A unified, neuro-physio platform to facilitate collaborative play in children with learning disabilities

Subhasis Banerji, John Heng

***Abstract*—While society is partly responsible for a feeling of isolation among children with learning disabilities, this isolation is exacerbated by the child's inability to adjust psychosocially.**

The authors hypothesize that social inclusion will be a natural outcome if technology can restore or assist the ability of basic self-expression and self-growth. One of the most promising methods of expression for children with learning disabilities is through play, both individual and collaborative.

The "Unified neuro-physio platform" explained in this paper focuses on the current development for a low cost signal acquisition and processing architecture aimed at making it easier for children to express themselves in play, both alone and collaboratively, using bio-signals like surface electromyography(SEMG) and electroencephalography(EEG). It is part of a larger study to develop an "active" play device to help children with learning disabilities.

The significance of the collaborative play approach is that it not only makes a child more self-sufficient but also opens up the possibility of this child helping and training another child through play, thus giving the child an opportunity for social inclusion from a position of strength.

The setup of such a neuro-physio platform, system description, methods used and results obtained are described in this paper.

Index Terms— human machine interface, SEMG, EEG, bio-feedback, learning disability, ADHD, neuro-physio platform, collaborative play.

I. INTRODUCTION

Not too long ago, people with learning disabilities were looked upon as "abnormal" and society was skeptical about including them, particularly children, in mainstream learning institutions. This has undergone a far reaching change, with the advent of new knowledge and technologies which have tried to close the perceived learning gaps in these children.

Isolation is not just imposed by society. In a large number of children who have problems coping and finding a channel to express themselves, the isolation is a result of psychosocial maladjustment [1], [2].

While the movement for social inclusion is of immense value to any child or adult who is mentally or physically challenged, its long term benefits, in the absence of self-expression and positive feedback, is debatable.

Current research has seen promising results in social behavior and learning skills using humanoid robots and various play scenarios, for children diagnosed with autism [3], [4]. Involving the child at a neuro-kinesthetic-audio-visual level through play will be an important step in the journey towards better learning and adjustment for a larger population of children, with or without disability.

Recent research has also found a very promising correlation between how children with learning disabilities think and behave and quantitative EEG signals [5], [6], [7]. Several diagnostic methodologies have been established observing the qualitative EEG signals as well, particularly in the field of epilepsy and brain injury [8]. It has also been seen in numerous studies that various bio-feedback protocols using SEMG, EEG, and other bio-signals, have short and long term benefits for children with learning difficulties such as improved attention and behavioral control, increased cortical activation, and gains on tests of intelligence and academic achievement in response to this type of treatment [9], [10].

The unified platform is a preliminary effort to put at the disposal of the child a tool for self- management, interaction and enjoyment through play with oneself and other children. The use of the device for diagnostics and monitoring by medical personnel is also evident.

The application of this platform to children with learning disabilities, particularly attention deficit disorder, is an extension of the research group's ongoing study to develop a multi-level platform for hemiplaegic stroke patients, so that they can work collaboratively for regaining functional ability of hand function [11].

II. BACKGROUND

A. Short comings of current computer screen based table top bio-feedback systems.

In the field of Human-Computer-Interaction, the limitation of computers used in social interaction environments are already acknowledged and takeninto account in the design of new systems. Important elements in face to face communication, such as eye-gaze, eye contact and body alignment, which help to establish the sense of engagement

Manuscript received February 6th, 2009. This work is supported by the National Medical Research Council of Singapore, under Grant NMRC/NIG/0024/2008.

Banerji Subhasis is with the Nanyang Technological University, School of Mechanical and Aerospace Engineering, Robotics Research Centre, N3-01a-01, 50 Nanyang Avenue, Singapore 639798.(email: banerji@ntu.edu.sg,subhashisb@hotmail.com)
Dr. John Heng is with Nanyang Technological University, School of Mechanical and Aerospace Engineering, N3.2-01-24, 50 Nanyang Avenue, Singapore 639798 (phone: +65 67905900, fax: +65 67924062, email: mkhheng@ntu.edu.sg,johnheng@pmail.ntu.ntu.edu.sg).

and maintain the focus of the interaction, are substantially (if not completely) reduced when the attention is focused on a keyboard and a screen [12], [13]. The use of body movement is also very restricted in this situation.

