Targeted Cognitive Training of Spatial Skills: Perspective Taking in Robot Teleoperation

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Abstract

Spatial skills are critical for robot teleoperation. For example, in order to make a judgment of relative direction when operating a robot remotely, one must take different perspectives and make decisions based on available spatial information. Training spatial skills is thus critical for robot teleoperation, yet, current training programs focus primarily on psycho-motoric skills of the task, and less on the essential cognitive aspects of spatial skills. This work addresses this need by considering previous findings on relative direction judgments in training robot teleoperation. We developed and tested a basic training paradigm of perspective taking skill targeting the cognitive skill rather than psycho-motoric skill. An experiment tested a basic training paradigm using a stationary robot, with a training group receiving perspective taking training and a control group without training, and both tested on a transfer test with the robot. The results show that participants who went through a targeted cognitive skill training reached mastery level during the training, and performed better than the control group in an analogue transfer of learning test. Moreover, results reveal that the training facilitated participants with initial poor perspective taking skills reach the level of the high-skilled participants in transfer test performance. The study validates the possibility to target only cognitive aspects of spatial skills and result in better robot teleoperation.

1998 ACM Subject Classification I.2.9 Robotics, I.2.10 Vision and Scene Understanding

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1 Introduction

Perspective taking, an egocentric perspective transformation [36], is the ability to "transfer" mentally oneself to another location in a 3D space in order to get a different point of view of the same object [1], [16]. Such skill is required in order to judge a relative direction where one must obtain the appropriate perspective, and determine the correct direction accordingly. Studies such as [12] and [11] continue to investigate the ability to take a different perspective in a 3D space, yet, the use of the perspective taking skill manifests itself differently when used for self-navigation vs. teleoperation. The ability to judge directions in a 3D space is compromised under suboptimal conditions. For example, there may be insufficient spatial information due to a camera's single perspective in robot teleoperation or a static perspective that constraint the operator to acquire partial spatial information and make the relative direction decision relying on this partial information.

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The present study focuses on training perspective taking skill during robot teleoperation. It is based on the theory and practice of cognitive training [28, 17, 3, 26, 6, 10, 2, 20] whereby repeated practice of cognitive skills under specific conditions will result in efficient and effective completion of tasks requiring those skills.

2 Previous Work

2.1 Spatial Skills in Teleoperation

In domains such as space teleoperation and Unmanned Ground Vehicle (UGV), effective operation requires skills such as mental rotation, visualization and perspective taking [7, 8, 9, 22, 23, 25, 34, 24]. The importance of visual information is evident in these domains of teleoperation. For example, according to [23], the three main categories which astronauts are evaluated on are: "(1) General Situation Awareness – based on the selection of appropriate camera views for the task, recognition of unexpected arm movements, and avoiding arm self-collisions. (2) Clearance – evaluated on maintaining proper clearance from structure and proper camera selection for clearance monitoring and (3) Maneuvers – evaluated on the astronaut operator's ability to make correct hand controller inputs, selecting the correct control frame for the task and planning a safe but efficient arm trajectory."

Exploring UGV teleoperation, [8, 7] used a video game/simulator to create the environment for the experiment. [8] used one monitor for the teleoperation of the mobile robot, with a single and dynamic perspective from a camera. [7] used one monitor mounted on the UGV and the other image was delivered from a unmanned aerial vehicle (UAV)

In the set of spatial skills for robot teleoperation, perspective taking is an important one. In order to specify the desired movement of the robot or the robotic arm, the operator must take the camera's perspective and use it in order to make a correct decision regarding the direction and path that the robotic arm will take. Such a skill must be trained and practiced.

2.2 Training and Transfer of Spatial Skills

The fundamental questions of training and transfer have been addressed before (for example see: [32, 4, 35]). Yet, it is unclear to what degree the training is transferred to a real task: "Estimates suggest that only 10 per cent of training expenditures transfer to the job" [13] as quoted by [15].

