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A Training Protocol for Controlling Lego Robots via Speech Generating Devices

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Abstract. Lego robots have proved to be effective assistive technologies for play and academic activities. With adapted interfaces, Lego robots provide children with disabilities a way of manipulating objects, creating opportunities for play and learning, thus promoting their cognitive development. However, children need to learn how to control the robot before being able to use it as a tool to perform educational tasks.
Objective: This paper describes a training protocol to control Lego robots via Speech Generating Devices (SGDs). Playful tasks of increasing complexity and appropriate metrics were designed such that the child progressively develops basic robot control skills, learns how to use the robot to manipulate items, and finally is able to use the SGD both for controlling the robot and for communication, switching between robot and communication modes. The protocol is used to bring participants to an adequate competency level for a larger study using Lego robots to perform math measurement activities.
Main content: The protocol is described including a familiarization session, trials doing a slalom course, and then a final operational accuracy test. Three children with cerebral palsy performed the protocol.
Results: Results of the application of the training protocol show that it provides an adequate method to incrementally develop children's abilities to use the robot as a tool to perform educational math measurement tasks.
Conclusions: Introducing domains (robot control, manipulation, communication) one at a time during the training protocol provided an opportunity for the participants to practice skills that they need for math measurement activities. This protocol also provided an opportunity for the investigators to evaluate the effect of adding manipulation and communication demands on top of robot control.

Keywords. Robot, Augmentative and Alternative Communication, Training

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Introduction

It can be difficult for children with severe disabilities to participate in classroom activities, especially when manipulation of items is used to learn concepts (1). To address this problem, switch adapted assistive robots have been used to give children access to manipulation in educational activities (2-4). Recent robot studies have utilized relatively inexpensive Lego^{TM} robots (5). Since children can control Lego robots using the built-in infrared (IR) output on some speech generating devices (SGDs), it is possible to give them the power to access both augmented manipulation and communication. This way they do not have to turn away from play or learning activities to communicate or vice versa, a known problem when using SGDs (6). In addition, using their own SGD addresses a limitation in other assistive robot studies. In previous studies, children who had severe physical disabilities had difficulty controlling all robot degrees of freedom since it required access to multiple independent switches (3, 5), or mapping robot functions using separate scanning or mouse interfaces (7). Using an SGD, one can take advantage of the different access methods available (e.g. sequential scanning with one or two switches) to provide access to all robot functions on a SGD page.

As mentioned, an integrated manipulation and communication system using a child's own SGD and a relatively inexpensive Lego robot could facilitate more active participation for children with disabilities in the curriculum. In a larger study, participants were expected to use their own SGD and alternative access method to control a Lego robot to perform math measurement activities (8). The main skills required for the envisioned math activities were: to stop the robot lined up on a line, maneuver in 2-dimensions, un-wind string along a pathway, line up units tip to tip, mark the end of a unit with a pen, and switch between robot control and communication modes. Investigators who have studied the use of assistive robots in educational activities have found that children need two phases, first to learn the robot functions, and then to use it in the educational activities (3). A training protocol was performed in order to bring the participants to an adequate competency level before performing the math activities. This paper reports on the training protocol used in the study, which was designed so that no math concepts were covered during training, but participants learned the robot skills that they would be required to perform in the subsequent math activities.

1. Methods

1.1. Participants

Three children who have spastic athetoid quadriparetic cerebral palsy participated in the study, a 14 year old female, a 10 year old male, and a 12 year old female (called here M01, M02 and M03 respectively). They used their own Vanguard^{TM} II SGDs which they activated using two Spec ^{TM} switches located at either side of their wheelchair headrests. They all used step scanning, where M01 and M02 used row-column scanning and M03 used group-row-column scanning. They were competent communicators, though M01 was less experienced when compared to M02 and M03.

1.2. *Materials*

The integrated communication and robot control system was operationalized by using the participant's own SGD and a car-like Lego robot, built from the Lego Mindstorms for Schools™ kit. The main features of the robot, which were in addition to the car-like capability of the robot used in previous studies (e.g., 5), were: 1) a low robot body with a flat surface, 2) a location to attach referents and non-standard units to the top of the robot, 3) a gripper, 4) a mechanism for moving a pen up and down on the side of the robot, and 5) a spindle to hold string (see Figure 1). The main design requirement in the environment was to affix items and non-standard units to the top of blocks so that they could be grasped by the robot gripper (see straw on block in Figure 1, left). Colored arms from the Mr. Potato Head™ game were also added to the robot (yellow on the left, and blue on the right) to facilitate deciding how to turn left and right when the participant's frame of reference was not the same as the robot's (e.g., when the robot came towards them). The SGD interface symbols were color coded accordingly.