In using a three dimensional embodied tool as a therapeutic or educational toy, not only can a child learn basic interaction skills in a naturally encouraging context (ie. playing) but it also promotes a full body experience on the part of the child (which a two-dimensional computer screen can't provide) [14]. This may encourage a variety of interactions, and can help to increase body awareness and sense of self, as well as providing greater opportunities to interact with and be sensitive to others [15], [16], [17], [18]. It is possible for the proposed "Active" play device can respond to a child's volition and brain state, give feedback in real time, as well as elicit a response from the child. Such a device will also be a powerful mediator in the interaction between two or more children [19].

There are commercially available EEG and SEMG measurement systems and devices to do the task of data acquisition. However they fall short of the requirements of our project for the following reasons:

1) They are limited in the functionality of recording multiple types of bio-potentials (eg. EEG, SEMG, or Electrocardiogram)
2) They are bulky and can be problematic for portable operation.
3) They are complex to operate.
4) They are very expensive and make individual ownership difficult.
5) Most of these devices operate only with their proprietary software and there is very limited support provided for development of third-party applications. This is a critical shortcoming because it leads to an integration problem in the platform development.

III SYSTEM DESCRIPTION

A. Proposed System Description

The system was designed to have certain inherent qualities such as:

1) Ability to accept as inputs bio-signals ranging from EEG to SEMG with a built-in interchangeability in all channels. The circuit boards were constructed in modules of 4 inputs.
2) Ability to talk to an industry standard signal processing software with graphic user interface.
3) Portable and low cost. The EEG acquisition could be a simple headset which has a low set-up time [20]. Substantial research is currently being carried out in this area for neuro-feedback and gaming.
4) 2 way interface between the computer screen and the play device via the data acquisition device and circuit.
5) Standard electrode system for signal acquisition, with a simple mounting system.

The schematic of the development platform as it was conceived is illustrated in Fig. 1.

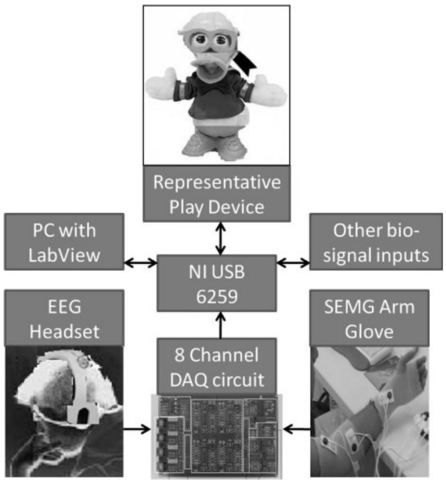

Fig.1. Schematic of the development platform

The total signal amplification is a maximum of about 20,000 for EEG signals and 200 for SEMG signals. The system was designed to provide a maximum peak-to-peak output of 4V to the NI USB-6259. This means that the range for differential EEG signals detectable is 0-200uV and that for SEMG signals is 0-20mV. The actual gain values obtained by using the component values obtained from FilterPro were 1108 to 1630 (for EEG filter).

Fig. 2 shows the basic layout of the circuit.

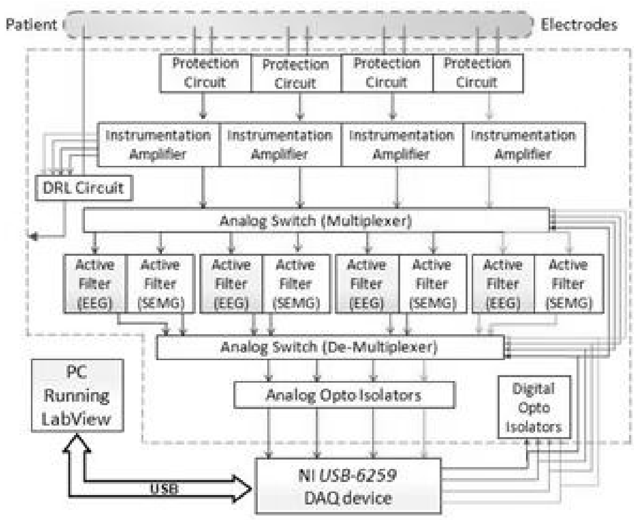

Fig.2. Layout of the 4 channel SEMG/EEG data acquisition system. 2 such modules are used to make up the 8-channel DAQ circuit described in Fig.1

The filters designed around op-amps have unique purposes, some constitute to the EEG filtering section and some constitute to the SEMG filtering section. Potentiometers are provided for variable gains on the EEG and SEMG filters respectively. The IC is TLC279 (LinCMOS precision quad operational amps) from Texas Instruments Inc. USA. After the amplification and filtering the bio-signals are ready for acquisition by the USB-6259.

