The Neurophysiology of augmentative manipulation: A method for technical implementation

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Abstract. The most well-known form of infant learning is motor experience. The strong relationship between motor and cognitive development suggests that the limited motor experience of children with physical disabilities can impact their cognitive and perceptual development. The assessment of cognitive skills of infants with physical disabilities is also compromised due to limited verbal communication and motor gestures. Robots have been used to give children with disabilities an opportunity to independently manipulate objects around them and to reveal their cognitive skills when they use the robots. However, little is known about the neural correlates that subtend robotic augmentative manipulation and its impact on the underlying mechanisms of neuroplasticity. Several technical considerations pose a challenge to such studies. This paper presents a methodology for the implementation of neurophysiological exploration of robot augmented manipulation. Preliminary results of an adult pilot study are presented. Advantages and disadvantages of this method for technical implementation are discussed.

Keywords. Augmentative manipulation, robots, neurophysiology, EEG

Introduction

Motor experience plays a central role in cognitive and perceptual development. Through physical manipulation, exploration and interaction with the environment a child develops perceptual and social skills that will allow him/her to learn and act on the world [1,2]. Object manipulation is a critical part of motor experience that enables the child to acquire skills required for learning, symbolic and referential communication and understanding relationships between objects and their environmental interactions [1, 3, 4, 5].

The strong relationship between motor skills and cognitive development suggests that a lack of motor experience can result in cognitive and perceptual delays [6]. Children with physical disabilities can lose opportunities to develop and demonstrate skills and have limited ability to physically manipulate objects [7] compromising the quality of their play and learning skills [8].

Several studies report the use of robots as augmentative manipulation systems by children with severe physical disabilities [9, 10, 11, 12, 13]. In these studies children independently controlled robots using switches adapted to their capabilities and needs. The characteristics of switches, such as simplicity, portability and safety, offer a means through which the child's independence and control over the task and environment increases [14]. By using robotic systems for augmentative

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manipulation, children's participation in academic and play activities, expressive language and level of engagement increased as reported by parents and teachers.
The outcomes of robotic augmentative manipulation systems use have largely focused on the perceptions of parents and teachers and the attainment of academic, play or therapeutic goals. The required cognitive and perceptual skills of direct manipulation of objects and of robotic augmentative manipulation are not equivalent. Little is known about the cognitive and perceptual benefits of augmentative manipulation using robots in early infancy. The use of neuroimaging techniques to support the study of augmentative manipulation can reveal its effect and implications. However, the nature of the manipulative task limits the use of techniques that are susceptible to movement artifacts such as fMRI and Magnetoencephalograpgy. The use of Electroencephalography and Event related potentials (ERP) provides an alternative for the functional analysis of brain function with the advantage of high temporal resolution and low cost. These neurophysiological measures are widely used to study cognitive development in typically developing children and have specifically been used to explore the substrate of early cognitive function. The integration of robotic systems and electrophysiological measurement creates technical challenges that are described in this paper. A method for technical implementation was designed and developed. A pilot study was first conducted with adult participants in order to test the technical implementation. This paper presents this technical implementation.

1. Method

1.1. *Objectives*

The main purpose of this study methodology is to identify the neural and behavioral correlates of early cognitive development. This methodology can also allow the exploration of whether robots can be used by infants with disabilities to reveal their cognitive skills. The purpose of this pilot with adult participants was to design and test the technical implementation of an augmentative manipulation system and the use of neurophysiological assessment.

1.2. *Task*

The A not B task with invisible displacement, developed by Piaget [4], was chosen for the future study, therefore was used for the current pilot. In this task children are exposed to an attractive toy hidden in a container. The container is moved to location ***A***. A screen is placed in front of the child and after a delay the child is allowed to search and retrieve the toy. Then this procedure is repeated. This time, after a screen is placed between the child and the container, an exact and empty container is placed on the opposite side, location ***B***. The child is encouraged to search for the object [15]. This task challenges children between 18 and 24 months, who often continue searching at the previously successful location, in spite of seeing the object being moved (perseveration) [16, 17]. Piaget's interpretation of this behaviour was that children at this age still associate the object with a previously successful scheme [4]. The ability to overcome this perseverative behavior results as the child engages in sensory motor behaviors acting on the environment. The nature of perseveration remains controversial. Other theories claim that preservation is a result of the child's difficulty inhibiting the reaching motor patterns in spite of cognitive understanding of the toy's location [18]. The strong relation between cognition and motor action in this task makes an accessible robot suitable for use with children with congenital physical impairments.

1.3. ***Robot augmentative manipulation system***

For this study, participants had to find and retrieve the toys by using three conditions: 1) using a robotic arm for manipulation; 2) directing the researcher to the desired container and objects by using eye gaze; 3) reaching for and grasping the objects with their hands (as typically developing children would).

