CROSS-CULTURAL USE OF PHYSICAL AND VIRTUAL ROBOTS TO REVEAL COGNITIVE UNDERSTANDING IN YOUNG CHILDREN

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ABSTRACT

Perceptual, cognitive, and social skills development are closely related to motor experience. Skills like tool use and problem solving depend on manipulation. Children with motor impairments may miss opportunities for independent interaction with their environment. Robots can provide means to overcome this limitation, and skills revealed by the children when operating a robot can provide insight into their understanding of cognitive skills. Robot use as a tool has different cognitive demands than direct manipulation. Exploration of robot skills required for operation by typically developing children of different ages can inform our understanding of skills displayed at different developmental stages. This paper compares the results of three studies conducted in Canada, Portugal and Colombia where typically developing children aged 3-5 used physical and virtual robots to execute the same play tasks. Cultural implications are discussed.

INTRODUCTION

Motor experiences are instrumental for perceptual, cognitive, and social skills development (Haywood and Getchell, 2009). Through manipulation children develop skills such as differentiation of means and end, tool use and problem solving (McCarty, Clifton and Collard, 2001). For example, when manipulating objects the child engages in trial and error behaviors that allow him or her to discover new ways to solve a problem, or to use an object to achieve a goal (Keen, 2011). Children with motor impairments lose opportunities for independent interaction with their environment. Because of restrictions in their manipulation skills, their learning skills and play behaviours may be compromised (Musselwhite, 1986). Additionally, they may be perceived as being more developmentally delayed than they actually are, leading to reduced expectations on the part of teachers, clinicians and parents (Harkness and Bundy, 2001).

Independent locomotion and manipulation constitute an observable outcome of the emergence of cognitive milestones. These observable motor behaviors provide insight into children's cognitive skills and overall development (Affolter, 2004). The skills revealed by the children when operating a robot to execute specially designed tasks can also provide insight into the understanding and attainment of certain cognitive skills. Children as young as 8 months of age have successfully used robots as tools to retrieve an object (Cook, Liu and Hoseit, 1990). More demanding tasks such as sequencing and academic related activities have been performed by children with disabilities while using a robot (Cook, Adams, Volden, Harbottle and Harbottle, 2011).

The use of a robot as a tool has different cognitive demands than those imposed by direct manipulation and interaction with the environment. The study and exploration of robot related skills of typically developing children of different ages can inform the understanding of the skills required for robot operation and the skills displayed at different developmental stages. A study conducted with eighteen typically developing children between the ages of three and five explored children's concepts of causality, inhibition, binary operations and sequencing at different ages (Poletz, Encarnação, Adams and Cook, 2010). Results showed that robot mediated play tasks can provide a proxy measure of children's cognitive development. For example, five year olds performed significantly better in the sequencing tasks than the four year olds, and the latter had greater success than the three year olds (Poletz, Encarnação, Adams and Cook, 2010).

Lego Mindstorms robots were used in this study. Though easy to operate and appealing to children, they still require technical skills to program and troubleshoot them, and their lack of accuracy sometimes complicates the execution of a task (e.g., when moving ahead for a relative long distance they tend to veer, requiring the user to correct the robot heading). Virtual robots and virtual scenarios, running on a computer screen, may offer a viable alternative to physical robots. Preliminary data from a study involving typically developing children and children with cerebral palsy shows that children's performance when executing the same play tasks with a physical robot and a matching virtual robot is similar (Encarnação, Piedade, Cook and Adams, 2012).

The two studies above evaluated the use of physical and virtual robots to assess and develop cognitive skills. However, it was still not clear if cultural backgrounds regarding technology use and exposure would impact children's performance. This paper compares the results of three studies conducted in Edmonton (Canada) (Poletz, Encarnação, Adams and Cook, 2010), Lisbon (Portugal) (Encarnação, Piedade, Cook and Adams, 2012), and Bogota

(Colombia) where typically developing children aged three to five used physical and virtual robots to execute the same play tasks. Cultural implications resulting from the comparison of Canadian, Portuguese and Colombian children are discussed.

STUDY OBJECTIVES

The study objectives were:

1. To assess if typically developing children's performance in executing play tasks requiring different cognitive skills using a physical robot varied with cognitive age;
2. To assess if the same performance was obtained if a matching virtual robot running in a virtual environment on a computer screen was used.