B. A unified neuro-physio platform for collaborative play using a play object.

We use our upper extremity, particularly our hands, to not just carry out activities of daily living but also to express ourselves and communicate. Our hands are an asset for us to fully and adequately express ourselves, our emotions and our desires. In conjunction with our facial expressions, we find ourselves proficient naturally in a different, silent language which many of us use as a powerful channel for communication.

Play is also conducted extensively using the upper extremity. The portable DAQ device will be the interface between the child and the proposed toy device, which will have sensors, actuators and feedback transmitting capability. Two children will be able to play with the same device and therefore, be able to respond to each other. With bio-signals input, it will be possible for the child to elicit response from the play device. The SEMG/EEG bio-feedback will also help the therapist to see the bio-signals in movement and in play, which will form the basis for developing a range of play devices.

Children with learning disabilities have to deal with high levels of anxiety. The use of SEMG bio-feedback techniques for reducing state and trait anxiety is well known [21]. Manipulation of a play object can be triggered by the same SEMG signals. The technology for processing SEMG signals and delivering triggers in real time was thus established early in the development of the platform.

Several studies have demonstrated the efficacy of correlating quantitative EEG techniques to disorders like ADHD, while qualitative EEG signals are used in the diagnostics of conditions like epilepsy. Hence it is necessary to demonstrate both qualitative and quantitative results in real-time for the kind of operation of the play object we have in mind. The difficulties in either case are as follows:

1. It is difficult to get good qualitative EEG signals with a low cost, portable system where the amplification takes place relatively far away from the location of signal.

2. It is difficult to process quantitative signals and obtain triggers in real time. One finds that some small delay is inevitable.

IV. METHODS

A. Experiments for SEMG acquisition and analysis

The study tried to determine whether it is possible to use SEMG and EEG signals from a simple breadboard circuit with sufficient sensitivity and repeatability to run a play device motor. Standard filtering and amplification was done without any attempt to completely insulate the circuit from environment.

The experiment tested the use of a simple statistical trigger from the signals to activate a relay to a servo motor, using large and small muscle groups in the arm and hand, especially with simple bipolar electrodes which do not need special set up. Four muscle groups were tested over 4 channels (upper arm, forearm, thumb and finger muscles). Combining of triggers from two individual persons to achieve a threshold were studied, using signal mean and RMS. In our experiments, we are using SEMG from two persons to jointly activate a trigger while the switch off can be done only by one person. The two persons can play interchangeable roles. It is possible for the same triggers to be activated in teamwork, join dots on a screen to create a picture or climb a virtual mountain together. It will enhance concentration, alertness and fun in therapy.

Recording the SEMG provided the immediate activity triggers while the quantitative EEG analysis showed periodically updating brain states. The game for individual and collaborative play could be now based on voluntarily altering the SEMG and brain waves towards more optimum values.

B. Experiments Conducted for EEG acquisition and analysis

The system is currently being tested on adults to establish signal quality, processing speed, real-time acquisition, setting triggers and identifying brain states. Once this is done and the reliability and safety is established, we will be in a position to start testing with child subjects.

Experiments were done on several healthy subjects in the age group 19-45, to test the circuit response. Tasks were categorised into mental and physical tasks. This age group is able to respond precisely to test instructions with respect to application of various levels and types of physical and mental effort.

Mental tasks included arithmetic calculation, movement imagery, emotional thoughts by visualizing respective events, visualizing two dimensional objects and listening to songs / auditory stimuli. Meanwhile physical tasks observed were hand and finger movement, eyes closure and squeezing, jaw movement (biting) and frowning. Each task was conducted with the relaxed state as the baseline. This series of experiments was targeted towards identifying real time EEG triggers which could modulate the SEMG triggers. For analysis of quatitative EEG characteristics, the test subject was also given a task to generate random numbers by himself, instead of being given by the observer, and added them for specific duration. Visualizing respective events to simulate emotional thought was done by asking the test subject to think about a particular event that could arouse certain emotional feeling. The simulated emotional feelings included angry, stressful, happy and sad. Recording of such emotional states was preceded and followed with relaxed state. Recording was done with eyes closed and eyes open condition. Visualizing two-dimensional objects was also done with eyes closed condition.

