Upper Extremity Rehabilitation after Stroke: Biofeedback Gaming for Attention and Muscle Use

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ABSTRACT

One of the most important objectives of therapy is the biomechanically correct use of muscles during various rehabilitation exercises, particularly functional tasks practice. Due to the lack of quantifiable real-time measures during therapy, wrong muscles can repeatedly be activated. Another important objective is that the patients maintain a highly attentive state during therapy sessions.

This paper outlines a biofeedback gaming system which will enable the user to interact with an 8-channel arm glove while self-administering basic therapy for hand, wrist and forearm. This graphic user interface is driven by muscle and brain signals. The game design keeps in mind specific challenges of patients with right side hemiplegia, i.e. those with left brain lesions. This category of patients has a high probability of difficulties with language, cognition, number and word recognition, visual resolution and the like.

Results are described as feedback from healthy subjects in various age groups who used the system, as a precursor to trying the games on stroke patients.

General Terms

Design, Human Factors.

Keywords

SEMG, EEG, stroke rehabilitation, biofeedback, muscle compensation, hemiplegia, unified platform.

1. INTRODUCTION

Stroke is one of the leading causes of long term disability and death worldwide and in Singapore [1] [2]. Stroke is caused due to sudden loss of brain function because of interruption in blood flow or rupture of blood vessels in brain. There may be complete or partial loss of voluntary movement especially in one side of the body (hemiplegia). Impairment caused by stroke depends upon the area of the brain that has been injured and depth of damage. This may even lead to inability of the patient to speak, recognize, understand, see and remember [3].

With increasing stroke cases, pressure on rehabilitation professionals is becoming severe. It has been observed that enough time and attention is not given to the patient undergoing rehabilitation [4]. This causes lack of motivation to perform rehabilitation and can have an adverse impact on functional recovery, cognitive functioning and even in survival. This lack of motivation can be attributed to psychosocial factors like lack of visible progress and acute pain [5] [6].

During rehabilitation it is vital that the correct muscles get activated in order to prevent compensatory movements. In the past there was no quantifiable measure for the patient or therapist to estimate that the correct muscle set was being activated, especially while the patient was performing exercises in an unsupervised environment. Rather it was dependent upon the experience, expertise and knowledge of the therapist supervising the session [7] [8] [9]. It is also vital that patients maintain a highly alert state during rehabilitation which would aid in faster recovery. However, none of the systems available commercially have been designed to train both attention and muscle use together [10].

2. SYSTEM CONSTRUCTION

The automation of basic stroke recovery exercises has been proposed. This would help to reduce burden on therapists as patients can perform exercises on their own with partial or no guidance. Moreover, this can potentially be part of a home based therapy system after discharge from hospital, with the interactive gaming features helping in maintaining both practice and motivation [11] [12]. Computer technology has widely been used and is considered a safe environment for training. Moreover, the exercise regime can be tailored on computers based on requirements and abilities of the patient. This would ensure that motivational levels are maintained and an enjoyable environment is sustained [13] [14]. The data stored would help the therapist in monitoring and analyzing the progress of patient. The games described in this paper focus on basic upper limb exercises such as extension and flexion of wrist, fingers, thumb along with pronation and supination of forearm.

Surface electromyography (SEMG) and electroencephalography (EEG) biofeedback was used in the games so as to have quantifiable measures of relative strength, sequence of muscle activation along with the brain state of patient. This would help therapists to have a better understanding of the progress of the patient [15] [16] using a composite physio-neuro picture. The biofeedback system was designed to give visual and audio cues to patients so that they can identify errors, make adjustments and do repetitive task practice. Post stroke, patients have difficulty in focusing their visual attention to various environment cues and therapist may be required to help them direct attention and vision to appropriate cues [9]. This system uses ratios derived from alpha and beta brain waves to indicate attention and relaxed brain-states. A decline in alpha-band frequency activity in the brain waves indicates cognitive defects and has been shown to be related to the Activities of Daily Living (ADL) disability scale [17] [18].

The EEG and SEMG based games are used to provide feedback to the patient, using the signals sensed from the SEMG arm glove and a standard EEG electro-cap. LabView 8.0 has been used to design the user interface and games. The SEMG acquisition system has been designed with a 10-500 Hz pass-band filters [19]. The EEG electrode headset was placed on the scalp according to the 10-20 electrode configurations. Thereafter the outputs were connected to the research group's unified platform DAQ circuit [19] and from there to NI USB 6259.This hardware interface were also connected to desktop computer using a USB cable. Signals were processed using LabView 8.6 and gaming interface was also designed entirely in LabView 8.6 thus avoiding use of another gaming software server.

