Delivering remote rehabilitation at home: An integrated physio-neuro approach to effective and user friendly wearable devices

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Abstract—**There is a global shortage of manpower and technology in rehabilitation to attend to the five million new patients who are left disabled every year with stroke. Neuroplasticity is increasingly recognized to be a primary mechanism to achieve significant motor recovery. However, most rehabilitation devices either limit themselves to mechanical repetitive movement practice at a limb level or focus only on cognitive tasks. This may result in improvements in impairment but seldom translates into effective limb and hand use in daily activities.**

This paper presents an easy-to-use, wearable upper limb system, SynPhNe (pronounced like "symphony"), which trains brain and muscle as one system employing neuroplasticity principles. A summary of clinical results with stroke patients is presented. A new, wireless, home-use version of the solution architecture has been proposed, which can make it possible for patients to do guided therapy at home and thus have access to more therapy hours.

I. Introduction

FOR the past several decades, repetitive practice has been the cornerstone and gold standard in rehabilitation methods worldwide, including after stroke [1], [2]. This was later modified to high intensity, high repetition practice as a way of leveraging the rapidly emerging understanding of neuroplasticity principles [3]. Rehabilitation technologies, including robotics, have evolved around the practice of high repetition modalities under the assumption that robots can deliver movements accurately, safely and repeatedly while relieving the effort required on the part of the therapist [4].

Although this approach has been somewhat successful in reducing impairments and restoring certain gross movements and abilities, it has not resulted in significant restoration of function and the ability to participate in activities using the affected hand in day-to-day life. This shortcoming is particularly highlighted with chronic "plateaued", long term stroke patients who are recommended a maintenance program in the late chronic phase with little hope of a return to independent living, let alone full recovery [5], [6].

One of the reasons for the above limitations is an inability to leverage the basic neuroplasticity principles in a simple, well integrated, easy-to-use manner. Some of these are multi-modal feedback, avoiding maladaptive muscle strategy, intensity modulation, specificity and mental engagement before moving onto multiple repetitions [7]. This paper describes the SynPhNe (synergistic physio-neuro platform) technology that helps train brain and muscle as ONE system. It captures electroencephalography (EEG) and electromyography (EMG) signals in a time-locked manner in real time while the subject is performing various movements and tasks. These are then used in a feedforward-feedback loop to help subjects "self-correct" movements in real-time. A previous study had explored the use of such a platform in combination with electrical stimulation [8]. This paper describes the feasibility of using solely "self-correction" without stimulation. This makes the device a cheaper, safer and easier option for home-use.

II. Materials and Methods

A. Technology description

The synergistic physio-neuro platform was built as a wired prototype version for the clinical study (Fig. 1).

Fig.1. The system consists of a data capture unit (black box) which has two connectors, one each for EMG and EEG inputs from armgear and headgear shown to left and right side of the black box respectively.

Eight channels of data each from the headgear and armgear are captured through wired connections in the data capture unit. The unit transmits the amplified and cleaned data to the PC through a USB cable. The software running on the PC processes these signals from 16 channels and combines them in a time locked manner for presentation on the screen as real time feedback showing muscle and brain over-activation and under-

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activation as cartoon characters. The subject tries to imitate an exercise and task practice video sequence running on the same computer screen, while attempting to correct maladaptive over-activation and under-activation in opposing muscle pairs, using an intensity suitable for maintaining an attentive, relaxed brain state.

B. *Study Methodology*

30 adult stroke subjects (28-76 years; 7 female, 23 male) were randomized into treatment and control groups. Each completed a six week, 3 sessions/week protocol. The treatment group performed four motor learning exercises and four object manipulation tasks using the device, while control group was provided standard care including occupational therapy. Pre and post outcomes were measured using standard clinical scales (Fugyl Meyer Assessment, Action Research Arm Test, Grip strength and Nine Hole Peg Test) to assess both gross and fine movements. An International Classification of Functioning, Disability and Health (ICF) problem solving form was also employed to track changes in activity and function. Subjects provided feedback on pain, fatigue, discomfort, usefulness and ease-of-use through rating scales. Ethics approval was obtained from the institutional review board at Max Healthcare Institute Ltd., New Delhi, India and all subjects provided signed consent.

III. RESULTS

Both chronic and sub-acute subjects showed clinically significant improvement when averaged across all five clinical scales. Overall improvements in treatment group with respect to Week 0 baseline ranged from >40% (n=7), between 5% and 40% (n=5) and less than 5% (n=3). The largest percentage improvement in chronic patients was in ARAT scale when compared to controls, while for sub-acute subjects it was grip strength. A two-tailed t-test showed no significant difference between the two groups in Fugyl Meyer and ARAT scales, when chronic and sub-acute subjects were combined. The ICF outcomes showed improvements in the treatment group in carrying out daily routine (>50%), caring for body parts (>40%), eating (>40%) and drinking (>90%) although these activities were not specifically trained.

IV. DISCUSSION

No adverse events were recorded during the study and subjects reported negligible post-session pain (mean 1.0/10) and low fatigue (mean 1.2/4). We noted that subjects devoted a large part of the therapy time to inhibition and relaxation of excessive, previously unrecognized muscle and brain activity. Subjects reported the device to be high on ease-of-use and usefulness (mean 3.9/5). This prompted us to propose a simpler, wireless solution architecture for future home-based rehabilitation studies (Fig. 2). This prototype is now ready for the next round of clinical studies, using wi-fi connectivity for data transmission to the PC and internet connectivity to a cloud server for remote monitoring, therapy personalization and support.

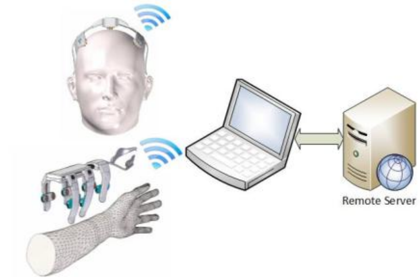

Fig.2. The new architecture for the SynPhNe home-use prototype. The previous data capture unit and wires are incorporated within the arm and head gear.

V. CONCLUSIONS

The treatment group showed significant progress in both long term and early stroke patients. While early stroke patients may be introduced to the physio-neuro platform for training neuroplasticity while in hospital, existing long term stroke patients may require home-based rehabilitation. The proposed wireless design of the SynPhNe platform can go a long way to solve the global problem of large scale chronic disability in the stroke affected population.

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