The same method was applied to the recording of listening to song or sound stimuli. The songs or sound stimuli were played repetitively with specific time of silence between each play. This gap of silence was considered as base line in this particular recording. The auditory stimuli were ranging from sound of birds, rock music to meditation audio that is believed to cause increased alertness.

Movement artifacts were visible in certain cases which were undesirable. One of the sources was the movement of the EEG electrode cables running to the DAQ device. Once these cables were secured, the left-right and up-down head movements did not result in visible artifacts. We are confident that the active EEG electrode currently under development will further reduce this problem.

V. RESULTS

Results of some of the SEMG and EEG experiments were reported earlier [22]. The results from the experiments on quantitative EEG will be reported in later papers. The main objective of this paper is to show that the system is sensitive to changes in SEMG and EEG differences and that these changes can be used to trigger a motor or some other actuator in a play device, in a collaborative manner. Only these results which highlight the simplicity and reliability are outlined below.

A. Sharing resources through HMHI for SEMG.

.

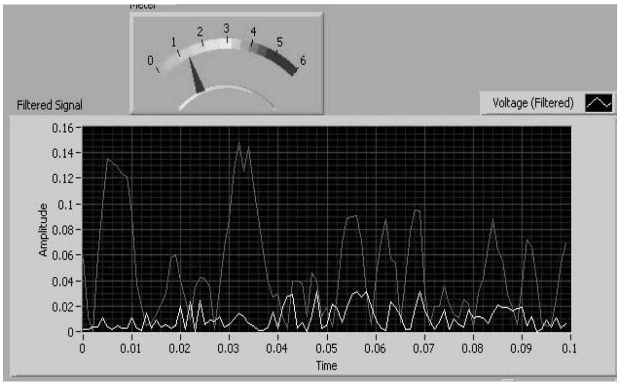

Fig. 3. LabView front panel showing simultaneous processing of signals from two persons.

Fig. 4 shows the distinct triggers generated by four different twitches of the little finger.

The use of muscle contractions in the real time operation of servo motors was tested in several formats. One of these was the combining of SEMG from muscle contractions of two persons to achieve a simple task. Fig.3 below shows the difference in contraction strength of two healthy young adult persons using the same muscle. The small and large amplitude generation in this case was voluntary. One person tried to pull the pointer on the scale to the left (zero on the scale) while the other tried to pull it towards the right (6 on the scale).

The algorithm was further modified so that it could display RMS values potentials generated even by small twitches of intrinsic forearm muscles like finger flexors and extensors.

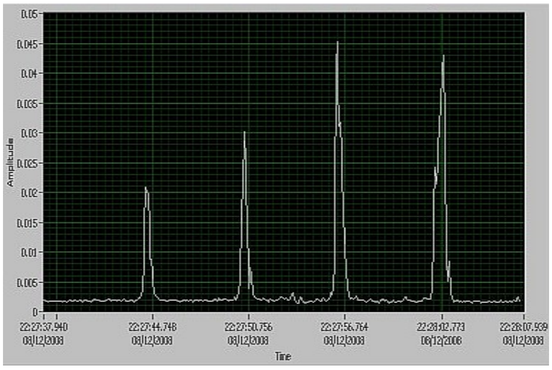

Fig. 4. Display of triggers generated by 4 twitches of the little finger of the dominant hand.

The unified neuro-physio platform has the analog and digital ports to communicate with the proposed play device, using the child's ability to control his SEMG and sharpen his kinesthetic perception, using both bio-feedback in solitary play and strength and timing feedback in collaborative play. This will increase confidence in interaction and team work for simple, guided tasks. At a later stage, it may facilitate the child's ability to play and train with another child freely, as well as set their own game parameters on the LabView user interface.

The 8-channel system mentioned in this paper can also accept other inputs like those from force and motion sensors, if these are incorporated into the proposed 3-dimensional play device. In case the channels are used up, the NI USB6259 can take the inputs directly.

B. Interacting with the play device using EEG and facial expression

In the development of an "Active" play object for which the sub-system is being designed, the use of quantitative EEG analysis is significant for detection of certain triggers and condition of the patient [23], [24], [25]. In most quantitative EEG applications, the frequency content of the signals is the most important parameter of interest. Hence, even if the EEG circuit could detect the main frequency contents of the test signal satisfactorily, it could still be used to activate the play object, both in order to elicit a response from another child, or as "on-the-go" bio-feedback.