The half human size MiniMover- 5[2] robotic arm with six degrees of freedom was used [19]. The robot stepper motors enable base rotation, flexion and extension of shoulder and elbow, wrist flexion, extension, supination and pronation, and a gripper that can open or close [20]. The robotic arm was programmed and controlled by a notebook computer running Microbot Control Center software[2]. The robot was programmed so that playback of a complete stored movement occurs when a switch is activated. Participants use three switches to activate the pre-stored robot movements.

1.4. ***Neurophysiology recordings and analysis: EEG and ERP***

EEG and ERPs are non-invasive methods to study brain electrical activity in relation to behavioural responses and in situations in which the child cannot give a verbal response or no observable movement is present [21]. Electrical activity has temporal resolution on the order of 1 ms or better [22]. Cognitive processing can be studied in synchrony with the observed behaviour. EEG and ERP are also inexpensive compared to other neuroimaging methods [22].

EEG was recorded with the use of a high-density 256 channel Geodesic Sensor Net®[3] referenced to the central vertex electrode. Recording took place in an electrically shielded and sound attenuated chamber. Impedances were maintained under 50 kΩ and the signal was sampled at 250 Hz and filtered and amplified at a gain of 1000. Data analysis was conducted in NetStation® [3] and EEGLAB open source toolbox that runs in Matlab ®[4].

The use of neurophysiological measures in cognitive tasks relies on the use of software primarily designed to provide a template for the creation of computerized behavioral experimental tasks. Based on the designed experiment, participants were presented with a screen in which certain stimuli are presented. The participants' responses were collected and analyzed. E-Prime®[5] presentation software version1.2, the most widely used software for visual and auditory experimental stimulation [23] was used.

1.5. ***Participants***

A pilot study with adult participants was conducted in order to test the functioning and reliability of the technical implementation before proceeding with the infant study. Participants completed one session in the EEG Lab of the department of Psychology, University of Alberta. Fifteen right handed graduate students at the University of Alberta participated in this adult pilot study. This paper presents the instrumentation including the design of a custom-made interface, and the methodological challenges based on the preliminary results of the pilot participants (4 females and

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[2] Quest Technologies, Farmington Hills, Michigan

[3] Electrical Geodesics Inc., Eugene, OR

[4] Mathworks, Natick, MA

[5] Psychology software Tools, Inc., Sharpsburh, PA.

2 males; mean age: 29.3 years, range: 23-34). All participants had normal or corrected vision. None of the participants reported having a previous history of neurological or psychiatric disorders, or taking any medications at the time of testing.

2. Results

Typically, exploration of neurophysiological substrates of cognitive function are obtained by designing an experimental task in which stimuli are presented on a screen and the participant responds by using the keyboard, or a response box with a set number of switches. These responses subsequently flag the EEG ongoing signal, making it easier to then extract the segments of interest. In the case of robot augmentative manipulation systems, the tasks and stimuli are dynamic and three-dimensional in nature, therefore not suitable for screen based response experimental designs. In the case of the A not B task, several events of interest replaced the standard screen presented stimuli: (1) when the barrier is lifted marking the beginning of a trial, (2) when the participant hits a switch to choose either side A or B for robot retrieval of the object, (3), when either cup is lifted, recognizing both the lifting and which cup was lifted.

A custom-made interface is required that can translate the stimuli described above into input signals that E-Prime can detect and use as markers for the EEG signal. For this purpose a custom-built wooden platform was designed to monitor the responses of the participant using three magnetic switches wired into the platform, and two switches controlled by the participant. E-Prime extensions for Net Station flagged the EEG signal for each of these events. The participant switch responses were connected to the robot to replay the stored movements. (See Figure 1). The wooden platform was wired through a common DB-9 connector typically used for the switch response box so that, events were registered by E-prime as keyboard inputs (see Figure 2).

Figure 1. Platform and Robot set-up

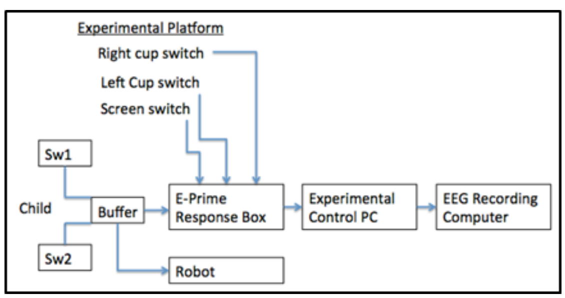

Fig.2. Experimental set-up

Figure 3 Illustrates the electrophysiological set up with E-Prime® and NetStation®.

Figure 3. Neurophysiological measures set-up.

Participants achieved 100% rate of successful trials as expected. After signal processing and filtering, no signal noise caused by robot step motors was detected. An exploratory analysis of Event related potentials and EEG baseline to task comparison for the fifteen participants is underway at the time of submission. Final results will be available at the time of the conference.

3. Discussion

The main purpose of this adult pilot study was to explore the feasibility of implementing neurophysiological recordings in a robotic augmentative manipulation system study task while using a dynamic 3D task. The technical implementation presented several challenges that were solved by the design of a custom-built platform with hidden wired-in magnetic switches that were programmed into the stimuli presentation software as keyboard responses.

