A Physio-Neuro Approach to Accelerate Functional Recovery of Impaired Hand after Stroke

Article *in* Procedia Engineering · December 2012

DOI: 10.1016/j.proeng.2012.07.171

4 authors, including:

Subhasis Banerji
National University of Singapore

John Heng
Nanyang Technological University

Available online at www.sciencedirect.com

SciVerse ScienceDirect

Procedia Engineering 41 (2012) 257 – 263

Engineering Procedia

www.elsevier.com/locate/procedia

International Symposium on Robotics and Intelligent Sensors 2012 (IRIS 2012)

A Physio-Neuro Approach to Accelerate Functional Recovery of Impaired Hand after Stroke

Subhasis Banerji[a]*, Christopher Wee Keong Kuah[b], Dr. John Heng[c], Dr. Keng He Kong[b]

[a]*National University of Singapore, 5, Lower Kent Ridge Road, Singapore 119074*
[b]*Tan Tock Seng Hospital, 11 Jalan Tan Tock Seng, Singapore 308433*
[c]*Nanyang Technological University, 50, Nanyang Avenue, Singapore 639798*

Abstract

Hand function disability after stroke is the greatest obstacle to independent living. Rehabilitation of hand function is known to be more effective if patients can start therapy as early post-stroke as possible, and dedicate maximum therapy hours during hospital stay. Constraints such as a rapidly increasing patient-therapist ratio and a shortage of beds for stroke patients often prevent ideal rehabilitation therapy. One solution could be a system that can guide the patient in practicing key functional hand movements unsupervised as well as record data for tracking and reviewing progress. This paper describes a pilot experiment with a new Rehabilitation Platform. It consists of a mirror-image instruction video which guides the stroke patient through a therapy protocol; an arm glove provides EMG biofeedback simultaneously to highlight incremental progress and self-regulation in muscle use. This forms a part of the overall physio-neuro platform named “SynPhNe”. It is being tested to drive an accelerated hand function rehabilitation process. Initial results suggest that in early post-stroke therapy, it may be possible to accelerate functional recovery of the hand by leveraging the ability of the brain-muscle system to respond favourably to both components of the platform - mirror image visual input and biofeedback.

Keywords: rehabilitation; functional recovery; SEMG; biofeedback; stroke; upper limb; SynPhNe; mirror image

1. Introduction

Over the past 30 years, the number of stroke cases has been steadily rising in Singapore hospitals. Between 1986 and 1996 there was more than a two-fold increase in the number of stroke patients [1]. In the USA, every 45 seconds someone suffers a stroke [2]. The World Health Organization reports that stroke leaves nearly five million people disabled every year, worldwide [3]. The rising number of stroke survivors raises the demand on therapists’ duties and responsibilities (whose numbers have not increased to that extent). This adversely affects the therapists’ ability to provide the required attention to patients. Such attention is especially crucial in the acute and sub-acute phases of stroke rehabilitation, during which the four key predictors of functional recovery are:

- an early start to therapy [6], [8]
- expert supervision [5]
- greater therapy hours [7]
- correct muscle use [4], [5]

* Corresponding author. Tel.: +65 94491767
E-mail address: dosbs@nus.edu.sg

1877-7058 © 2012 Published by Elsevier Ltd.
doi:10.1016/j.proeng.2012.07.171

In the present day, technology is unable to satisfy all four above requirements. In addition, recent neurological studies show that it is crucial to leverage the phenomena of increased brain plasticity immediately after a stroke to improve chances of motor recovery [6]. The SynPhNe system discussed in this paper is designed to address these gaps. The simple design allows a patient to start therapy at bedside by following the video instruction. The biofeedback is designed to identify that the appropriate muscles are being used for each action. After a brief training, most patients can use the system with a low level of supervision.

