results suggest that performance improvements on concept learning persist over time, at least in this subset of participants.

The results of the texture recognition subtest showed a marginally significant decrease in performance from posttest-1 ($M = 65.7$, $SD = 7.3$) to posttest-2 ($M = 57.9$, $SD = 4.9$)—$t(6) = 2.09$, $p = .08$, d = 1.38—such that no significant difference between pretest ($M = 60.0$, $SD = 7.6$) and posttest-2 was observed ($p = .63$), suggesting that the transferred effect of training on texture memory did not persist after three to six months in this subset of participants.

Performance on the other three subtests did not show persistence in this small subset of returned participants (ps $> .15$).

Discussion

This study provided the first evidence showing that in individuals who are blind, only five days of the Cognitive-Kinesthetic Drawing Training resulted in enhancement of spatial-cognitive abilities beyond the drawing task itself. Using the CTB (Dial et al., 1991), we demonstrated transfer of learning from drawing to basic cognitive skills—concept learning, item recognition, texture recognition, spatial pattern recall, and spatial analysis. Importantly, performance improvements between the two CTB sessions were observed only in participants who underwent drawing training in the interim; for control (untrained) participants, CTB performance between the two sessions did not differ on any subtest, consistent with the established high test-retest reliability of CTB (Dial et al., 1990), suggesting that, without any intervention, performance is expected to remain stable across testing sessions. Thus, in addition to the previously observed neural reorganization and improved drawing performance (Cacciamani & Likova, 2016, 2017; Likova, 2010, 2012, 2013, 2014, 2015, 2017, 2018), we now have evidence that the Cognitive-Kinesthetic Training not only teaches individuals with blindness how to draw, but it also enhances basic cognitive abilities, especially ones reliant on internal spatial representations.

These results are consistent with the conceptual framework underlying the Cognitive-Kinesthetic Drawing method for blindness rehabilitation (Likova, 2012, 2013), which postulates that "space transcends any sensory modality" (Likova, 2013, p. 3) and, consequently, "drawing, which deals with spatial structures, . . . has the advantage that can readily be 'translated' from a visual into a tactile form" (Likova, 2012, p. 3). Drawing is a task that requires extensive spatial understanding (Del Giudice et al., 2000; Eliot & Smith, 1983; Likova, 2012, 2013; Piaget & Inhelder, 1956). In order to draw an image without vision, the person who is blind must learn how to attend to its spatial components during exploration, create a mental spatial representation of those components, and accurately "project" it onto the drawing space to guide proper hand movements (Likova, 2014). These spatial skills were a point of focus during the Cognitive-Kinesthetic Training. Thus, it is appropriate that transfer of learning was most apparent in the spatial domain (the spatial pattern recall and spatial analysis subtests). Improvements were also observed in concept learning, texture recognition, and item recognition, supporting Likova's (2014) proposal that the learning resulting from the Cognitive-Kinesthetic Training transferred to a wide range of spatial-cognitive abilities. Moreover, the results of the three- to six-month follow-up with a subset of trained participants suggested that these training-induced performance improvements might persist over time, at least for some tasks.

The etiology and degree of blindness varied within our sample of participants, reflecting individual differences present in the greater population. Importantly, none of these demographic factors were correlated with the change in CTB performance between the testing sessions. Thus, these individual differences did not affect our result, and instead provided evidence of training-induced performance improvements across different levels of blindness. Future studies could examine demographic information with respect to success in drawing, which we have not done here, and further investigate factors that underlie it. We acknowledge that our sample of 21 participants was another potential limitation. Our sample size was restricted due to the nature of this study; the multiple training and testing sessions required a large time commitment from both participants and experimenters, which made it difficult to recruit and train and test more participants. Nevertheless, the fact that we observed pretest-posttest changes with only 21 participants speaks to the robustness of the training effect.

Overall, this study provides the first evidence that a wide range of spatial-cognitive abilities in individuals with blindness can be enhanced through the Cognitive-Kinesthetic Drawing Training—a finding relevant to research on blindness rehabilitation and transfer of learning. This training technique could be implemented in rehabilitation programs focused on improving independence, cognition, and quality of life across levels of visual impairment.

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