Assistive Technology Labs
3-59 Corbett Hall – University of Alberta Edmonton, AB T6G 2G4
Ph: (780) 492-5422 Fx: (780) 492-1696 Email: atlab@ualberta.ca
Alberta Health Services
UNIVERSITY OF ALBERTA

VIRTUAL ASSISTIVE ROBOT FOR PLAY

Pedro Encarnação[a], Gonçalo Piedade[a], Kim Adams[b,c], Albert M. Cook[b]
[a]Faculty of Engineering, Catholic University of Portugal
Sintra, Portugal
pme@fe.lisboa.ucp.pt
[b]Faculty of Rehabilitation Medicine, University of Alberta
Edmonton, Alberta, Canada
[c]Glenrose Rehabilitation Hospital
Edmonton, Alberta, Canada

ABSTRACT
Play is of utmost importance for child development. This paper presents a virtual assistive robot that enables children with disabilities to actively participate in play activities simulated on a computer screen. Children with and without disabilities participated in a feasibility study to assess if children have the same performance on play tasks using a physical robot and a matching virtual robot.

KEY WORDS
Assistive Robotics, Virtual Robots, Assistive Software Technology, Augmentative Manipulation

1. Introduction

Play has a central role in child development, fostering learning of cognitive and social skills [1]. Also, through play, children reveal their internal emotions and cognitive skills, and play activities have been used in diagnostic and therapeutic functions [1, 2]. Children with physical disabilities may experience primary forms of play deprivation, not being able to participate in some play activities as a direct consequence of their impairments [3]. For example, a child with spinal muscular atrophy would not be able to run after a friend in a chase and capture game. They may also experience secondary forms of play deprivation, if they do not have access to analogous forms of play in which they can take part. As a consequence, social, emotional, and psychological disabilities may arise [3]. Assistive technology can provide a means for children with disabilities to actively participate in play activities, thus overcoming secondary forms of play deprivation. In the above example, a powered wheelchair could allow the child to take part in the game.

Low-technology solutions such as applying Velcro fasteners on doll clothes or enlarged play materials are commonly used by occupational therapists to make play activities accessible for children with motor disabilities [4]. Other useful resources are switch-activated toys. These are battery-operated toys that produce action, sound, visual effects, or tactile sensations upon switch activation. If appropriately chosen, switch-activated toys may help children develop skills such as object permanence, cause-effect relationships, and directionality, and provide a means to act on the environment [4]. Other materials can be used with switch-operated toys to enrich the play experience (e.g., place a stack of blocks in front of a teleoperated car to be knocked over). However, switch-activated toys quickly become boring as the child gains proficiency and provide limited opportunities for creativity, due to their limited repertoire of actions.

Robots have more degrees of freedom and can be programmed to exhibit different levels of autonomy. They can be teleoperated, with the user directly controlling all degrees of freedom, have some actions programmed such that the user only needs to select those actions to replay them, or be completely autonomous, performing a task without user intervention. These characteristics make robots good candidates to be used as assistive technologies for play.

In [5] the authors report that children with disabilities with a cognitive developmental age of 8 months are able to use a small educational robotic manipulator controlled using a single switch as a tool to obtain objects out of reach. An adapted robotic manipulator was also used in [6]. Three tasks (position the robotic arm, dig an object from a tub of macaroni, and dump the cup held by the robot's gripper) were programmed, each activated by a single switch. These tasks were used in increasingly complex interactive play activities (e.g. the researcher filled the cup with macaroni and the child had to dump it, or the child had to position the robot, dig the object buried in the macaroni by the researcher, and then dump it). The study, involving twelve children with severe physical disabilities, ranging in age from 6 to 14 years, showed that the robot provided a more motivational environment for children to play when compared to switch-activated toys, appliances, or simple computer-based activities, and was a means to reveal children's hidden skills [6]. A dedicated robot to enable children with severe physical impairments to play with Lego® bricks is reported in [7]. Children with and without disabilities enjoyed using the robot in play activities. Robots built from Lego bricks and motors have been used to move, pick up and place toy items in play activities [2]. Lego robots are relatively inexpensive, when compared to robotic manipulators, they're appealing to children and playmates, portable, and the control interface can be adapted to meet special needs [8].

