NEW DIRECTIONS IN THE CREATION OF UPPER EXTREMITY(UE) ROBOTIC REHABILITATION DEVICES FOR STROKE PATIENTS

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ABSTRACT

On reviewing products and literature in recent UE rehabilitation engineering research, one finds significant differences in the directions that rehabilitation engineering is adopting and that which clinical practice is advocating.

Combining a study of current practices in robotic device development for the hand, clinical practice for stroke, biological mechanisms and natural movement, an attempt has been made to re-align the thinking on UE Orthosis development.

In this paper we propose new directions which have been adopted by us to bridge this gap, with respect to UE Orthosis. Preliminary study with some of these often neglected design considerations are then presented as a low cost, versatile, and simple option that may help to keep the patient motivated to continue UE therapy.

Three new directions discussed in this paper are:

1. Making robotic therapy more "collaborative" by encouraging more HMHI (Human Machine Human Interaction) rather than just HMI (Human Machine Interface).

2. Using other natural positions during UE motor re-learning rather than only sitting.

3. Giving patients a menu of triggers to choose from and adapt, rather than single or fixed triggers.

Description of preliminary experiments have been discussed.

General Terms
Performance, Design, Experimentation, Theory

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Keywords
Human machine interface, triggers, UE orthosis, Stroke, Disabled, Design

1. INTRODUCTION
Current theories of motor function adopt two completely opposite points of view. One states that the body follows the movement form using constraints for control, whereas the other says that the form follows from the functioning of the body [30].

Bernstein emphasized that the basic problem of natural movement is one of co-ordination."The co-ordination of a movement is the process of mastering redundant degrees of freedom of the moving organ, thus making it a controllable system"[31]. Between skeletal and muscular geometry, nature has found a skilful and highly sophisticated yet simple way of controlling the redundant degrees of freedom in countless day-to-day actions[29].

The Journal of Neuroengineering and Rehabilitation, 2004-2007, lists interesting bodies of work such as biologically inspired neural networks controllers, computer assisted motivation systems, markerless motion capture of human movements, wireless body area network of intelligent motion sensors. There also exist hundreds of studies on the significant or insignificant effects of robot assisted therapy for various robots and protocols [1,2,3,4,5,6,7,8].

However, we are still in an age where try as we might, computers and robots can at best act as aids. By themselves they have not been able to dramatically impact recovery.

The synthesis of technology and clinical practice has been forced in this century by the dramatically increasing numbers of Stroke, Spinal Cord Injury (SCI) and Traumatic Brain Injury (TBI) survivors. This coming together demands a re-evaluation of certain design criteria. These criteria must be added to the State-of-the-Art, whose authors have called for revolutionary solutions to rehabilitation, patient motivation, cost and versatility[7].

2. DISCUSSION

2.1. Ensuring more HMHI (Human Machine Human Interaction) – Moving away from "Isolation"(HMI) to a more "Collaborative" Approach (HMHI).

Each one of us who has visited a rehabilitation clinic or ward will have etched in their minds images of lonely, dejected looking stroke patients going through their paces by themselves, while the new patients get the major part of the attention from the overworked and outnumbered clinicians and therapists. Some studies have shown that de-motivation is one of the major reasons for patients stopping rehabilitation prematurely. Two acknowledged factors are progressively decreasing therapist contact and steadily decreasing rate of improvement leading to de-motivation [38,39,40]. This scenario is in sharp focus now with an exponentially increasing disabled population. In 2007, the US added almost 2 million people to its number of disabled, covering stroke, TBI and hip fracture cases. The number of people with significant disability in the US alone now totals more than 10 million.

From this perspective, it may be beneficial to design the robotic rehabilitation devices to be multi-station systems instead of single station systems. Here two or more patients can play against or with each other, driving each other or even physically sharing strength and mobility resources to assist each other in exercise and functional movement (fig. 1). It is possible that this will go a long way to address both problems currently faced, namely de-motivation and cost. The patients may be chosen to pair up against each other in a way that they complement each other. Besides two or more patients sharing the same hardware will substantially reduce cost and therapist time (fig.2).

Figure 1. An opportunity for HMHI-a device may assist in playing cards for UE retraining with 2-4 stations.

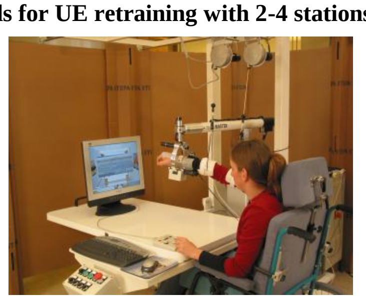

Figure 2. The Gentle/s System – Can be converted to HMHI with 2 chairs, 2 guides and common controls.

For example, a system like the MIT Hand Guide [32] the Gentle/s System [7] can be reconfigured so that one patient can assist the other to complete the movement correctly. The creators of the Gentle/s system acknowledge its shortcomings in terms of cost and patient motivation, as well as grasping function. An exercise like the simple Peg Board can be configured with a slow conveyor so that two or more patients can compete or assist in a time trial over a fixed number of cycles with varying degrees of difficulty. Indexing work stations can take the patients on a musical chairs of performing varying Activities of Daily Living (ADLs) with each other eg. simulate making a sandwich.