The experiment explained in this paper focuses on leveraging the effects of neuroplasticity using video guided instruction delivered as a mirror-image of the affected arm. Following instructions demonstrated in mirror-image is known to affect the firing of neurons in the motor cortex related to these actions [9], [10]. This can help tap into the large brain-body redundancies that are built up during the learning of functional tasks throughout a person's life [11].The authors have simultaneously employed SEMG (surface electromyography) mode of biofeedback since it can detect and display compensatory muscle use, unconscious muscle co-contraction and minute muscle activations, thus allowing patients to self-correct and train muscle use strategies in real time, while attempting the tasks displayed on the video screen. The authors hypothesize that using mirror image instruction and biofeedback together may result in an accelerated recovery of functional ability and may be even faster than the standard repetitive task practice based on verbal instruction. This pilot study was, therefore, conducted as a single session feasibility study to identify whether the system could identify minute differences in muscle use strategies and whether stroke patients with different levels of disability could respond to such a biofeedback, while trying to imitate simple everyday tasks. If this was indeed possible, it was reasonable to expect some visible gains in function in the first therapy session itself.

2. System description

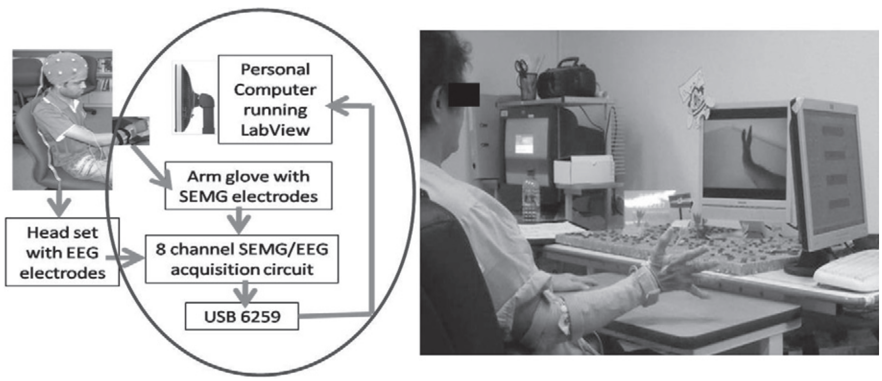

Fig.1. Block diagram of Rehabilitation Platform setup showing SEMG glove and Signal flow path

Fig 1 explains the overall "SynPhNe" Platform setup. For this experiment only SEMG bio-signal inputs were used. Relaxation instructions were delivered manually. This ensured that the patient's attention is directly engaged by the mirror-image instruction video, run at a pace appropriate to the level of disability (one action repetition every 30 seconds). The biofeedback arm glove consisted of dry SEMG sensors which tracked 7 muscles of the arm and hand. The design of this glove has been reported in a separate paper by the authors [12]. The detailed design and testing of the amplification circuit was reported by the authors previously [13], [14]. Results of the system validation experiments were also reported [15]. After signals were acquired on all channels, the target thresholds to be used in the guided therapy sequences were calibrated for the individual patient. Then, the instruction video and biofeedback screens guided the patient through different movements and tasks.

3. Methods

3.1. Experiments conducted for SEMG acquisition and analysis in healthy subjects

The experiments with 8 healthy subjects in the age group 25-74 involved recording 7-channel SEMG in 1) neutral resting state, 2) in an induced relaxation state and 3) during hand movements and performing tasks. This was aimed at understanding which muscles are best targeted for the hand movements and tasks that the authors had selected for the study. The muscles targeted for standard therapy exercises are listed in Table I.

Table I: Muscle groups tapped for "dry" electrode SEMG signals

S.No.	Movement	Muscle group
1	Wrist extension	Extensor carpi ulnaris
2	Wrist flexion	Flexor carpi ulnaris
3	Fingers extension	Extensor digitorum
4	Fingers flexion	Flexor digitorum profundus
5	Forearm pronation	Pronator teres
6	Forearm supination	Supinator
7	Thumb flexion	Opponens pollicis

The experiment with healthy subjects also helped to identify the SEMG signal threshold ranges for these muscles. This information was used to determine the gain settings and tune the system while doing the experiment with stroke patients.

3.2. Experiments conducted for SEMG acquisition and analysis in stroke afflicted subjects

Nine right-hand hemiplegic stroke subjects ranging from 30 to 71 (51.8 ± 15.4) years old were recruited from a rehabilitation centre in Singapore to participate in the pilot study. Key inclusion criteria were (1) less than 90 days after stroke; (2) Motor Power MRC grade between 0 and 4 of the hemiplegic upper extremity; (3) passive range of motion less than 50% of normal range of motion for the elbow, wrist, fingers in extension and flexion, and the forearm pronation and supination. Table II contains the basic profile of the stroke subjects. This feasibility study was approved by the Institutional Review Board of the rehabilitation centre. All subjects provided informed consent before participation.