The robot was controlled by direct commands to three motors or by programs. The commands used in the training were: forward and backward (approximately 10 cm in length), left and right (approximately 15 degrees in angle), optional small movements (forward and backward, approximately 2 cm in length, and left and right, approximately 5 degrees in angle), open and close gripper commands, and up and down pen commands. Each participant's SGD interface was modified to give them access to the robot control commands (reported elsewhere, (9)). A Lego IR remote control unit was used to train the SGD to send the required IR commands to the robot.

Figure 1: Robot with: (left) gripper, (middle) pen, and (right) spindle for string

1.3. *Procedure*

Domains were introduced one at a time: first robot control only; then robotic control with manipulation of items; and then robotic control with manipulation of items and communication. The protocol consisted of a familiarization session, trials doing a slalom course, and then a final operational accuracy test. Participants had three to four sessions of 30 to 60 minutes each, and all sessions were video recorded.

Familiarization session: The purpose of this learning phase was to familiarize participants with the robot controls. Participants learned each direct robot command one at a time in a task protocol based on a previous robot study (10). The goal in each task was to knock over a stack of blocks and the participant did the following tasks 3 times each (his/her success or failure at knocking over the blocks was recorded):

- Task 1 (causality): go forward by pressing and holding the selection
- Task 2 (negation): go forward and stop at a pile of blocks for the investigator to load them on the robot, then go forward and stop again to unload them (the participant could also back up to be more accurate)
- Task 3A (binary logic) and Task 3B (sequencing of actions): go left or right appropriately, and then go forward

Slalom course trials: After robot control understanding, the protocol aims at training children on using the robot to maneuver in two dimensions, manipulate items, and switch between manipulation and communication modes. Participants drove the robot through a course 1.15 m long. The course was on a large sheet of paper and a pen was attached to the back of the robot so accuracy measures could be made afterwards from the pen-trace. Small 5 x 5 x 5 cm blocks were used as obstacles and two toy ships were used as the sides of a goal at the finish line. The trials increased in complexity (by adding obstacles) and progressed through performing robot control only, robot control with manipulation, and robot control with manipulation and communication (see Table 1). Accuracy of each slalom trial was measured as the area enclosed between the participant's pen-traced pathway and the mid-line from the start to finish locations (i.e., the smaller the area, the better the accuracy). To determine the area, a photo of the pathway was taken, each pathway and mid-line was digitized using ImageJ™, and the software automatically calculated the area. Time to complete the slalom trails was measured by a research assistant with a stop watch and the values were verified by the investigator from the recorded video of the session.
The participant was told that accuracy was more important than time. After each set of trials participants were asked how difficult they felt it was using the following rating scale: really easy, easy, so-so, hard and really hard.
Final robot operational accuracy test: The final test phase of the protocol provides an accuracy measure of robot control. A pen was now mounted through a block and grasped in the robot gripper. Eight target 10 cm diameter circle locations were randomly determined prior to the test. The first target was drawn quickly on a large sheet of paper by the investigator, and the participant was required to drive the robot to the target. When the pen reached the target, the robot was placed back to the start position (at the centre of the paper) and the procedure was repeated for the remaining targets.

Accuracy was measured as the ratio of the length of the actual trajectory taken by the participant divided by the ideal trajectory (i.e., the closer to 1.0, the better the accuracy). The ideal trajectory was chosen as if the participant spun the robot around in a circle until the robot faced the target dot, and then traveled directly forward to reach it, which was actually the basic strategy used by all of the participants. To automatically determine the ratio, ImageJ™ was used. Once more, time to complete the task was measured and cross checked with the values from the session video.