A patient with lesser disability can help a more disabled recent CVA patient. The performance of each may be recorded for future reference, analysis and assessment. We believe the ability to help a fellow patient will be a huge self esteem and motivation boost for a patient who has struggled with therapy for quite a few months[36]. To the clinic it will mean less therapist load with a cost saving for both.

Community rehabilitation projects in Japan[28] and Turkey [27] have proved several advantages but patients may be in the same room and yet lonely and disconnected, especially if there is significant cognitive impairment. Engagement through multi-station devices is worth researching especially for those patients "in-need-of-care" and "quasi-in-need-of-care" states[28]. Most stroke patients are elderly. We find worldwide across cultures, senior citizens feel motivated to come together in groups for recreation and socializing and travelling. So why should rehabilitation be any different? Some studies have shown encouraging results [35].

2.2. Exploring other Natural Positions for UE Relearning – Moving away from an "Upright Mindset".

Almost all the machines and equipment for active movement and motor retraining are designed to be used in the upright position only. Right from the MIT- Manus [32] to the Gentle/s System [7], we find the patient is expected to sit upright and do all the relearning and retraining. Some FES orthosis like the Freehand System [19] or Ness HandMaster [13] may allow the patient to lie down, but they do not have mechanical assist or HMI comparable to MIT Manus. However we are seeing that events such as Carviovascular Accident (CVA) may be accompanied by scapular instability [33, 34] and shoulder subluxation or shoulder pain [33] for up to 70% of the cases.

Post stroke, we find many patients finding it difficult and strenuous to sit upright for long periods of time. Apart from the fact that they may be also in a state of de-motivation and dementia, carrying out repetitive tasks in an uncomfortable and tiring position is not exactly something they look forward to every day, especially in the early post-CVA days. With the emerging proof in recent studies [8] that several hours of daily therapy can bring dramatic results in early post-CVA rehabilitation[2,37], we find maintaining an upright position a stumbling block. The most commonly used robotics devices, eg MIT Manus, Gentle/s, do not address this problem as they are table top mounted.

Head, Shoulder,Spine stability — **A.**

Elbow, wrist, finger extension — **B.**

Figure 3.

We know from biomechanical studies that sufficient stabilization of key muscles is key to the application of strength and the control of distal musculature and joints. The most natural method of scapular stabilization is to lie down supine on a firm surface. The idea is to use gravity to be able to keep the scapula fixed while focusing on the distal (finger) joints which are manipulating some object. We find from the natural learning process of an infant (fig. 3, A) that before the child develops the ability to roll over into a prone position, it starts mastering pinch, cylindrical grasp, the spherical grasp and pronation/supination of the forearm. Throughout this learning process, the scapula, shoulder, spine and head, assisted by gravity and the resting surface, are stable. The large muscle of the chest assists in lifting the arm against gravity and moving in various planes.

Once the child is old enough to get into prone position it starts the second phase of scapular / shoulder stability and the first phase of elbow/wrist stability, as also core muscles. One finds the strength training commencing only now for the entire UE kinetic chain, starting from scapula to digit, especially when the child starts crawling on fours. The elbow, wrist and phalanges are now extended fully together for the first time with constraints at the shoulder end and the wrist end, sandwiched by gravity and the firm floor (fig.3, B).

Hence it may be worthwhile for robotics devices to seriously explore these other learning postures instead of being preoccupied with the upright position, especially for early onset of therapy. The position of the head in supine position ensures maximum blood supply to the brain, which may aid brain plasticity [2].

In that case robotic devices must incorporate a design feature to make this possible. The only devices which allow a supine or any other position may be FES devices which have their limitations for long term therapy[9, 10,11]. The Bionic Glove [17] has not reported wide usage.

2.3. A la Carte Menu rather than Fixed Triggers - Giving the Patient a choice of Triggers.

Why use a single trigger type or a single muscle contraction to drive a robotic device? The disabled person, apart from his need to communicate, needs to be as active as possible with whatever muscles are at his command. This is critical for his survival. Otherwise over a period of time, muscle wastage will also hit the muscle that he has trained for triggering the device, since surrounding muscles are wasting. Hence it is important to use as many different muscle contractions as possible.

This will also enable simultaneous selection (eg. close eyes and raise eyebrows) of more than one trigger at the same time, thus speeding up his functions and enabling some level of multi-tasking (fig. 4), which is an important and much desired quality by humans. It gives them a feeling of efficiency and control.

Figure 4. Multi-tasking is our natural mode

In many BCI systems, the user has to continuously look at a navigation screen. It may be more practical to have a few muscle contractions dedicated for certain user defined actions (as we are doing with our UE orthosis) and have some contractions or brain signals act only as navigation tools (e.g. wheel chair and PC).