Robots have also been used to assess cognitive skills of children with disabilities. Standard cognitive tests usually rely on verbal or motor answers and thus are not appropriate for children with severe physical disabilities. Adapted tests where children have to choose from a set of possible answers using eye gaze or directed scanning require sustained attention and children quickly lose interest. As a result, children's capabilities may be underestimated reducing expectations on the part of teachers, clinicians, and parents [9]. Different play activities, requiring different cognitive skills, may be designed to be performed with robots, taking advantage of the versatility and motivational aspect of robots. In [2] Lego robots were used to reveal cognitive skills. Ten children, ages 4 to 10 years, diagnosed with cerebral palsy and related motor conditions, were able to control a Lego robot to perform unstructured play tasks, in some cases demonstrating cognitive skills that were not assessed with traditional standardized tests. Poletz et al. [10] observed eighteen typically developing children aged 3 to 5 years playing with Lego robots. Success in performing the specially designed play tasks was indicative of participants' cognitive skills. Comparing the performance of children with disabilities with the performance of typically developing children executing the same tasks, allows investigators to say that a particular child with disabilities performs like a typically developing child at the same cognitive age, as assessed by the robot.

However, even the cost of Lego robots (~$300) may be prohibitive in some contexts. Additionally, Lego robots are not very reliable (e.g. if programmed to make a right-angle turn upon a switch hit, they may not turn exactly 90 degrees, leaving the robot with an undesirable orientation for subsequent forward moves). To conduct the sessions with children it is advisable to have a person present with the technical background necessary to assemble and program the robots, and troubleshoot possible failures. This fact can also hamper wide use of robots in rehabilitation settings. Virtual robots to perform play activities in a simulated environment on a computer screen have the potential to overcome these limitations. Having a software package that could run on a standard computer made accessible for children with disabilities would highly facilitate distribution and translation of research into the clinical and home settings.

This approach is similar to using computer games. Educational and training software is widely available for children of every age [11]. Programs can be accessed by children with disabilities using commercially available technology for computer access [12]. However, there's not sufficient evidence that computer use has an effect on children's play, communication and development [13]. Some studies (please refer to [11] and the references therein) report a positive effect of computer use on the emergence of reading and writing skills, and on the development of language, social behaviours, and higher order cognitive skills. Comparative studies between traditional methods and computer-assisted interventions show that children with disabilities exhibited more sophisticated levels of play behaviours and more positive, interactive social behaviours in computer-assisted interventions [14], and that substituting classroom manipulatives with computer software had a positive impact on skill building for young children with learning impairments [15]. Critics of computer based solutions often refer to the danger of isolation and loss of interest in any activity that does not use a computer. However, observation shows that children like a balance between self-play and social play, and that they need to constantly change activities and games to maintain the interest [13]. Cost, lack of training and technical assistance, and time constraints have been identified has the major barriers to computer use in school settings [11]. The potential benefits of using computer-based robot programs (e.g. accuracy, ease of dissemination, ease of changing activities quickly) indicate that research is needed to investigate if the beneficial effects of using physical robots can be achieved when using virtual robots.

In this paper a virtual robot that can be controlled through single switches to perform play activities in virtual environments is presented. Different activities and virtual environments were developed, showing the potential of the software to embed a database of play activities designed for different purposes (e.g. assess cognitive skills or provide a free play environment). For the study presented here, three different virtual scenarios were implemented, in which equivalent tasks to assess cognitive skills can be performed. The goal was to evaluate if using a virtual robot to perform a given play task in a virtual scenario would be the same as using a physical robot to perform the same task, thus contributing to the research on using virtual robots instead of physical robots as assistive technologies for play. The software was trialled with typically developing children and children with cerebral palsy. Preliminary results, here presented, indicate that children's performance with the virtual robot is similar to the performance with the physical robot and thus that it is worth pursuing a line of research investigating the efficacy of virtual robots in virtual environments as assistive tools for play activities.