Table 1: The robot training protocol

Domain	Number of obstacles in slalom course and concurrent activity
Robot only	**1** obstacle, **2** obstacles, & **3** obstacles including stopping on a finish line
Robot & Manipulation	**2 obstacles** while gripping a **block** at the start position and releasing it at the end position, then gripping a second block at the start position and releasing it lined up tip-to-tip with the first block
	2 obstacles while lifting the side-mounted **pen up or down** when passing obstacles
	2 obstacles while lifting the side-mounted **pen** up and down to make a **dotted line**
Robot & Manipulation & Communication	**2 obstacles** while lifting the side-mounted **pen up or down** when passing obstacles (i.e., twice), and switching to **communication** mode to say a randomly chosen word (pulled from an envelope by a research assistant) once every 2 minutes (notified by a timer)
Two additional tasks were performed: 1) 1 obstacle while gripping a block with a straw attached to it (lining up 2 blocks tip to tip) 2) un-winding string behind the robot through 2 obstacles and requesting the string to be taped down. The areas used to measure accuracy in the first additional task were much smaller than those reported in Figure 2 due to the long length of the straws, and the pen had to be removed to install the spindle for the second task, thus compromising the comparison with other tasks results.	

2. Results

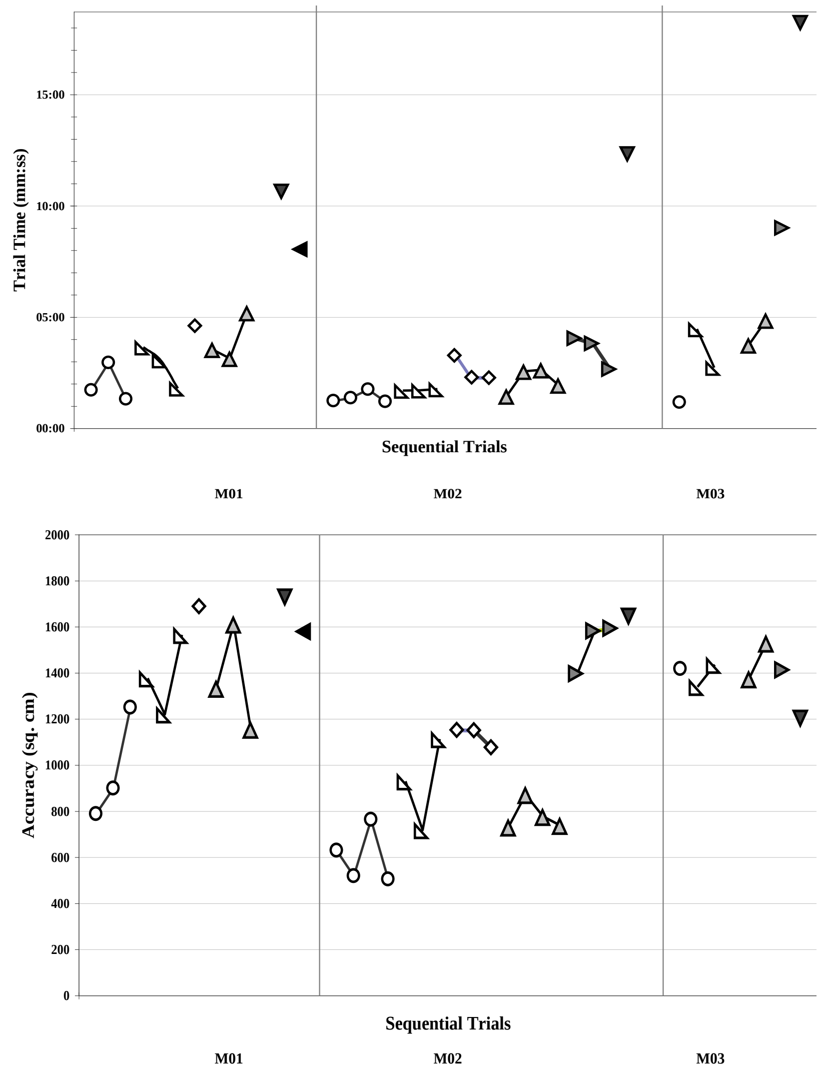
Familiarization session: All participants accomplished the goal of knocking over the blocks 3 out of 3 times in all tasks.