While many papers present valid engineering ideas, few address the clinical point of view. Clinically, those muscles should be used for generating trigger signals which most need to be exercised! Then we have enhanced rehabilitation. Else the patient becomes an expert at communicating but his physical condition deteriorates due to disuse of some body parts. This is a key point that we feel no new HMI adequately addresses. What muscle group is the patient using for the device and what clinically does he really need to use?

If we make this one of the considerations for design, the spinoff for the patient is that even for passive activities, the person can have the option of exercising clinically important large or small muscles or muscle groups. This will ensure that clinical requirements related to muscle disuse, overuse and co-ordination can be addressed through the device, even outside the therapy session eg. using forearm tightening instead of fingers to operate the remote while watching television. We feel having such an option is a key step to integrate the patient better to the device and make the device a part of everyday life, thus leading to extended use and more repetition.

3. METHODS

3.1 Preliminary Experiments Conducted

1. To study whether it is possible to use SEMG and EEG signals from a simple breadboard circuit with sufficient sensitivity and repeatability to run an orthosis motor. Standard filtering and amplification was done without any attempt to completely insulate the circuit from environment (fig. 5).

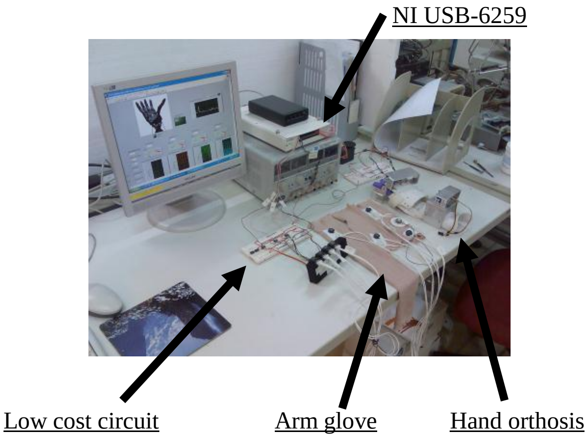

Figure 5. Experiment Setup

2. To study 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, 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 different persons to achieve a threshold were studied, using signal mean and RMS.

In our experiments, we are using SEMG from 2 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.

3. To use surface EEG and SEMG signals detected by electrodes on the head which are easily recognizable and repeatable eg. Presence and absence of sensory stimuli in open and closed eye, eyes tightly shut, frown, blink, etc.

4. To study a simple self assessment system which shows relative “strength” and “frequency” of a particular action on a display panel, with therapist defined targets. This gives the user and therapist an indication of the sequence of muscle contractions used to achieve an action. The therapist can then demonstrate the biomechanically recommended sequence or allow the patient to adapt. This we believe will exercise the “kinetic chain” which may be more useful for regaining functional movements than only individual muscles (fig. 6). The experiment is aimed at developing a simple sensor glove which can be used by stroke patients as early as a few days post stroke, in lying down position. This glove is easily fitted with a SEMG powered or manually controlled FES system and forms a part of the proposed hand/wrist orthosis.

Figure 6. Using Visual Feedback to track Kinetic Chain

5. Development of a low cost hardware platform which can detect SEMG, EEG and any small electrical input (e.g. goniometer, pressure transducer) signals and able to feed raw signals into LabView NI USB-6259 multi I/O unit for simultaneous processing and comparison. From this we expect in future to use several triggers (brain waves, facial expression, isometric muscle contraction, joint movement, tongue movement, shift of body weight, etc.) in combination or isolation. This will give us a haptic system which is closer to the biological model which uses multiple and interchangeable sensory signals for different actions (eg. shifting of body weight towards right foot before lifting a heavy weight with right hand). These triggers can drive various motors on an orthotic device or manage access and environment.

Results: The above experiments are in their early stages. Further data needs to be collected before we can confirm the results. Initial data has shown the above directions to be promising.

3.2 Equipment Used by the Research Group

1. Electrodes MC5SGW and MC5SW with J+J Engineering I-330 C2+ SEMG / EEG recording device
2. Mindset 24 channel EEG device with skullcap
3. LabView along with NI USB-6259 DAQ device
4. Low Cost Circuit
5. Proposed prototype arm glove
6. Proposed prototype hand/wrist orthosis

4. CONCLUSION

The world is faced with an urgent need for rehabilitation devices that fulfill clinical requirements, are cheap, modular, versatile, compatible, easy to set up and monitor. Large disabled populations with differing levels of disability necessitate a fresh design hypothesis [7]. Certain new guidelines were proposed for the development of an UE orthosis which attempts to fulfill these requirements.

Preliminary experiments proved it was possible to get distinct repeatable EEG / SEMG triggers with a low cost circuit. It was possible to detect and combine multiple triggers. Some algorithm changes could enable one patient to collaborate with another in rehabilitation. Thus the UE orthosis could have three modes :

1. Passive Exercise

2. Active Rehabilitation (using multiple EEG/SEMG triggers and using the graphical interface for visual feedback)

3. Collaborative Rehabilitation (One patient assisting another via the machine, thus ensuring safety)

The proposed arm glove prototype is suitable for starting therapy in supine position even before the patient can sit up post stroke. The proposed hand / wrist orthosis is not restricted to only sitting position use.

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