The paper is organized as follows. Section 2 describes the virtual robot and different virtual scenarios developed for play activities. In Section 3, results of the trials with the virtual robot involving children with and without disabilities are reported. The conclusions section points to different possible applications of the virtual robot that will be explored in future studies.

2. Virtual assistive robot

2.1 Overview

Microsoft® Robotics Developer Studio[1] (MS-RDS) was used to develop the virtual robot. MS-RDS is a freely available .NET-based programming environment for building robotics applications. It includes a programming model that simplifies the development of asynchronous, state-driven applications to control a wide variety of robots. Applications may be created using a Visual Programming Language (VPL) by dragging-and-dropping blocks and then converted to human-readable C#. Decentralized Software Services (DSS) enable a system-level approach for building scalable applications. A DSS Manifest Editor (DSSME) is available to easily edit services configuration (e.g. to assign one service to a specific entity). DSSME stores lists of services and their configurations into XML files, called manifests, which are used to start services using the DSS runtime (Manifest Loader Service). MS-RDS also includes a Visual Simulation Environment (VSE) to simulate and test robotic applications using a 3D physics-based simulation tool. Robotic applications can thus be created without the hardware. Moreover, robot control programs can be used either with the physical or the virtual robot by changing the respective service. User-defined 3D virtual environments can be designed using VSE.

The virtual assistive robot was created using MS-RDS to take advantage of the available services regarding robot control and because of the possibility of implementing the developed system with a physical robot. This is useful, for example, to assess the effectiveness of the virtual robot when compared to a physical robot (please refer to section 3). Since, Lego robots have been used in previous studies with physical robots [2, 10] the first virtual scenario implemented was with a virtual Lego Mindstorms® NXT 2.0 Tri Bot. This facilitates the comparison of virtual versus physical robot use. A virtual classroom with piles of blocks positioned to be knocked over by the robot was designed, mimicking the activities reported in [10] (see Figure 1). Two additional virtual scenarios were created to illustrate the potential of the software to provide different scenarios that may be more appealing for a particular child or simply to keep the child engaged during interventions. In one of the scenarios a prince drives a carriage to take flowers to a princess and to take the princess to the castle or to the garden (Figure 2). In the other additional scenario, a farmer operates a tractor to bring hay to animals (Figure 3). The activities in all scenarios are equivalent in the sense that the same user skills are necessary to perform corresponding activities in different scenarios. Table 1 summarizes three activities in each environment and the skills necessary to accomplish them. In the present application, different virtual scenarios are chosen by clicking one of the colored baskets on the ground of the virtual room.

	Lego Tri Bot	Prince on a carriage	Farmer on a tractor
Task 1 – move forward until an effect is produced	Stack of blocks is knocked over	Flower is given to the princess	Hay is given to an animal
Task 2 – stop at a particular location	Stop by a pile of blocks to load them on to the robot and then stop at the location where the stack of blocks should be built	Stop by a garden to collect a flower and then stop by the princess to give her the flower	Stop by a pile of hay to load it on to the tractor and then stop by the animal to feed it
Task 3 – turn in the appropriate direction and then move forward until an effect is produced	With the robot facing forward between two stacks of blocks, turn in the direction of the chosen stack of blocks and then move forward to knock it over	With the carriage facing forward between the castle and the garden, turn in the direction of the castle or the garden and then move forward to drive the princess there	With the tractor facing forward between two corrals, turn in the direction of the chosen animal and then move forward to feed it

Table 1. Equivalent tasks in different virtual environments

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[1] http://www.microsoft.com/robotics/

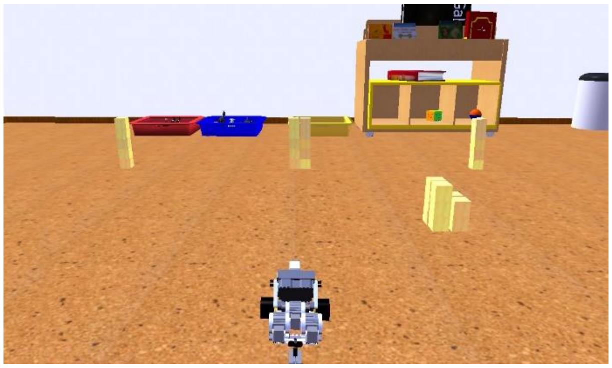
Figure 1. Virtual environment with Lego Mindstorms NXT 2.0 Tri Bot and piles of blocks