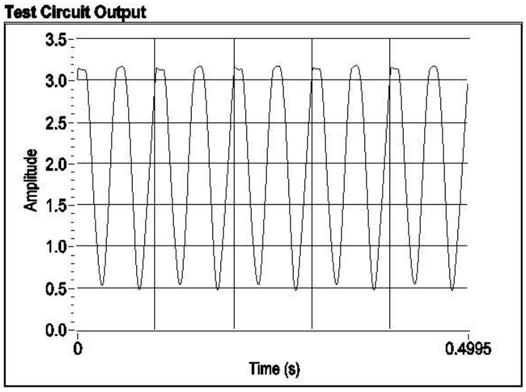

Fig. 5: Test Output from circuit operating in EEG Mode

Fig.5 shows the amplified and filtered signal from the designed circuit operating in EEG mode.

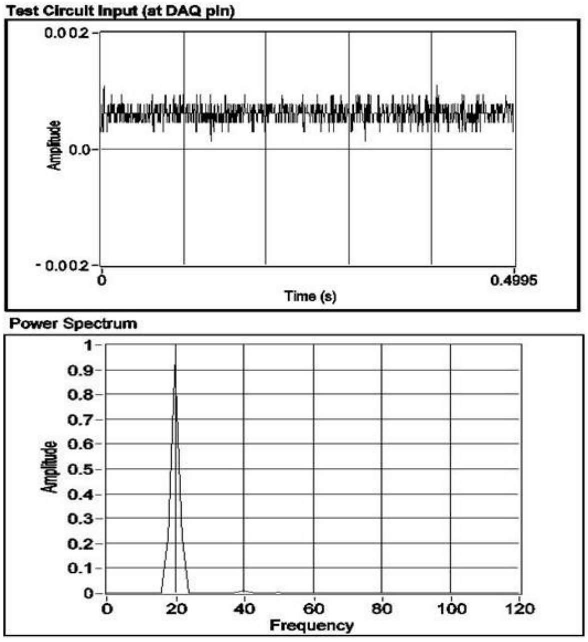

Fig. 6: Power spectrum of test output for circuit operating in EEG Mode. The noisy input signal is shown above.

Fig. 6 shows that in spite of the severe noise distortion in the input signal, the designed circuit is able to fairly reproduce the main frequency contents (20 Hz in this case) of the signal which lies in its pass-band (0.16 to 59 Hz). The power spectrum shows a sharp peak at 20 Hz indicating that noise in other frequencies is rejected by the EEG circuit. There are very small bumps at 40 Hz (as it is the harmonic content from the 20 Hz signal) and at 50 Hz (power line frequency). These results do indicate that the EEG circuit did perform it chief function in a satisfactory manner.

Even if qualitative signal acquisition and display is not noise free at present, we find we can still tap into some signals (Fig. 7) from the forehead using the EEG electrodes which are repeatable enough to act as triggers for certain functions.

During the experiment some muscle artifacts were also recognized by the recording instrument.

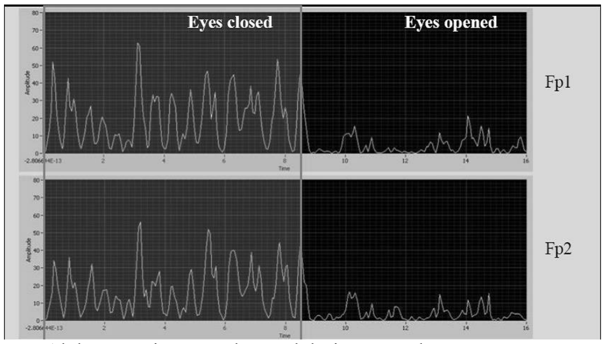

Fig. 7. Alpha wave increase detected during eyes closure

Some apparent artifacts were recorded when the person was squeezing his eyes in eyes close and open position as well as blinking(Fig.8).