3. METHODS

3.1 SEMG Based Games

During the first setup, the electrode positions are customized for the patient, gain in individual channels is adjusted and SEMG thresholds are tested for repeated muscle contraction. Once the game is started, the game progresses based on the biofeedback attained from arm movement of the subject. Based on a study conducted on healthy subjects it was decided that the game would progress only when the subjects were activating the correct set of muscles for the desired tasks. The bar indicators in the game screen (Figure1) show the levels of activation for each muscle.

In the game, there are two circular buttons which light up one after another based on SEMG which is recorded at the muscle site corresponding to a particular such button. Once the subject has achieved a trigger, the subsequent action to be performed is indicated by lighting up of the next button. This ensures that the system leads patient and the patient's attention stays with the biofeedback screen. A video instruction guide which the patient can see and follow, as well as a set of verbal instructions if the patient has problems with vision has been provided. Single joint movement of fingers open and finger closed is explained in figure 4. EMG is recorded from finger extensor muscle and flexor muscle. The subject starts with his forearm and hands resting on arm support mounted on the table top, palm facing down, fingers closed lightly. Once the game starts subject is required to gently try to open fingers and hold it in position (Figure 1). The close finger button lights up if correct muscle set is activated. Thereafter subject gently tries to close fingers and hold it in position. The "open fingers" button lights up if correct muscle set is activated and this activation crosses the set threshold. The action is repeated (open fingers - close fingers) for the number of preset cycles.

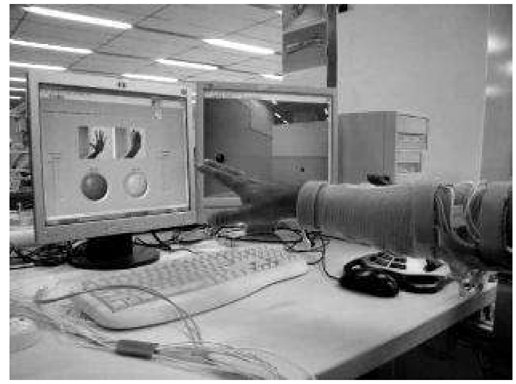

Figure1. EMG Game indicating that fingers should now be closed

Similar games for other single and multiple joint movements of forearm, wrist and hand have been implemented.

3.2 EEG Based Games

3.21 Tracking Game

This game is aimed at enhancing hand eye coordination of the subject along with sustained concentration since this is necessary in functional tasks. The subject has to follow the moving object (a ball on a squash court shown in Figure 2) with the cursor using a mouse or joystick. Once the cursor is inside the object (ball) a clock starts and records time till user loses his concentration and cursor falls out of the boundaries of the ball being tracked. The motive of the player in this game should be to increase the time duration for which he is able to hold the cursor inside the ball and hence, increase the concentration span. If the subject is able to stay relaxed while playing, a high relative alpha is maintained in his EEG signals and this is used to slow down the ball and make it easier for him to score. Thus the brain state is co-ordinated with eye-hand movement, which is recommended for brain plasticity to occur and accelerate motor learning [21].

Figure 2. Tracking the ball in a squash court, an added element of anticipation about how the ball may bounce off the edges

3.22 Maze Game

This game (shown in Figure 3) has been designed keeping in mind people who have a flair for solving puzzles or drawing pictures or tracing images. It may be more suitable for those whose sequential thinking has not been too badly affected. In this game, a subject can chose the task he wishes to accomplish from a gallery. The gallery is an eclectic collection of images ranging from portraits to puzzle games to tracing alphabets, etc. However if the subject wishes to draw on his own, an empty board is also provided. Subject has flexibility to change width and color of the pen. Choice of line like straight, dotted etc is also provided. In an activity like this, the patients go beyond just physical movements and eye-hand co-ordination as done in conventional therapy. They can involve and train faculties of planning, creativity, fine motor control with and without arm support.