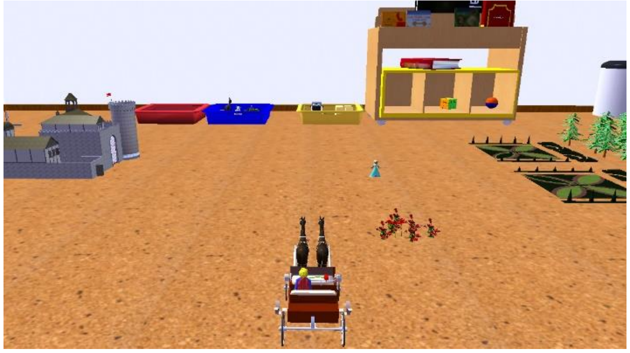
Figure 2. Virtual environment with a prince on a carriage to take flowers to a princess or to take the princess to the castle or to the garden


Figure 3. Virtual environment with a farmer on a tractor to bring hay to animals

2.2 Human-computer interface

The human-computer interface needs to be adapted in order to make the software accessible for children with motor disabilities. Since the robot control programs run on a computer, standard assistive technology for computer access can be used [12]. The application described here used three standard Jelly Bean® switches connected to the computer via a Sensory Software Joybox[2]. The Joybox was configured such that the three switches emulated the forward, left and right keyboard cursor keys. Within MS-RDS, the forward key was programmed to make the robot move straight forward as long as it is pressed, and left and right keys were programmed to make the robot turn exactly 90 degrees with each press. For children that are not able to use three switches, a scanning process could be arranged to choose from one of the above three options.

2.3 Programming of the virtual environments

Visual Studio C# was used to create a base empty Microsoft Robotics project adding the *Physics Engine* as a partner project and including the libraries SimulationEngine.dll, SimulationCommon.dll, SimulationCommon.Proxy.dll, RoboticsCommon.dll, RoboticsCommon.Proxy.dll, and PhysicsEngine.dll that are available with MS-RDS. Running this project opens the Visual Simulation Environment (VSE) where it is possible to load the Entity.UI manifest. This manifest already contains the sky, sun, and floor entities, and includes gravity in the *Physics Engine*. Three *Motor Base* entities were then added corresponding to the different vehicles (Tri Bot, carriage, and tractor). Under VSE edit mode, *Single Shape* entities allows for the inclusion of basic objects with box, sphere, or capsule shapes, specifying their dimensions and initial positions within the virtual scenario. Textures can be added to the objects. Different *Single Shape* entities can be combined into a single object. Objects have physical properties (e.g., mass, static friction, dynamic friction, restitution) and can be covered with 3D meshes to give them the appropriate appearance. Google SketchUp[3] was used to create 3D models of all the objects in the virtual environments and these models were imported to VSE to cover basic objects.

After having all the entities within the virtual scenarios, DSSME was used to add *Simulated Differential Drive* services, adequate to simulate robots with two motorized wheels, and connect them to the *Motor Drive* entities. *Contact Sensor* services were also added and associated to the moving entities to provide contact notifications that can be used to trigger a data flow. Data flows are designed within VPL making use of the available services associated to each entity. For example, when a block falls down and touches the table, a contact notification from the *Contact Sensor* service will trigger the flow designed for the block and the *Play Sound* service (available in VPL) is used to play a knocking sound. The *Graphical User Interface* (GUI) service is used in VPL data flows to be able to get user commands, creating a virtual console. In the virtual console shown in Figure 4, options were included to control the activities described in Table 1, to keep track of users' performance in executing those activities, offering the possibility to save it to an Excel file, and to control the robots. Another service used in VPL data flows was the *Teleporter* service. This service, used to move virtual objects, doesn't come with MS-RDS but is available at http://mrdssamples.codeplex.com/[4]. A modification was introduced in order to provide the object orientation through a quaternion, in addition to the object coordinates. Sounds to be associated to different events (e.g., blocks