Different approaches to the training and transfer of skills are evident in the literature. [30, 33, 31] investigated the issue of simulation-based training in laparoscopic surgery and came to the following conclusion: "Skills acquired by simulation-based training seem to be transferable to the operative setting". Another approach was used by [14]. They concluded that training in a computer game improves the performance of pilots during real flight. Another kind of studies such as, [35], investigated the transfer of skills from one task to another. These studies used pen and pencil tests or computerized traditional spatial ability tests in order to train the subject's spatial skills.

Using targeted training ensures that the specific targeted skills are enhanced and gives insight into the core skills that need the attention and practice. For example, in their study, [19] used paper-based exercises, hands-on block construction, and two computer-based activities. Each focused specifically on the training of the spatial visualization of the student. Furthermore, [27] used a computerized training program which focused on the student's spatial skills. They concluded that targeted training had improved the spatial skills of undergraduate students as was measured by standardized spatial ability tests. Moreover, studies show that low-skilled students benefit more from spatial training than higher-skilled students as measured both with standardized tests and tasks with dominant spatial elements.

2.3 Analogic vs. Adaptive Transfer

An important distinction is made between analogic and adaptive transfer of training. In a broad sense, analogic transfer is training on one task followed by testing on an analogue task ([5]). On the other hand, adaptive transfer is training on one task followed by testing on a novel task in which there are no similarities to the training task ([29]). An example of adaptive transfer is learning moves and ball passing between players in a professional soccer game which involve geometry elements followed by taking a written geometry test. An example for an analogic transfer task is learning geometry in a class followed by being tested in the classroom on the same subject of geometry. The current study will use an analogic transfer task to evaluate transfer of acquired spatial skills.

3 Goals and Questions

The main goal of this study was to test a new paradigm for training and acquiring perspective taking skill as an essential part of robot teleoperation training. The main objective is to study perspective taking training in a stationary robot environment where people remotely operate robots and the transfer of the acquired skill to an analogical teleoperation task. The main questions are:

1. Will targeted training of perspective taking, in a robotic environment, improve performance in a spatially analogical task with a stationary robot?
2. Can we quantify and predict the improvement of performance?

In order to answer the questions presented above, a basic paradigm for perspective taking training was established and transfer of perspective taking skills in a stationary robotic environment was investigated. The following hypotheses were tested:

H1. Targeted training of perspective taking with a stationary robot will facilitate the acquisition of perspective taking skill as measured by performance during training and standardized tests.

H2. Performance in a teleoperation task of participants who receive targeted training of perspective taking will be better than participants who do not receive such training.

H3. Improvement of low-skilled participants will be greater than the improvement of high-skilled participants.

4 Method

4.1 Experiment Design

The study was a between-participant experimental design with two conditions: 1. Receiving perspective taking training and 2. No training (Figure 1). A given training trial consisted of a sequence of eight robot arm movements requiring the participant to make a decision before the subsequent movement. The training tasks requirements were to determine the relative direction of a location of a graphic element on a single plane. The direction is with respect to a figure held by the robotic arm, facing a given direction. For example: "if the figure is facing the direction of the blue star, in which direction is the yellow circle?". An example for an answer is: "Front-Right direction with regards to the front of the figure".