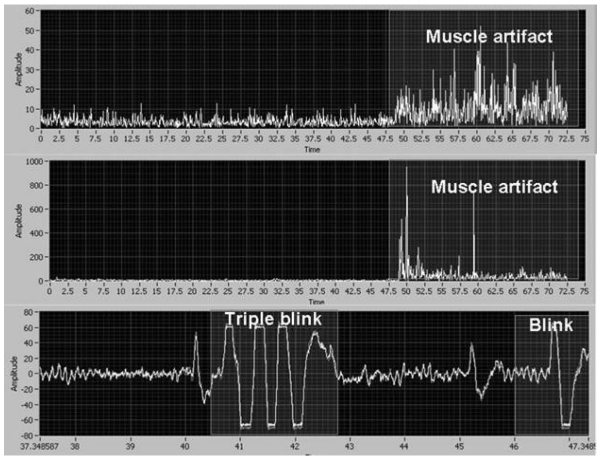

Fig. 8. top – gamma wave of eyes squeezing artifact with eyes closed; middle – gamma wave of frowning artifacts in eyes open condition; bottom – blink and triple blink detected as saturated signal

Muscle artifact due to eyes squeezing in eyes close condition and frowning in eyes open condition resulted in excessive signal detected in gamma wave band. It was found that not all of the wave bands were significantly affected by the muscle artifacts. Meanwhile eyes blinking artifact was recognized as a saturated signal in the original signal after the application of 50 Hz low pass filter.

Figure 8 shows artifact signals due to eyes squeezing, frowning and blinking detected from electrode channel Fp1.

Online signal processing algorithm as described above was also tested using simulated signal taken from existing experiment data. With proper signal threshold value, it was able to recognize difference in alpha wave activity between eye open and close within 10 seconds.

If signals are tapped from two different areas of the head, it is possible to isolate and detect EEG and artifact signals separately and simultaneously. For example, detecting the alpha band increase at O1, O2 and the brow squeeze at Fp1, Fp2 can give us two simultaneous switches. The eyes open and the biting signals described above is another combination where the two signals do not interfere with one another. These signals detected at the head can be also combined with muscle SEMG from anywhere in the body.

Whereas the signals from the EEG channels can decide the level or intensity of effort, the signals from the hand SEMG channels be the ON/OFF switch for the action, based on previously calibrated thresholds.

Thus we can develop a multi-level interface which is robust, easy to set-up, versatile, adaptable and of low complexity. No complicated signal processing is required. This increases the possibility of having a portable, miniaturized system.

VI. CONCLUSION AND FUTURE WORK

The experiments show that it is feasible to acquire and process certain SEMG and EEG signals with a very simple circuit which can be further miniaturized. The LabView platform can provide the processing capabilities as well as a graphical user interface.

Using an algorithm for individual and collaborative therapy, the platform can be a tool for a more wide-ranging bio-feedback to the child as well as for doctors to study the changes in brain states while at play. This can be used for additional EEG/SEMG studies in experiments with humanoid robots in play scenarios.

It is reasonable to assume that this platform will make it possible for a child who has used it for some time to train another child at the introductory levels. In the long run, this will address issues of therapy cost as well as therapist time, both of which are emerging causes of concern in both developing and developed countries.

In future, we shall be looking at improving the qualitative EEG acquisition, as well as incorporate active EEG and SEMG electrodes in a wireless format.

ACKNOWLEDGMENT

The authors wish to thank the staff of Robotics Research Centre, NTU, Singapore, for the use of their facilities in the conduct of this project. Our gratitude to all the members of the Rehabilitation Mechatronics group for all their efforts in helping with the experiments and analysis.

REFERENCES

[1] N. Garnefski, C. Rieffe, F. Jellesma, M.M. Terwogt, V. Kraaij, Cognitive emotion regulation strategies and emotional problems in 9–11-year-old children, European Child and Adult Psychiatry, vol 16(1), Feb, 2007.

[2] W.P. Witt, A.W. Riley, M.J. Coiro, Childhood functional status, family stressors, and psychosocial adjustment among school-aged children with disabilities in the United States Arch Pediatr Adolesc Med., vol 157, pp.687-695,2003.

[3] B. Robins, E. Ferrari, K. Dautenhahn, Developing Scenarios for Robot Assisted Play, Proceedings of the 17th IEEE International Symposium on Robot and Human Interactive Communication, Technische Universität München, Munich,Germany, August 1-3, 2008.

[4] K. Dautenhahn, Robots as social actors: Aurora and the case of autism. In Proc. CT99, The Third International Cognitive Technology Conference, August, San Francisco, pp. 359--374, 1999.

[5] S.M. Snyder, H. Quintana, S.B. Sexson, P. Knott, A.F.M. Haque, D.A. Reynolds, Blinded, multi-center validation of EEG and rating scales in identifying ADHD within a clinical sample, Psychiatry Research, vol 159 : pp. 346–358, 2008.