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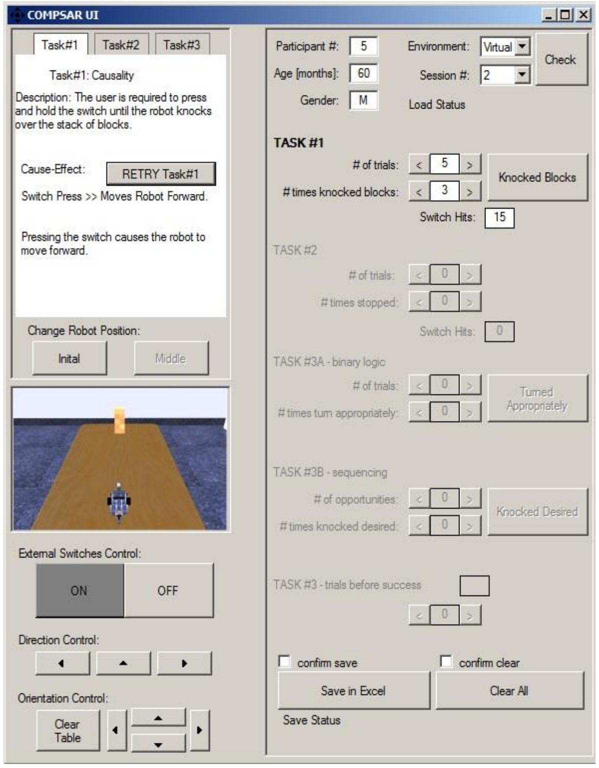
[2] www.sensorysoftware.com

[3] http://sketchup.google.com/

[4] *Teleporter* service was developed by Trevor Taylor, Microsoft Robotics Group.

falling, robot moving, reaching checkpoints) were selected from http://www.freesound.org and edited using Audacity®[5]. Finally, the VPL diagram was compiled to generate the service and the manifest associated with the virtual assistive robot application.

To run this application it is necessary to have MS-RDS (release 3 or above) installed. The dll files associated with all services, including the final service created by VPL, should be stored in the MS-RDS bin folder. The 3D models and textures used for creating the virtual objects should be in the store/media MS-RDS folder. Additionally, sound files should be placed in a pre-defined folder. Only then, within DSS Command Prompt, the virtual assistive robot manifest can be called. An installation package was developed that takes care of all these actions, creating a shortcut on the Desktop to run the application.



COMPSAR UI

Task#1: Causality

Description: The user is required to press and hold the switch until the robot knocks over the stack of blocks.

Cause-Effect: RETRY Task#1

Switch Press >> Moves Robot Forward.

Pressing the switch causes the robot to move forward.

Participant #: 5

Age [months]: 60

Gender: M

Environment: Virtual

Session #: 2

TASK #1

# of trials: 5

times knocked blocks: 3

Switch Hits: 15

TASK #2

# of trials: 0

times stopped: 0

Switch Hits: 0

TASK #3A - binary logic

# of trials: 0

times turn appropriately: 0

TASK #3B - sequencing

# of opportunities: 0

times knocked desired: 0

TASK #3 - trials before success

0

☐ confirm save

☐ confirm clear

Figure 4. Virtual console

3. Virtual assistive robot trials

The virtual assistive robot developed was trialed in the context of the COMPSAR project[6]. This is a two-year project aimed at comparing the performance of children with and without disabilities when executing play activities with a physical robot and a matching virtual robot. Participants were selected within the cognitive age brackets 33-39, 45-51, and 57-63 months, using the Pictorial Test of Intelligence (PTI-2) [16]. Data regarding twenty typically developing children and nine children with cerebral palsy has been collected so far. Participants with cerebral palsy had the motor skills necessary to use three switches. All participants were seen for two sessions approximately one week apart. In each session they were asked to perform the tasks in Table 1 with the Lego Tri Bot, both using a physical Lego Mindstorms robot and a matching virtual robot. A scenario with a table on top of which piles of blocks were positioned to be knocked over by the robot was used (Figure 5). The order in which the robots were used in the first session was randomly assigned for each child but ensuring a balanced number of participants starting with the virtual and with the physical robot. Robot order was switched for each child's second session. The same set of three Jelly Bean switches was used to control the robots.