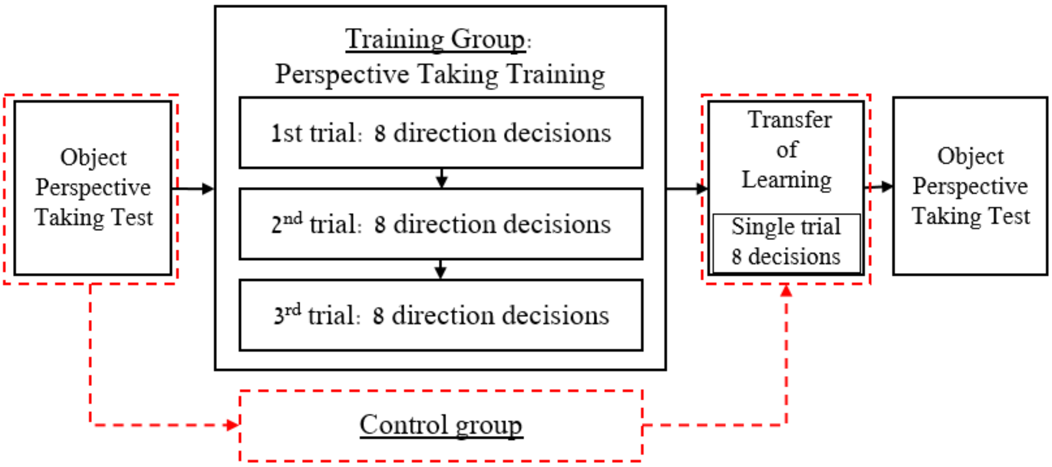


Figure 1 Experiment design: (1) Solid lines and arrows – the experiment flow of the training group. (2) Dotted red lines and arrows – the experiment flow of the control group.

Table 1 Descriptive Statistics of Participants.

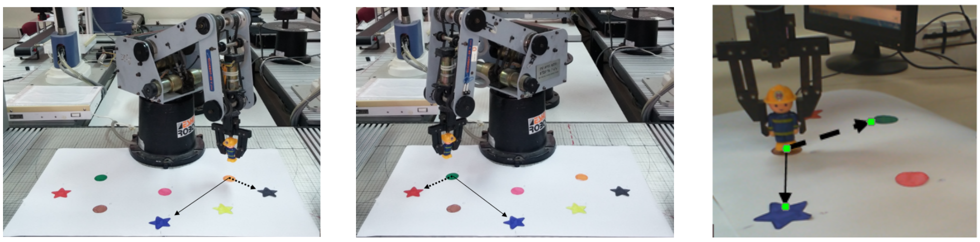
Descriptive Statistics of Participants			Number of Participants	
	age		Control group	Training group
	M	SD		
Male	24.84	3.25	15	13
Female	24.83	3.21	7	8

The transfer of learning test phase (Figure 1) included a different sequence with different locations of graphic elements and relative directions from the sequence in the training phase. In addition, a pencil & paper test of perspective taking skills ([21]) of each participant in both groups was administered before the tasks to create a baseline. Participants in the training group also did the test after the training to assess if there were any changes in the skill due to training.

4.2 Participants

Forty-three participants took part in the experiment, all from STEM (science, technoloy, engineering and mathematics) fields . Although there are known gender differences in spatial skills and performance, we could not address this factor due to large differences in the sample size between male and female participants. The assignment to the experimental conditions along with age and sex parameters are presented in Table 1.

Thirty-nine of the participants were undergraduate students, and four graduate students from various faculties at the Technion. Twenty-nine participants had no previous experience with controlling robots. Fourteen either took an undergraduate course at the faculty of industrial engineering and management (Engineering of Production Systems) or had some kind of experience with robots. The experienced participants were randomly assigned to the training and the control groups. Participants received forty New Israeli Shekels for participation.



(a) The relative direction is Left.
(b) The relative direction is Right.
(c) The relative direction is Back-Left.

Figure 2 Perspective Taking training and transfer of learning objects. The robotic arm is grasping the policeman figure. Solid line – The direction the figure is facing. Dotted line – The relative direction.

4.3 Apparatus

The experiment was conducted in the Computer Integrated Manufacturing & Robotics laboratory in the Industrial Engineering and Management Faculty, Technion – Israel Institute of Technology.

The robot: An industrial stationary robot, SCORBOT ER-V plus was used for the training and test of the transfer of learning.

The program execution: For each training session, an algorithm was written using Advanced Control Language (ACL) to execute the rotating command. During the training sessions, the participant was required to use only certain keys on the keyboard in order to send desired rotation commands to the robotic arm.

Training objects: For perspective taking training, a policeman figure (Figure 2) and a map with eight graphic locations indicated using different colors were used (Figure 2).

Technological apparatus: For each training session: one desktop computer, one Microsoft HD-3000 web camera and two computer screens were used. During the tasks, participants had no direct line of sight, and received a streaming video of the working area along with the robotic arm through one camera on the right screen (Figure 3). The participants used only the right hand keys on the keyboard to insert their numeric answers.