PARTICIPANTS

The Ages and Stages Questionnaire[1] was used to assess the cognitive age of the participants in the Edmonton study. The PTI - Pictorial Test of Intelligence (French, 2001) was used in the Bogotá and Lisbon studies. Since children in the Bogotá study spoke Spanish and children in the Lisbon study spoke Portuguese, the PTI[2] sentences for each question were translated by bilingual researchers using the Direct Translation Technique (Hóegh and Hóegh, 2009). In addition, questions related to phenomena or objects not common in Colombia were not used (e.g. activities related to winter games), and the picture of a stool was replaced by a chair since the Portuguese word for stool and bench is the same ("banco").

Edmonton study (Poletz, Encarnação, Adams and Cook, 2010)**:** eighteen typically developing children participated in the study. Three age brackets were defined: 3 years old – 33 to 39 months, 4 years old – 45 to 51 months, and 5 years old – 57 to 63 months.

Lisbon study (Encarnação, Piedade, Cook and Adams, 2012): twenty typically developing children participated in the study. Three age brackets were defined: 3 years old – 33 to 39 months, 4 years old – 45 to 51 months, and 5 years old – 57 to 63 months.

Bogota study: fifteen typically developing children participated in the study. No age brackets were defined. Participants were recruited in a continuum of ages between three and five years old.

EXPERIMENTAL SESSIONS

In the Edmonton study participants used a physical Lego Mindstorms RCX 2.0 robot in two sessions approximately one week apart. For both the Lisbon and Bogotá studies participants used a physical Lego Mindstorms NXT 2.0 robot and a matching virtual robot (Encarnação, Piedade, Cook and Adams, 2012) in each of two sessions also approximately one week apart. The first robot to be used by each child was randomly assigned, assuring a balanced number of participants starting with each robot. Participants of all three studies were asked to execute the same robot mediated activities (Poletz, Encarnação, Adams and Cook, 2010):

- Task 1 –cause and effect: press and hold a switch to make the robot move forward until it knocks over a stack of blocks;
- Task 2 –inhibition: children were asked to stop the robot beside a pile of blocks by releasing the switch, an assistant loaded some blocks onto the robot, then they had to stop for blocks to be unloaded at the initial stack position
- Task 3A –binary choice: with the robot in the middle of two stacks of blocks and facing forward, turn in the appropriate direction using one of two additional switches that make the robot turn 90 degrees to face one of the stacks of blocks;
- Task 3B –sequencing: after turning in the appropriate direction, press and hold the original forward switch to move towards the chosen stack of blocks.

Success rates in each task were recorded.

The participant's parents were asked to fill out a questionnaire to assess the child's previous familiarity with on/off switches, multi-button remote controls, and directional controls. Frequency of use (1 – Never, 2 – Seldom, or 3 – Often) and how children mastered those controls (1 – Low skill (trial and error), 2 – Medium skill, or 3 – High skill (mastered)) were assessed. The participant's mother's level of education was recorded as a proxy measure of the child's socio-economic level (Davis-Kean, 2005)

RESULTS

Edmonton

[1] http://www.agesandstages.com/index.html

[2] The sentences of the PTI are short enough for an easy translation and most of the pictures are universal concepts.

Success rates in each activity for the Edmonton study are plotted in Figure 1. The relationship between performance of each task and age level was evaluated by pairwise comparison between groups with a Welch's t-test ($p < 0.05$) (Poletz, Encarnação, Adams and Cook, 2010). All of the children successfully carried out the first task on all trials. In the second task, the average number of successes in Task 2 for the four year olds was significantly greater than for the three year olds (Welch's test, $p = 0.044$). The average number of successes for the five year olds was not significantly greater than for the four year olds (Welch's test, $p = 0.120$). In Task 3A the four year olds performed better than the three year olds, but this was not significant (Welch's test, $p = 0.063$), and the five year olds performed significantly better than the four year olds (Welch's test, $p = 0.019$). In Task 3B, the average number of successes for the four year olds was significantly more than the three year olds (Welch's test, $p = 0.002$) and the successes for the five year olds was significantly more than for the four year olds (Welch's test, $p = 0.007$).