The acquisition of neurophysiology data of augmentative manipulation represents a first step for subsequent studies with infants and children with severe congenital physical disabilities that are underway. Even though the experimental setup can be challenging in exploratory studies, this constitutes a starting point for further investigation of robots and neuroimaging interactions.

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References

[1] McCarty, M. E., Clifton, R. K., & Chollard, R. (2001). The beginnings of tool use by infants and toddlers. Infancy, 2(2): 233-256.

[2] Flanagan, J. R., Bowman, M. C., & Johansson, R. S. (2006). Control strategies in object manipulation tasks. Current opinion in Neurobiology, 16:650-659.

[3] Bates, E. (1979). The biology of symbols: Some concluding thoughts. In E. Bates, L. Benigni, I. Bretherton, L. Camaioni, & V. Volterra (Eds.), The emergence of symbols: Cognition and communication in infancy (pp. 315–370). New York: Academic Press.

[4] Piaget, J. (1954). The construction of reality in the child. Great Britain: Routledhe.

[5] 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. 169-199). San Diego: Elsevier.

[6] Bertenthal, B. I., & Campos, J.J. (1987). New directions in the study of early experience. Child Development, 58, 560 - 567.

[7] Jennings, K., & MacTurk, R. (1995). The motivational characteristics of infants and children physical and sensory impairments. In R. MacTurk, & G. Morgan, Mastery Motivation: Origins, Conceptualization and Applications (pp. 201- 220). New Jersey: Ablex Pusblishing Corporation.

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

[9] Tejima, N. (2000). Rehabilitation robotics: a review. Advanced Robotics, Vol. 14, No. 7, pp. 551– 564.

[10] Cook, A., Bentz, B., Harbottle, N., Lynch, C., & Miller, B. (2005). School- Based Use of Robotic Arm System by Children With Disabilities. IEEE Transactions on Neural Systems and Rehabilitation Engineering, 13(4), 452-460.

[11] Besio, S., Caprino, F., & Laudanna, E. (2008). Profiling Robot-Mediated Play for Children with Disabilities through ICF-CY: The Example of the European Project IROMEC. ICCHP '08 Proceedings of the 11th international conference on Computers Helping People with Special Needs (pp. 545-552). Berlin: Heidelberg.

[12] Cook, A., Adams, K., Volden, J., Harbottle, N., & Harbottle, C. (2010). Using Lego robots to estimate cognitive ability in children who have sever physical disabilities. Disability and Rehabilitation, 1-9.

[13] Kronreif, G., Kornfeld, M., Prazak, B., Mina, S., & Fürst, M. (2007). Robot assistance in playful environment - user trials and results. IEEE International Conference on Robotics and Automation (pp. 2898-2903). Roma, Italy: IEEE.

[14] Isabelle, S., Bessey, F., Dragas, K. L., & Blease, P. (2002). Assistive Technology for Children with Disabilities. Occupational Therapy in Health Care , Vol. 16(4) .

[15] Diamond, A., Prevor, M., Callender, G., & Drun, D. (1997). Prefrontal cortex cognitive deficits in children treated early and continuously for PKU. Monographs of the Society for Research in Child Development, 62(4), 1-206.
[16] Wiebe, S., Lukowski, A., & Bauer, P. (2010). Sequence Imitation and Reaching Measures of Executive Control: A Longitudinal Study Examination in the Second Year of Life. *Developmental Neuropsychology, 35*(5), 522-538.
[17] Diedrich, F. J., Thelen, E., Smith, L. B., & Corbetta, D. (2000). Motor memory is a factor in infant perseverative errors. Developmental Science, 479- 494.
[18] Thelen, E., Schoner, G., Scheier, C., & Smith, L. (2001). The dynamics of embodiment: a field theory of infant perseverative reaching. Behavioral and Brain Sciences, 24, 1-86.
[19] Patterson, P., & Katz, J.(1992).Design and evaluation of a sensory feedback system that provides grasping pressure in a myoelectric hand. Journal of Rehabilitation Research and Development, 29(1)1-8.
[20] Cook, A., & Polgar, J. M. (2008). Cook and Hussey's Assistive Technologies: Principles and Practices (3rd ed.). Philadelphia: Elsevier Inc.
[21] De Hann, M. (2002). Infant EEG and Event Related Potentials. Psychology Press.
[22] Luck, S. (2005). An Introduction to Event Related Potentials and Thier Neural Origins. In S. Luck. Cambridge: MIT Press.
[23] Kim, H., Choi, M.H., Kim, J.H., Yeon, H.W., Yi, J.H., Chung, S.C. (2013) Development of a computer tactile stimulator with simultaneous visual and auditoy stimulation. In: Toi, V., Toan, N.B., et al. (Eds.) 4th International Conference on Biomedical Engineering in Vietnam. IFMBE Proceedings, Volume 40. Pp. 132-134. Springer: London.