Spatial skills standardized tests: The perspective taking ability was evaluated by the Pen & Paper Perspective Taking Test [21].

Teleoperation environment setup: A camera was placed in the front-right corner of the working surface (45 degrees deviation of the robotics' arm "Front"), 30 degrees above the working plane, capturing both the map and the robotic arm as depict in Figure 3. This specific setting allowed the flexibility to create multiple situations that require different levels of mental transformation in order to take the perspective of the robotic arm and judge a relative direction to a location of a graphic element on the map. There were no situations in which any of the colored markers were occluded.

A partition was placed between the robot and the desk with the two monitors. This allowed only the information received from the camera on site, with no direct line of sight. The proposed setting: 1. did not allow situations in which some of the graphic elements were occluded and, 2. elevated the spatial complexity of the task. Figure 3 presents the perspective taking task environment.

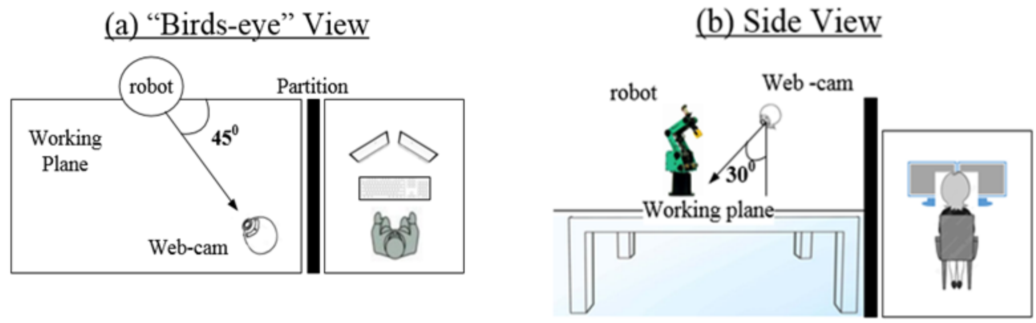


Figure 3 Perspective taking task environment. (a) "Birds-eye" View: a stand with a web-camera in the front right corner (45 degrees deviation of the front of the robotic arm). (b) Side View: a stand with a web-camera located 30 degrees above the working plane, capturing both the map and the robotic arm in the camera's perspective.

4.4 Measurements

Performance of perspective taking skill was measured by the following:

- Mean Time to Decision (TTD) – time from "ENTER" keying until a correct decision is made.
- Mean Number of Mistakes – Mean number of mistakes for each of the trials and each of the decisions in every trial. (Any incorrect direction to target location of a graphic element was considered a mistake)
- Perspective Taking Test Score – The sum of correct answers on the Perspective Taking Test.

4.5 Procedure

First, each participant signed an informed consent form and was administrated the object perspective taking test to establish a baseline. Next, the participant received a demonstration of the operation of the robotic arm and instructions as to how to operate it using the keyboard.

After receiving the instructions, the participant sat behind a desk with two monitors. On the left, the monitor displayed the instructions during training, and on the right a display of the robotic arm and the working area as it seen from the camera's perspective. Next, the training group participants engaged in a training session, according to the original assignment, consisting of three trials. Each participant took a test with general knowledge questions at the end of each trial in order to clear the working memory and minimize the probability of memorizing the answers.

After the training session, the training group participant engaged in an analogical task to test the transfer of learning followed by a spatial ability test. The control group received no training and engaged in the same analogical task.

Perspective Taking Training: Each trial began with the robotic arm holding a figure in a given direction above a specific location of a graphic element on the map. The participant set behind a desk with two monitors and a keyboard. Once the participant started the session, a question would appear on the left screen, asking for a direction to another location of a graphic element on the map (Figure 2). The participant was required to determine the relative direction of the location of the graphic element with respect to the figure held by the