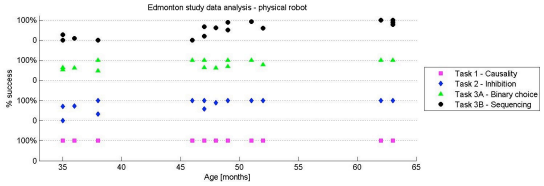

Figure 1: Edmonton data plot

Lisbon

Figure 2 shows the Lisbon study participants' success rates in each activity.

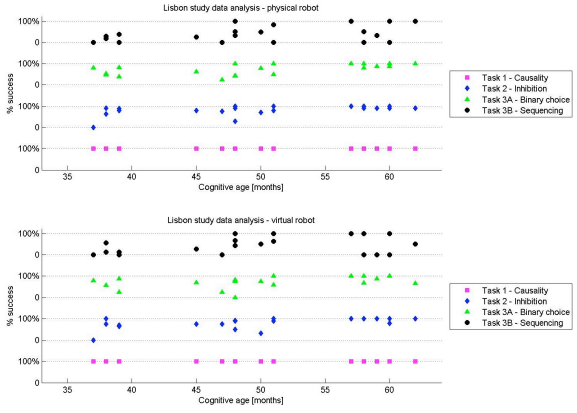

Figure 2: Lisbon data plot

Assuming the ANOVA assumptions are met (Devore, 2011), a three way ANOVA analysis ($p=0.05$) without taking into account Task 1 revealed that the factors age and task significantly influence the success rates, while the factor robot does not. A multiple comparison ($p=0.05$) revealed that there were significant differences between the success rates' means of groups 3yo and 5yo in tasks 2, 3A and 3B, and groups task 2 and task 3B, and task 3A and task 3B for all ages.

Bogotá

Performance of the Bogotá study participants is depicted in Figure 3. A two way ANOVA analysis ($p=0.05$) was used to assess the influence of the task (2, 3A and 3B) and of the robot (physical or virtual). Success rates for each task were significantly different, as expected ($p=0.00102$). Significant differences were identified between Task 1 and Task 3B, and between Task 3A and Task 3B. The effect of the robot was not statistically significant ($p=0.19552$).

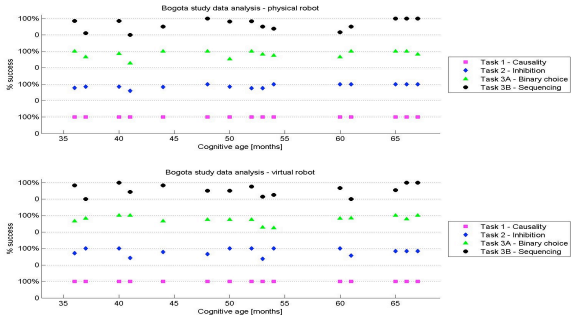

Figure 3: Bogota data plot

DISCUSSION

The tasks were designed to involve increasingly complex cognitive skills and, from developmental psychology theory (Forman, 1986; Piaget, 1953), it is known that children at the study cognitive ages would not have mastered all the cognitive skills for all tasks. The goal of this research is to use task success rates as a proxy measure of the children's cognitive age, avoiding tests requiring verbal or physical responses not available to children with severe disabilities.

Edmonton

The results of the Edmonton study revealed that proficiency in the tasks increases with age (Poletz, Encarnação, Adams and Cook, 2010). All of the participants successfully completed the first task. Task 2 had more mixed results, where four year olds performed better than three year olds and all five year olds completing the task successfully. All children succeeded in Task 3A on most trials. For Task 3B children aged four and five years old quickly understood that two switches were required. However, the three year olds often hit the turn switch several times. A number of children did not have any success at Task 3B.

Lisbon

Tasks 2 to 3B illustrate differences between cognitively aged 3 and 5 year olds. Though the mean success rates for the 4 year olds was not significantly different in any of these tasks from the 3 and 5 year olds, it is clear from Figure 2 that task 3B success rates are higher for four year olds than for three year olds. Also, success rates in task 3A are higher for five year olds than for four year olds. These differences might be significant with a larger sample.