Figure 5. Experimental setup with the physical and the virtual robots

Success rates for each task were registered. Figures 6 and 7 show the results for the participants with and without disabilities. In these figures one can identify the three age groups at the three vertical stripes corresponding to the cognitive age brackets 33-39, 45-51, and 57-63 months. Horizontally, one can read the success rates between 0 and 100% in each of the four tasks. Thus, a vertical comparison informs on the success rates for the different activities for a given cognitive age, while a horizontal comparison provides a task success rate analysis across ages. The two plots in each of the figures refer to the physical (top) and the virtual (bottom) robot. Different success rates for different activities are related to the cognitive skills required to perform them and to participant's cognitive age, and are not analysed here (please refer to [10] for a discussion of performance relative to cognitive age in the context of a former study). In this paper only the comparison between the performance with the physical and the virtual robots is addressed.

Assuming a statistical additive model in which each success rate sample is the result of summing i) a common average value, ii) a factor related to the robot, iii) a factor related to the task, iv) a factor related to the interaction of the robot and task factors, and v) an independent normal residual with zero mean and equal variance for all groups, an ANOVA test ($p<0.05$) was conducted to assess if performance was influenced by the robot or the interaction factor. For participants with cerebral palsy, a p-value of 0.75 was obtained when testing if the success rates are not influenced by the robot and a p-value of 0.83 was obtained when testing if the success rates are not influenced by the interaction of robot and task factors. These p-values clearly show that the participants' performance was not influenced by the robot, independently of the task that was being done.

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[5] http://audacity.sourceforge.net/

[6] http://www.compsar.anditec.pt

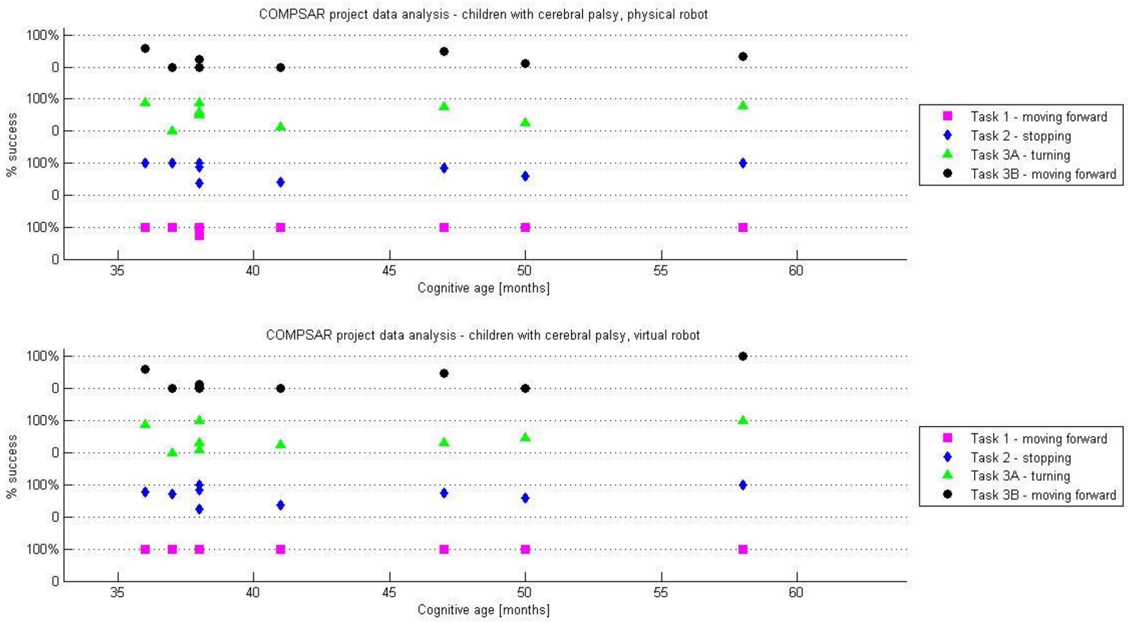

Figure 6. Success rates in the three activities with the physical (top) and the virtual (bottom) robots for the participants with cerebral palsy

The same conclusions were obtained for the typically developing participants, with p-values of 0.95 and 0.97, respectively for the influence of the robot and of the interaction of robot and task factors.