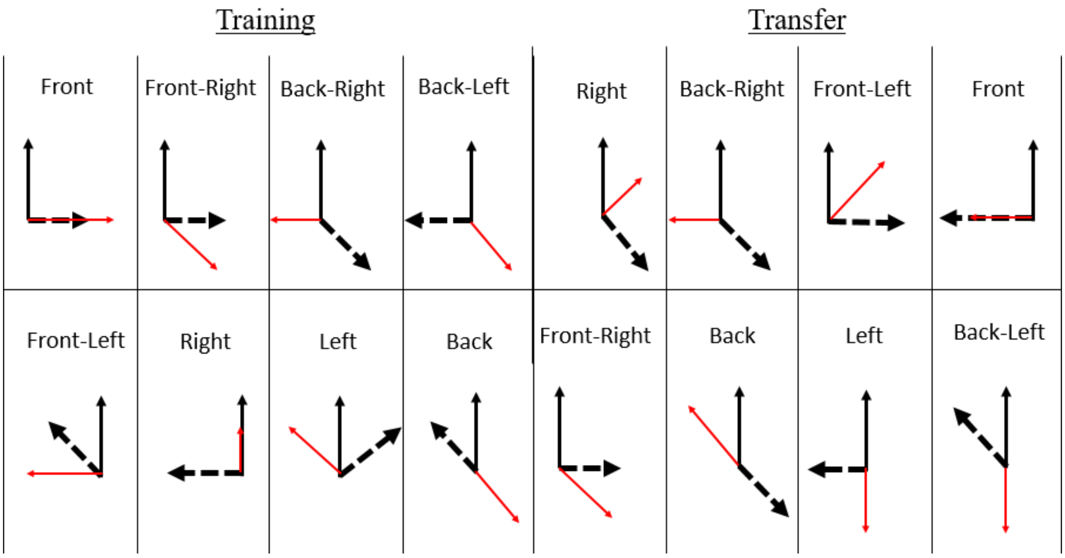


Figure 4 Judgment of relative direction: the solid black up arrows represents the camera's perspective. The dotted black arrows represent the direction of the figure. The thin red arrows represent the relative direction to the target location of a graphic element (relative to the figure's perspective).

robotic arm. The participant entered a code direction (for example, Front=482) and pressed the "ENTER" key on the keyboard. Figure 4 presents the perspective of the participant as given by the camera, the imagined heading (dotted line-the direction of the figure in the gripper) and the relative direction of the location of the graphic element to the imagined heading (red line).

Test of Transfer of Learning: The analogical transfer test resembled the training task and included one trial with eight decisions. In the perspective taking task, the order of the required directions were changed and so were the starting and target locations of the figure held by the robotic arm.

5 Results

5.1 Training Perspective Taking Skill

Twelve participants of the training group who completed all tasks successfully were included in the final analysis of the learning phase. Two of the participants had at least one unsuccessful attempt in at least one trial (9.5%). Additional seven participants (36%) were excluded (out of the successful) due to TTD greater than three standard deviations above the mean of the TTD.

Time To Decision (TTD). Analysis of variance showed there was a significant trial effect, $F(1.23, 13.57) = 31.51, p < 0.01, \eta = 0.741$ and observed power of 1, indicating that the mean TTD was significantly different in the three trials. Overall, an improvement in performance as measured by TTD is evident in Figure 5.

There was a significant relative direction effect, $F(7, 77) = 17.67, p < 0.01, \eta = 0.616$ and observed power of 1, indicating that the TTD differs significantly between the relative

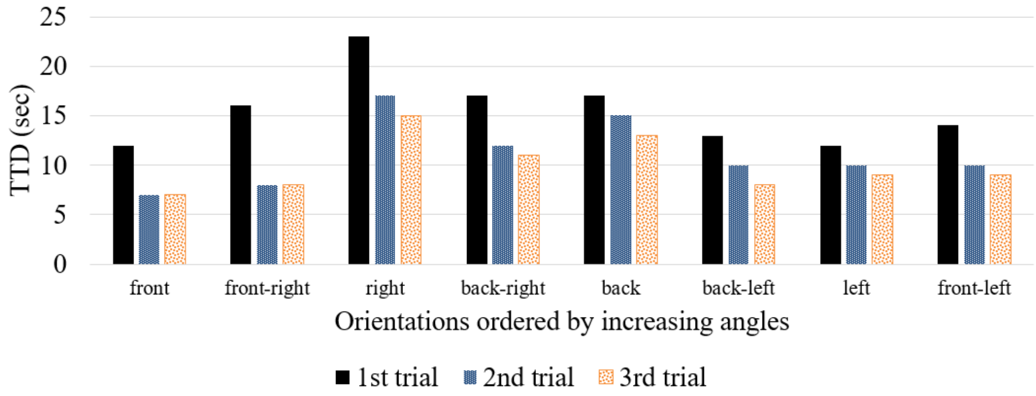


Figure 5 Practice effect of each relative direction. Presented with rotations ordered by increasing angles.