Slalom course trials: Figure 2 shows each participant's accuracy in terms of area (i.e., the smaller the area, the better the accuracy) and time as each participant progressed through the slalom trials. Robot & Manipulation & Communication trial results are only plotted for M01. M02 did not formally perform the task, but his ability to change from robot control to communication mode was demonstrated during trials where he stopped moving the robot through the slalom course to say things (e.g., "I can't see"). M03's trial, first without and then with communication, was with 1-obstacle and straws on blocks and her accuracy went from 641 to 1037 cm^2 and her time went from 4:53 to 5:51 (due to time constraints she performed fewer trials than the other participants, and the communication trial was incorporated into her straw trials). The participant's rating of difficulty of the training tasks is shown in Table 2.

Final robot operational accuracy test: Accuracy and time are shown in Table 3.

Table 2: Rating of difficulty of slalom trials (not all participants rated all trials)

Domain	Trial Description	Really easy	Easy	So so	Hard	Really hard
Robot only	1,2,3 obstacles					M01
		M02				
		M03				
Robot & Manipulation	Robot with blocks					M01
				M02		
			M03			
	Robot with pen up/down				M03	
	Robot with pen dotted line				M02	
					M03	
Robot & manipulation & communication	Robot with pen up/down and communication					M01
				M03		



Legend: Robot only through course with:

1 Obstacle 2 Obstacles 3 Obstacles

Robot through 2-obstacle course with manipulation of:

Blocks Pen up&down twice Pen dotted line

Robot through 2-obstacle course with manipulation of:

pen up&down twice and communication

Figure 2: Accuracy (top) and Time (bottom) for all participants in training activities.

Table 3: Robot operational accuracy test controlling the robot with the SGD

Participant	Accuracy (actual/ideal)	Time (mm:ss)
M01	1.53	7:57
M02	1.13	6:30
M03	1.16	9:28

3. Discussion

All participants easily accomplished the tasks in the familiarization session, which is not surprising since the participants obviously have causation, negation, binary, and sequencing skills, evidenced by the operational competence with which they accessed their SGDs' (all used scanning to access their SGDs, which requires these skills).

Visual observation of the slalom course trials data shows that, generally, accuracy decreased and time increased as the trials became more involved by adding more obstacles, manipulation and then communication. There are a few instances where this trend is not seen, as follows:

1) M02 had a large improvement in accuracy in his trials manipulating blocks due to re-programming smaller turns (at his request).

2) M02 showed a large decrease in accuracy in the trials with the side-mounted pen (up & down twice) probably due to having to change the direction of travel of the robot in order for him to see the pen (from driving away from himself to driving towards himself). Examination of erroneous selections for left and right turns showed an increase from 0 to 1 when driving away from himself to 4 to 7 when driving towards himself. Changing the direction of travel for the pen trials was also necessary for M03, but it manifested as only left/right turn errors rather than area error (increasing from 0 to 4). The direction of travel did not change for M01's pen trials since she could already see the robot pen from the initially chosen side for viewing the workspace. Her left/right error frequency did not change.

3) M03's accuracy data did not increase in her trials, but there was an environmental factor which probably influenced this result. The table used for her trials was smaller in width than that used in the trials for the other participants, so M03 was probably influenced to stay away from the sides of the table, regardless of the task demands.

4) M03's accuracy on the dotted line trial was better than her other trials because she frequently chose to use the small forward and turn movements, instead of the larger ones. It is likely that she chose them because they were in the same scanning group as her pen up/down command.

Of course, time was expected to increase as the trials progressed because of the added requirements of gripping objects, moving the pen up/down, and/or switching to communication mode and finding vocabulary. However, a decrease in accuracy is not necessarily expected, so the decrease that was seen may point to an added cognitive load. M02 and M03's reporting on the perceived difficulty of the tasks supports that they found the trials to be more difficult as the trials became more involved: using the Robot Only was really easy; using the Robot and Blocks was easy for M03 and so-so for M02; and using the Robot and Pen was hard for both. M01, an inexperienced SGD user compared to M02 and M03, found all of the tasks involving the robot to be "really hard" (although she clearly enjoyed using the robot in all activities). A qualitative analysis of the results in the Robot and Pen dotted line trial also indicates that the cognitive load was very high. M01 forgot to go around one of the obstacles and she also had considerable trouble remembering to raise and/or lower the pen, so her "dots" were sporadic and sometimes dragged along for 20 cm. M02 and M03 had some trouble at the beginning of the trial, but became more rhythmic with raising/lowering the pen and moving the robot by the time they passed the first obstacle.