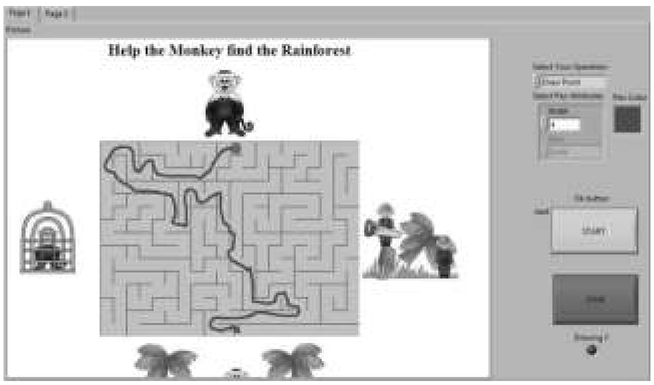

Figure 3. Layout of a maze game in LabView

3.3 Experiment Set Up

For the SEMG games, healthy subjects (subjects without any visible motor impairment) in the age group 25-74 were selected. While the EEG games were tested on adults in the age group 25-45 and youth in the age group of 10-16 years. These subjects had never faced any neurological or motor disorders. The rationale behind doing the EEG experiments with the younger age group was to explore if they would find any interest in simple games and be able to utilize brain and muscle signals jointly. A quiet room was chosen in order to avoid distraction and disturbance for the subjects. SEMG electrodes were placed on the identified muscles using the arm glove. These electrodes provide feedback to the system. Subjects were made to sit upright in a comfortable position. Before starting the game, system was calibrated for each subject by setting individual SEMG and EEG amplifications and threshold values. Details of this will be published in a separate paper.

4. RESULTS

4.1 SEMG Games

Most of the subjects were able to repeatedly activate EMG threshold triggers on instruction. Simultaneous activation of more than one set of muscles e.g. wrist and fingers to be extended simultaneously as in grasp opening, was successfully performed over 5-20 repetitions. Maximum difficulty was perceived in achieving a high EMG threshold level while doing pronation and supination of forearm. Results from subjects whose age group was above 40 were quite consistent, indicating that it may form a suitable interface for stroke patients as well for those who lie in a similar age group. Real time SEMG data recordings indicated that correct set of muscles were being activated while performing the gaming sequence. Where compensation was taking place e.g. excessive medio-lateral elbow movement during pronation/ supination of forearm, the subject was able to quickly correct the action to activate correct muscles, within 3-5 repetitions. In case of oldest subject aged 74, she was habitually not using wrist extension much in the grasp opening action. Being unable to switch on the lamp in the game, she explored options and in a few minutes, started activating wrist extensors along with finger extensors and continued with the game.

During discussions with stroke therapists, several points were highlighted. While healthy subjects liked colour and interesting shapes, stroke patients with left side lesions may have problems with colour recognition, shape boundaries and contrast. After every muscle activation, healthy subjects were able to relax the muscle and this was reflected in SEMG signals. For stroke patients this may not be so. While healthy subjects felt that bright colours and sound cues keep them alert and engaged, this may cause sensory overload and distress to stroke patients since their sensory channels are highly excited. Many stroke patients may not have pain-free range of motion to complete whole movement. Hence, for these games, options were built in to use separate colours or just black and white contrast, switch sound/visual cues on and off, as well as to adjust the threshold and amplification of the 8 SEMG channels so that it can be configured for subjects who cannot get a full range of motion. It may be an interesting experiment later on to see whether the pain signals register in the EEG during hand therapy using SEMG games. This will be a useful indicator for the therapist to fine tune the therapy intensity, therapy duration and rest periods.

4.2 EEG Games

Various forms of formal and informal feedback were taken via questionnaires, rating charts and verbal discussions. It was aimed at having a general view from people of all relevant age groups and walks of life to improve the relevance of the games and to see if they were usable in a repetitive, reliable manner.

4.21 Trials with Children

Five children of age group of 10-16 years were involved in this study. It comprised of two boys and three girls. Feedback from the children was that they enjoyed playing the games. Girls found it difficult to catch the ball in the ball tracking game and complained the ball speed was too fast for them to catch while boys enjoyed the game because of the speed. Boys were not impressed with the background and indicated that a background with war zone or cars would attract them more. Girls found current background pleasing as long as it was coloured. For the drawing related games both groups enjoyed the maze and puzzle games and suggested to have more of these. While they felt it was monotonous and boring to trace alphabets and numbers, they would enjoy drawing images like dog, cat, tree, etc.

4.22 Trials with Adults

These were conducted with eight subjects (four boys and four girls) between the age group of 18 years to 23 yearsl. In general girls enjoyed playing the games while boys felt it was becoming boring after a while. Boys emphasized lack of advanced graphics as a reason for disinterest and wanted level of difficulty to be higher. Girls, on the other hand, appreciated simple graphics and recommended that more graphics would make the game complex to understand and play. However, they emphasized that the speed and complexity levels should increase to make the game more interesting. Four more subjects between the age group of 24years to 30 – two girls and two boys-were asked to play the games. These adults did not enjoy the games much. However, it was noticed during their feedback that as individuals they had their own interests which they wished to pursue, such as painting and video games.