directions (Figure 5). The interaction effect between trial and relative direction was not significant, $F(14, 154) = 1.044, p = 0.4$.

Mean Number of Mistakes. There was a significant trial effect, $F(2, 22) = 4.827, p = 0.018, \eta = 0.305$ and observed power of 0.74, indicating that the mean number of mistakes was significantly lower in each subsequent trial. There was a significant relative direction effect, $F(2.369, 26.064) = 4.822, p = 0.013, \eta = 0.305$ and observed power of 0.795, indicating that the mean number of mistakes was significantly different throughout the different directions. The interaction between trial and direction was not significant: $F(14, 154) = 0.702, p = 0.43$.

5.2 Test of Transfer of Learning

Performance was measured by TTD and Number of Mistakes of successful trials. Due to the nature of the repeated measure design, only seventeen participants from the training group and seventeen from the control group were included in the final analysis. In the training group, four participants (19%) were excluded due to TTD greater than three standard deviations above the mean of the TTD in the relative direction performance. In the control group, one participant (4.5%) was excluded because of one unsuccessful attempt. Four participants (19%) were excluded due to TTD greater than three standard deviations above the mean of the TTD in the relative direction performance. Nothing particular was observed in the skill test scores of the excluded participants. Descriptive statistics is presented in the following results.

Time To Decision (TTD). A two-way analysis of variance with repeated measures and group as a between subject effect resulted in a significant group effect, ($F(1, 32) = 8.012, p = 0.008, \eta = 0.2$ and observed power of 0.784), indicating that the TTD of the training group (M=14, SD=7) is significantly better than the control group TTD (M=27, SD=33) (Figure 6). The relative direction effect was significant, $F(2.22, 71.16) = 6.057, p = 0.003, \eta = 0.159$ and observed power of 0.896. The interaction effect between group and relative direction was not significant.

Mean Number of Mistakes. The group effect was not significant with SL of 0.05, $F(1, 37) = 0.249, p = 0.621$. The relative direction effect was significant: $F(7, 259) = 3.864, p =$

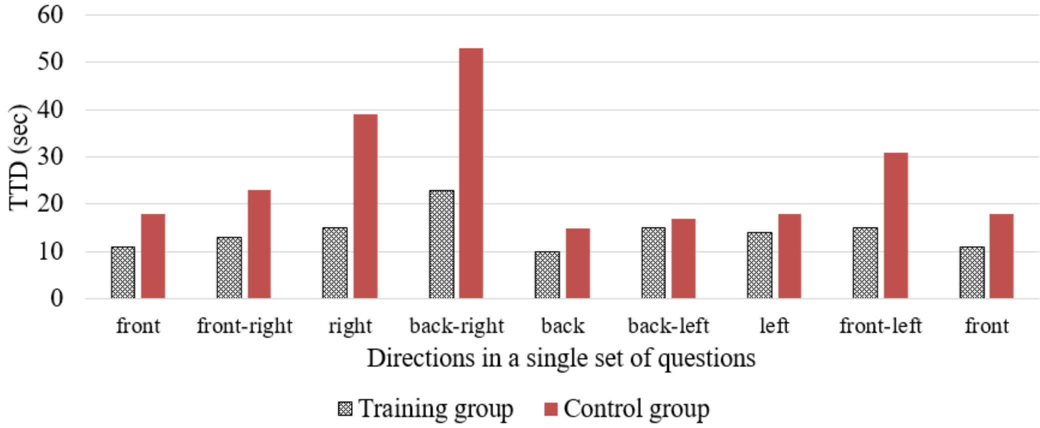


Figure 6 Perspective taking transfer of learning test performance. Presented with directions ordered by increasing angles.