[6] V.J. Monastra, J.F. Lubar, M. Linden, The development of a quantitative electroencephalographic scanning process for attention deficit-hyperactivity disorder: reliability and validity studies, Neuropsychology, Vol. 15(1), pp. 136-144, 2001.

[7] R.A. Chabot, H. Merkin, L.M. Wood, T.L. Davenport, G. Serfontein, Sensitivity and specificity of QEEG in children with attention deficit or specific developmental learning disorders. Clinical Electroencephalography, vol. 27, pp. 26-34, 1996.

[8] M. Salinsky, R. Kanter, R.M. Dasheiff, Effectiveness of multiple EEGs in supporting the diagnosis of epilepsy: an operational curve, Epilepsia, vol 28(4); pp 331-334.

[9] V.J. Monastra, S. Lynn, M. Linden, J.F. Lubar, J. Gruzelier, T.J. LaVaque, Electroencephalographic biofeedback in the treatment of attention-deficit/hyperactivity disorder, Applied Psychophysiology and Biofeedback, Vol. 30, No. 2, June 2005.

[10] M.A. Tansey, EEG sensorimotor rhythm biofeedback training: Some effects on the neurologic precursors of learning disabilities. International Journal of Psychophysiology, Vol. 1, pp. 163-177, 1984.

[11] S. Banerji, J. Heng, W. Kangdra, New directons in the design of UE rehabilitation robotic devices for stroke patients, Proceedings of the 2nd International Convention on Rehabilitation Engineering and assistive Technology, i-CREATe 2008, Bangkok, Thailand, May, 2008.

[12] G. Mindes, Social and cognitive aspects of play in young handicapped children, Topics in Early Childhood Special Education, vol. 2(3), pp.39-52, 1982.

[13] J. Piaget, Play, dreams and imitation in childhood. New York Norton, 1962.

[14] A. Billard, Robota: Clever toy and educational tool, Robotics and Autonomous Systems, vol. 42, pp. 259–269, 2003.

[15] P. Gaussier, S. Moga, J.P. Banquet, M. Quoy, From perception-action loop to imitation processes: a bottom-up approach of learning by imitation, Applied Artificial Intelligence, vol. 7 (1)pp. 701–729, 1998.

[16] I. Horswill, A laboratory course in behavior-based robotics, IEEE Intelligent Systems, vol. 15 (6), pp.16–21, 2000.

[17] S. Rogers, Cognitive characteristics of handicapped children's play: A review. Journal of the Division for Early Childhood, vol. 12, pp. 161-168, 1988.

[18] L. Vygotsky, Mind in Society, Harvard University Press, Cambridge MA, 1978.

[19] S. Nabe, S.J. Cowley, T. Kanda, K. Hiraki, H. Ishiguro, Robots as social mediators: coding for engineers, The 15th IEEE International Symposium on Robot and Human Interactive Communication, ROMAN 2006.

[20] J.V. Aart, E. Klaver, C. Bartneck, L. Feijs, P. Peters, EEG Headset For Neurofeedback Therapy - Enabling Easy Use in the Home Environment. Proceedings of the Biosignals - International Conference on Bio-inspired Signals and Systems, Funchal pp. 23-30,2008.

[21] L.S. Wenck, P.W. Leu, R.C. D'Amato, Evaluating the efficacy of a biofeedback intervention to reduce children's anxiety, Journal of clinical psychology, vol. 52(4), pp. 469-473, 1996.

[22] J. Heng, S. Banerji, A Step towards Multi-level Human Interface Devices: A System that responds to EEG/SEMG Triggers, International Journal of Biorobotics and Biomechatronics, special issue on Rehabilitation Robotics, 2009, accepted for publication.

[23] M.J.A.M van Putten and D. L. J. Tavy, Continuous quantitative EEG monitoring in hemispheric stroke patients using the brain symmetry index, Stroke vol. 35, pp. 2489 - 2492, 2004.

[24] F. Cincotti , et al.,High-resolution EEG techniques for brain – computer interface applications, J Neurosci Methos , vol.167(1), pp. 31-42, 2008.

[25] R. J. Barry, A. R. Clarke, S. J. Johnstone, C. A. Magee, and J. A. Rushby, EEG differences between eyes-closed and eyes-open resting conditions. Clinical Neurophysiology , vol.118 (2007), pp. 2765 - 2773, 2007.