5. CONCLUSION

The duration allocated for upper extremity therapy in hospitals is decreasing as the number of stroke patients increases. This calls for a smart system, which can be used for rehabilitation in the presence or absence of therapist. It would aid in reducing work load on therapists as they can attend to more patients in same time period. SEMG games allowed the user to view and measure actual degrees of muscle isolation, co-ordination and contraction and relaxation. With EEG games enabled, players were able to control pace of the game to yield best results. This resulted in better concentration and attention states. However, needs of cognitively and physically impaired patients are dramatically different. Any game interface for them should preferably have low complexity, low speed, more spatial distribution, with a choice of images, audio cues and difficulty levels.

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7. REFERENCES

[1] Venketasubramanian, N., *Singapore Stroke in Singapore*, an Overview Medical Journal; 1999; Vol 40(01).

[2] Singapore Stroke Association, http://www.snsa.org.sg.

[3] National institute of neurological disorder and stroke, http://www.ninds.nih.gov/disorders/stroke/knowstroke.htm

[4] M. Mulas, M. Folgheraiter, and G. Gini, An EMG – Controlled exoskeleton for hand rehabilitation in *Rehabilitation Robotics*, 2005.ICORR 2005: pp. 371-374

[5] Gainotti, G., Mcmarra, C., *Determinants and Consequences of Post Stroke Depression,* Current Opinion in Neurology; 2002; 15; 85–89.

[6] American Psychiatric Association, DSM-IV. Washington DC: American Psychiatric Press 1994

[7] Dombovy ML, Whisnant JP., *Stroke: Populations, cohorts and clinical trials*. Oxford (UK): Butterworth-Heinemann, 1993, 317-338

[8] Carr, J., Shepherd, R., *Stroke Rehabilitation: Guidelines for Exercise and Training to Optimize Motor Skill*, Butterworth-Heinemann, 2003.

[9] Bogousslavsky J., *Long-term Effects of Stroke copyright reserve*, Marcel Decker Inc, 2003.

[10] G. Kjellby-Wendt, J. Styf and S. G. Carlsson. 2001. *"Early active rehabilitation after surgery for lumbar disc herniation: A prospective, randomized study of psychometric assessment in 50 patient"*, Acta Orthopaedica, 72(5):pp. 518 — 524, 2001.

[11] R. W. Teasell and L. Kalra, *What's new in stroke rehabilitation*, Stroke: 36: pp. 215-217, 2005.

[12] Yim. J, Graham N. T. C, *Using games to increase exercise motivation*, Proceedings of the 2007 conference on Future Play, 2007, 166–173

[13] Basmajian, JV., Gowland, C., Brandstater, ME., Swanson, L., Trotter, J., *EMG Feedback Treatment of Upper Limb in Hemiplegic Stroke Patients: A Pilot Study*, Archives of Physical Medicine and Rehabilitation;1982;63(12);613-616.

[14] Rizzo, A., Kim, GJ, "*A SWOT Analysis of the Field of Virtual Reality Rehabilitation and Therapy,* –Presence, Tele-operators and Virtual Environments; 2005; 14,119-146.

[15] Paiva, A, Prad, R, *Affective Computing and Intelligent Interaction*, 2007; 102–113.

[16] Middaugh, SJ., EMG *Feedback as a Muscle Re-education Technique:A Controlled Study*. Physical Therapy. 1978;58(1);15-22.

[17] Yuasa,T., Maeda,A., Higuchi,S., Motohashi,Y., *Quantitative EEG Data and Comprehensive ADL (activities of daily living) Evaluation of Stroke Survivors Residing in the Community,* Journal of physiological Anthropology and Applied Human Science;2001; 20(1);37-41.

[18] Finnigan,S., Walsh,M., Rose,S., Chalk,J., *Quantitative EEG Indices of Sub-Acute Ischemic Stroke Correlate With clinical Outcomes*, Clinical Neurophysiology;2007;118(11),2525-2532, .

[19] Raichur, A.; Wihardjo, G.; Banerji, S.; Heng, J., *A step towards home-based robotic rehabilitation: An interface circuit for EEG/SEMG actuated orthosis*, Proceedings of IEEE/ASME International Conference on Advanced Intelligent Mechatronics, 2009. AIM 2009. Pag(s): 1998-2003.