$0.001, \eta = 0.095$ and observed power of 0.981. The interaction effect between group and relative direction was not significant in S.L of 0.05.

Descriptive statistics of the excluded participants from the training analysis reveals that four of the seven participant succeed in the transfer task with mean TTD of 15.4 seconds (similar to the mean of the training group).

5.3 Perspective Taking Standardized Test

Twenty-one participants from the control group were included in the test analysis, one participant did not follow the instructions and therefore was excluded from the analysis.

Control Group: A linear regression was performed to test the relationship between required spatial skills in the test of transfer of learning and standardized tests. Results show that pre-task perspective taking test score significantly predicted the single set of robotic task performance in the control group, where no confounding variables are present, $\beta = -0.756, t(19) = -4.9, p < 0.01$, with $R^2 = 0.572, F(1,19) = 24.013, p < 0.01$.

Training Group: A linear regression was performed to test the relationship between required spatial skills in the training task and standardized tests. Results show that pre-training perspective taking test score significantly predicted the first set of training task performance in the training group, $\beta = -0.633, t(19) = -3.563, p = 0.002$, with $R^2 = 0.401, F(1,19) = 12.693, p = 0.002$.

Multiple regression analysis was used to test if the standardized perspective taking test score and training performance significantly predicted participants' performance on the transfer task as measured by TTD. The results of the regression indicated the two predictors explained 83% of the variance ($R^2 = .83$, $F(3,30) = 48.88$, $p < 0.000$). It was found that training performance significantly predicted transfer performance (B = -44.818, $t(1) = -4.452$, $p < .000$), as did standardized test score (B = -4.503, $t(33) = -10.543$, $p < .000$), and their interaction (B = 4.203, $t(33) = 4.182$, $p < .000$). Participants' predicted transfer task performance is equal to 62.354-4.5(spatial skill level)-44.818(training)+4.203(level of skill*training) where training is coded as 1=trained, 0=control, and level of skill measured by standardized test score. In the control group, participant's TTD decreased 4.5 seconds for each point in the standardized test. In the training group, the more skilled the participant, the less improvement in TTD is evident. On the other hand, for less skilled participants, the improvement was greater. Descriptive statistics of the excluded participants from the training analysis reveals that four of the seven participant who succeeded in the transfer task had also improved their initial perspective taking skill level as measured by standardized test score from 8 to 10.75.

6 Summary

Recapping the findings, the effectiveness of the targeted cognitive training of the perspective taking spatial skill was particularly evident for participants with poorer initial perspective taking skills. The training helped them reach the performance level of participants with high initial perspective taking skills.

The Time To Decision (TTD) measure of the training group suggests that the most difficult directions to judge during the training sessions were Back-Right and Front-Left. Nevertheless, even these directions kept improving during the third trial. This may imply that one more session would have reduced all differences between directions. From the TTD performance of the training group during the transfer of learning test, it is evident that there were no substantial differences between TTD of the relative directions, including the more difficult directions from the training phase, other than the Back-Right direction. This implies that a learning process took place during training, which had leveled all differences between TTD of different directions. The difference between the training and the control group in the transfer of learning test was significant, indicating the training was effective and improved the performance of the training group.

Results of both the training and control group, in the transfer of learning test, resemble previous findings of relative direction judgment [21, 18]. Back and front directions are relatively easy, and directions with angles greater than 90 degrees are more difficult to judge. However, in the present work, not all relative directions follow the performance pattern found in previous literature ([18]). An example of an exception of that rule is Back-Left, which was relatively easy to judge as opposed to the literature ([18]) that suggests that Back-directions should be the hardest to judge. A possible explanation is presented in the discussion section.

7 Discussion and Theoretical Implications

A model of information processing can be adapted to teleoperation tasks with a focus on the cognitive spatial aspects. Figure 7 presents a model, which is composed of links that were empirically studied here (Solid lines) and hypothetical links (Dotted lines).