Bogota

Success rates for each task were significantly different. The influence of age was not calculated for the Bogota participants. Figure 3 shows that older children had more success at the higher tasks than the younger children. Hence, success rates were influenced by the age of children attaining success.

Socioeconomic strata

The Edmonton and Lisbon participants were largely from a medium-high socioeconomic level and are quite familiar with technology controls.

The Colombian socioeconomic stratification goes from very low to high in a scale of six levels with 90.3% of the population in the three lower strata and 46% below the poverty line. Eight children came from lower social strata and attended public schools or educational non-profit organizations. All eight children had no exposure to computers or video games. Seven children came from the three higher social economic strata and they had previous exposure to computers or video games either at home or at the private school where they attended. All children had previous experience with battery operated toys.

In spite of the fact that more than half of the Bogota sample came from the three lower socioeconomic strata, there were no significant differences between the two robots (physical and virtual), just as in the Lisbon study. This could suggest that the cognitive skills required for the operation of the virtual and the physical robots are similar and the ability of the child to operate the virtual robot is not influenced by previous exposure to technology related to socioeconomic differences.

CONCLUSIONS

Results from all three studies show that children's performance varied with age. The Lisbon and Bogota studies did not reveal significant differences between the performances with the physical and virtual robots. Success rates in the tasks do not give the entire picture of children's experiences with the two robots. Evaluation of questions such as level of engagement and strategies used to accomplish the tasks is underway.

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REFERENCES

Affolter, F. (2004). From action to interaction as primary root for development. In I Stockman, Movement and Action in Learning and Development: Clinical Implications for Pervasive Developmental Disorders (pp. 169-200). San Diego: Elsevier.

Cook, A., Liu, K., and Hoseit, P. (1990). Robotic Arm used by Very Young Motorically Disabled Children, Assistive Technology, 2, 51-57.

Cook, A., Encarnação, P. and Adams, K. (2010). Robots: Assistive Technologies for Play, Learning and Cognitive Development, Technology and Disability, 22, 127- 145.

Cook, A.M., Adams, K., Volden, J., Harbottle, N., and Harbottle, C. (2011). Using Lego robots to estimate cognitive ability in children who have severe physical disabilities, Disability and Rehabilitation: Assistive Technology, 6(4), 338-46.

Davis-Kean, P. E. (2005). The Influence of Parent Education and Family Income on Child Achievement: The Indirect Role of Parental Expectations and the Home Environment. *Journal of Family Psychology, 19*(2), 294-304.

Devore, J.L. (2011). Probability and Statistics for Engineering and the Sciences. Duxbury Press.

Encarnação, P., Piedade, G., Adams, K., and Cook, A.M. (2012). Virtual assistive robot for play. Proceedings of the 2nd IASTED International Conference on Assistive Technologies. Innsbruck, Austria.

Forman, G. (1986). Observations of young children solving problems with computers and robots, Journal of Research in Childhood Education, 1(2), 60–73.

French, J.L. (2001). Pictorial test of intelligence (2nd ed.). Austin, TX: Pro-Ed.

Haywood, K. and Getchell, N. (2009). Life Span Motor Development. 5th. Illinois : Human Kinetics.

Høegh, M., and Høegh, S. (2009). Trans-adapting outcome measures in rehabilitation: Cross cultural issues. Neuropsychological Rehabilitation, 955-970.

Keen, R. (2011). The Development of Problem Solving in Young Children: A Critical Cognitive Skill, Annual Review of Psychology, 62, 1-21.

Harkness, L. and Bundy, A. (2001). The test of playfulness and children with physical disabilities, Occupational Therapy Journal of Research, 21(2), 73-89.

McCarty, M.E, Clifton, R., and Collard, R. (2001). The Beginnings of Tool Use by Infants and Toddlers. Infancy, 2, 233-256.

Musselwhite, C.R. (1986). Adaptive Play for Special Needs Children. San Diego: College- Hill Press.

Piaget, J. (1953). The Origins of Intelligence in Children. London: Routledge and Kegan Paul.

Poletz, L, Encarnação, P., Adams, K. and Cook, A.M. (2010). Robot Skills and Cognitive Performance of Preschool Children. Technology and Disability, 22, 117-126.