4. Conclusion and future work

A virtual robot software package was presented that enables children with disabilities to actively participate in play activities. Different virtual scenarios with different robot looks were implemented providing a way to adapt the software to children's preferences. The software provides highly interactive play opportunities, a characteristic that has been reported to be engaging for children with disabilities [17]. Tests with children with and without

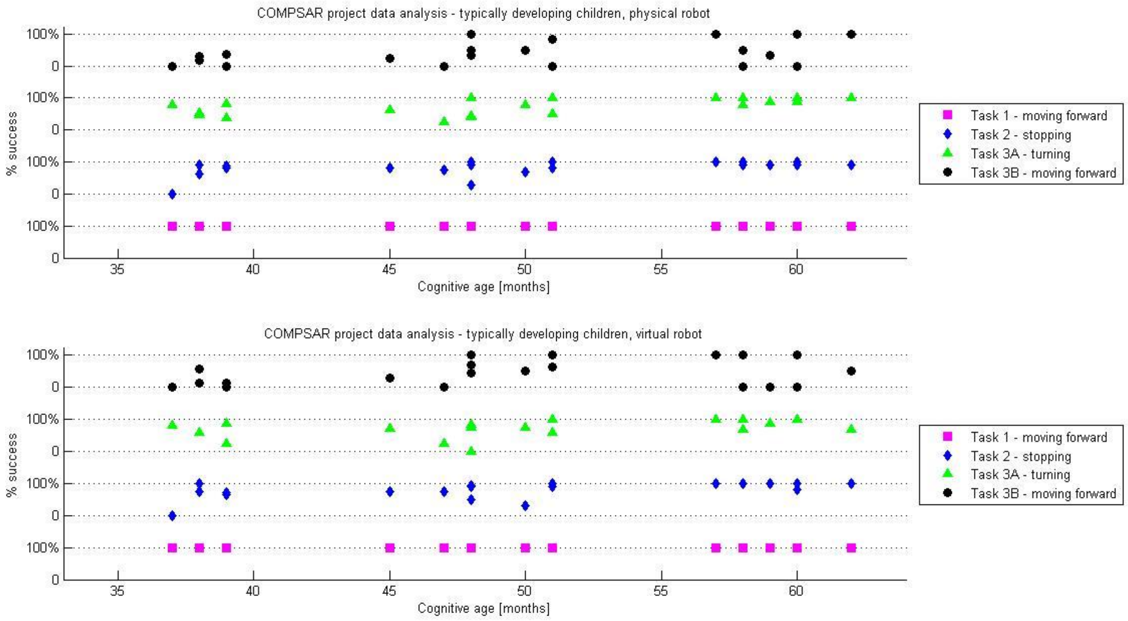

Figure 7. Success rates in the three activities with the physical (top) and the virtual (bottom) robots for the typically developing participants

disabilities have shown that the success rates of the participants while executing the same play activities with both robots in one of the scenarios are similar. This is an indication that the virtual robot provides the same experience as a matching physical robot. However this result may be culturally dependant and the study is being replicated in Canada and Colombia to assess possible cultural differences.

The developed software is being used in the COMPSAR project in the context of assessing cognitive skills of children with disabilities, using the robot and piles of blocks scenario. The prince on a carriage and the farmer on a tractor scenarios still need to be validated with children. Different play activities, different virtual scenarios, and different robot controls may be easily designed to meet other goals. For example, turn controls could be modified to make the robot turn in each direction as long as the switches are pressed, allowing for turning any angle, more objects that could be carried by the robot could be added, and free play scenarios could be designed like the ones described in [2], where physical robots were used. Or the robot controls and the virtual scenario could be adapted to train scanning skills for computer or augmentative and alternative communication systems access.

The positive results reported here show that it is worth pursuing this line of research in which virtual robots are used by children with disabilities as tools to interact with a virtual environment, providing them the opportunities to actively participate in play activities.

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