The model depicts the information-processing-action flow while teleoperating a robot, and the influence of initial spatial skills and training of spatial skills. The flow starts from the point where the remote robot position or movement (at the left of the diagram in Figure 7) is perceived through a technological aid, such as a camera. The flow ends with the control of the remote robot's movements through a technological aid, such as a remote control (at the right of the diagram in Figure 7).

The model is based on the premise that spatial skill level influence the process of acquisition of spatial skills; Initial spatial skills influence the acquisition of spatial information, the spatial cognitive processes such as perspective taking, and the decision how to proceed with the robot operation. Specifically, lower-skilled participants will benefit more and are more effected by the process of training. The model also suggests that training spatial skills such

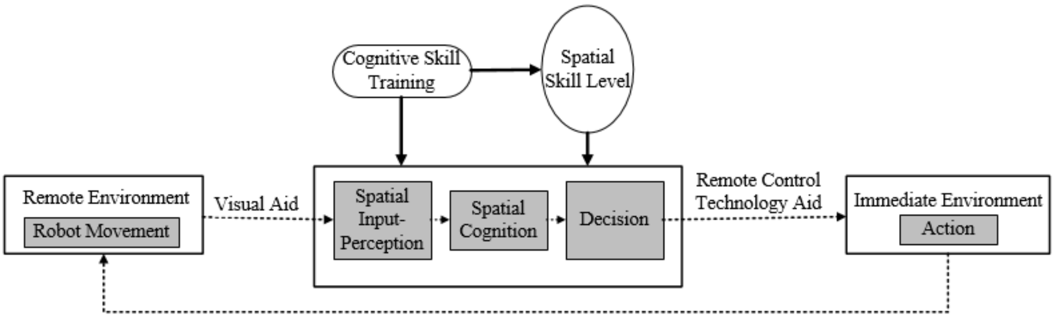


Figure 7 Cognitive task flow. The technology aid tool that effects the perception can be a visual aid or other feedback from the environment. The technological aid tool that effects the relationship between decision and action is a remote control such as joystick or a keyboard.

as perspective taking will influence those cognitive processes, but can also facilitate the acquisition of further spatial skills. Finally, the model suggests that the technological aids, such as the camera, either at the perception stage or at the action stage, can also influence the cognitive processes.

The pattern of reaction times is different from previous findings on relative direction judgments. An example is the TTD of left directions with respect to right directions. In the current setting, the camera's perspective was fixed to the left of the participant's perspective. This implies that relative direction judgments might be influenced by external technological aids such as camera's perspective during teleoperation, which attenuates the available spatial information. Specifically, it seems that the teleoperation environment: specific perspective during the task, limited visibility and the usage of egocentric frame of reference, might have had an effect on the ability of the operator to judge directions in space. The notion of the impact of limited visual information attained through technologic aids on performance is consistent with current results found in literature.

The findings here suggest that training perspective taking skill using the proposed paradigm had different benefits for different initial perspective taking skills as the model implies. In light of these results, we propose revisiting the approach to training and acquisition of spatial skills, both on the theoretical and practical levels. Specifically, future studies, should explore the theoretical aspect of teleoperation performance in terms of: 1. the cognitive processes that underlie training and acquisition of spatial skills; and, 2. the technological factors present in teleoperation that may moderate our ability to perceive, analyze, and execute spatial strategies.

The effectiveness of the paradigm should be explored further with regards to its length, for example, a different design to test a single training trial and its effect on perspective taking skills acquisition. Moreover, due to unsuccessful trials of participants, the sample size was smaller than predicted, this had an influence on the effect size and observed power. Additional studies should also consider the effect of the technological aids on the process of skill acquisition and the transfer of learning in various teleoperation settings. Specifically, exploring the process of perception, analysis and decision during robot teleoperation with various control methods and visual aids systems. For example, teleoperation using virtual reality with a head mounted display. In such 3D environment, the process of spatial perception, analysis and decision may be effect by the issue of telepresence and present different results. The effect of technology aids on performance in spatial tasks should be investigated, and the suggested model would help future studies generate and explore hypotheses regarding the acquisition of spatial skills.

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