Unfortunately, not all participants performed the same Robot and Manipulation and Communication task, making inter-participant comparisons difficult. Looking at M01 and M03, though, both of their times increased when adding communication: M01 increased by 3 minutes over other 2 obstacle trials and M03 increased by 1 minute in her 1 obstacle straw trial (M01 took longer because she was less experienced and struggled to find vocabulary). Consistent with added manipulation demands, accuracy also decreased with the added communication demands (M01's was the same as the lowest accuracy in other 2-obstacle trials and M03's accuracy went from 641 to 1037 cm^2). Only M03 was asked about the difficulty of adding a communication requirement to the Robot and Manipulation trial, and she found it to be "so so" (an increase in difficulty from "easy").

As expected, M02, who had the best accuracy in the slalom trials, had the best accuracy in the final robot operational accuracy test. Likewise, M01, who generally had the lowest accuracy in the slalom trials, had the lowest accuracy in the final accuracy test. M03's accuracy on the slalom trials was similar to M01's yet her final accuracy test was as good as M02's. M03's time was slower than M02 on both the slalom trails and the final accuracy test, but the participants were told that accuracy was the most important criteria. A possible explanation for M03's good performance on the final robot accuracy test could be that the test only involved operational control skills (turn, go forward towards the target, then turn to hit the target) which she may have transferred from her power mobility (PM) skills (M02 also had PM, but M01 did not).

4. Conclusions

Introducing domains (robot control, manipulation, communication) one at a time during the training protocol provided an opportunity for the participants to practice robot skills for the math measurement activities. The maneuverability required in the math activities was similar to the resolution in the 2-obstacle training trials, and accuracy results of the slalom trials showed a posteriori to be good predictors of the children’s ability to use the robot as a tool to perform those math activities [8]. Time was not a factor since the participants were given as much time as they needed to perform the math activities. However, the protocol failed to identify some robot problem solving issues. M03 revealed difficulties in determining the right way of approaching an object in order to grab it with the robot gripper (in the protocol, the straws affixed to blocks were placed directly into the robot grippers by the investigator). Tasks to train these skills should be added.

This protocol also provided an opportunity for the investigators to evaluate the effect of adding manipulation and communication demands on top of robot control. It was observed in the slalom trials that participant performance deteriorated as they moved to increasingly complex tasks, and this information was used in reflecting on the contribution of cognitive load on participant accuracy in the math activities.

References

1. Schlosser RW, McGhie-Richmond D, Blackstien-Adler S, Mirenda P, Antonius K, Janzen P. Training a School Team To Integrate Technology Meaningfully into the Curriculum: Effects on Student Participation. Journal of Special Education Technology. 2000;15(1):31-44.
2. Eberhart SP, Osborne J, Rahman T. Classroom Evaluation of the Arlyn Arm Robotic Workstation. Assistive Technology. 2000;12:132-43.
3. Howell R, Martz S, Stanger CA. Classroom applications of educational robots for inclusive teams of students with and without disabilities. Technology and Disability. 1996;5:139-50.

4. Harwin W, Ginige A, Jackson R. A Robot Workstation for Use in Education of the Physically Handicapped. IEEE Transactions on Biomedical Engineering. 1988;35(2):127-31.
5. Cook A, Adams K, Volden J, Harbottle N, Harbottle C. Using Lego robots to estimate cognitive ability in children who have severe physical disabilities. Disability and Rehabilitation: Assistive Technology. 2010;Early On-line:1-9.
6. Light JC, Drager KDR. Improving the Design of Augmentative and Alternative Technologies for Young Children. Assistive Technology. 2002;14:17-32.
7. Prazak B, Kronreif G, Hochgatterer A, Fürst M. Development pilot: a toy robot for physically disabled children. Technology and Disability. 2004;16:131-6.
8. Adams K. Access to math activities for children with disabilities by controlling lego robots via augmentative communication devices. Edmonton, Alberta: University of Alberta; 2011.
9. Adams K, editor Involving Users in the Design of a Speech Generating Device Interface for Lego Robot Control RESNA; Submitted for review; Toronto, ON.
10. Poletz L, Encarnação P, Adams K, Cook AM. Robot skills and cognitive performance of preschool children. Technology and Disability. 2010;22(3):117-26.