Table II Profile of stroke subjects

Stroke Subject (SS)	Age	Stroke Type	Days Post Stroke	Fugl-Meyer Scale (full 66)	Motoricity Index (full 100)
SS1	30	Hemorrhagic	57	21	40
SS2	53	Ischemic	15	43	73
SS3	31	Hemorrhagic	37	9	10
SS4	50	Ischemic	8	38	58
SS5	67	Ischemic	44	57	77
SS6	46	Ischemic	18	18	45
SS7	70	Hemorrhagic	32	62	77
SS8	48	Ischemic	8	6	1
SS9	71	Ischemic	9	58	77

Both healthy and stroke subjects were asked to do a total of 12 activities. The first two were resting and relaxation, done to sample the baseline SEMG activity of the arm muscles. The other exercises performed were (1) wrist extension and flexion, (2) finger extension and flexion, and (3) pronation and supination, (4) wrist and finger extension (open grasp), (5) pick up a pen, (6) grasp a bottle, (7) flip a page, and (8) use a pair of chopsticks. Each movement was repeated five times. Video led basic exercises were followed by video led task practice. Training with individual muscle groups was supported by the biofeedback interface. Where poor activation, co-contraction and compensation would become evident, the subject was instructed to try and self-correct these on the fly. After a while, such correction was expected to be intuitive.

The root-mean-square (RMS) of the data points was exported to Microsoft Excel and the graphs for each electrode pair's data were plotted. Signal peaks and actions performed by the subject were correlated with the aid of the video recordings. Once the action peaks had been identified, the start and end points of an action peak were taken to calculate the mean and median of the action. A period of more than 100 data points where the subject was not performing any actions was then identified to be used as the baseline activity to subtract from the mean or median of the action peaks to get the effective muscle activation amplitude. To minimize error due to perception bias, only one person worked on picking out the points. It is well accepted that real life physiological signals are highly non-Gaussian in distribution [16]. Wilcoxon signed rank test was thus used to classify the transition between the action peaks of each electrode pairs to baseline activity as significant or non-significant, based on a confidence level of 95% ($p < 0.05$). It was also used to classify baseline activity during the exercise against baseline activity at induced relaxation. The Kruskal-Wallis test was used to determine if there were significant differences between baseline activities and action peaks across subjects in each study, based on a confidence level of 95% ($p < 0.05$).

4. Results and discussion

Due to space limitation, only SEMG activity of the wrist extension and flexion exercise will be discussed and summarised in this paper. The remaining data will be reported in subsequent publications, using action and task specific discussions. Since the experiment was originally conceived as a feasibility study, observational results of functional gains are enumerated without any post-session clinical assessment. The trials observed the ability of stroke patients to self-correct maladaptive muscle strategies, particularly in wrist flexion, finger extension and pronation. All stroke subjects were able to maintain attention towards the video throughout the whole experiment (47 minutes with a 5 min break at 30 min), with minimum verbal communication. No significant involuntary muscle activity was seen in either the healthy or stroke subjects. SEMG threshold values in stroke subjects were in the range of 0.005 – 0.02 V, while threshold values in healthy subjects were 0.015-0.02V (reported by the authors earlier) [12].

4.1 Wrist extension and flexion

The healthy subjects predominantly used the biomechanically correct muscle groups in synergy with other muscles. For wrist extension, significant differences in transition between action peaks to baseline activity were observed in thumb flexor, wrist extensor, wrist flexor, finger flexor, and pronator muscle groups. The largest effect size recorded by each stroke subject was found to be in the wrist extensor except for subjects SS.4 and SS.7 (see Table II), which were found to be in the finger flexor ($T = 197$, $p < .001$, $r = -.60$) and thumb flexor ($T = 26$, $p < .001$, $r = -.61$), respectively.

For wrist flexor, significant differences were observed in all muscle groups for all stroke subjects, except SS.4 in finger extensor ($T = 8907$, *ns*, $r = -.06$) and pronator ($T = 9794.5$, *ns*, $r = -.01$). The largest effect size recorded by each stroke subject was found to be unique. For SS.2 and SS.4, it was found to be the finger flexor ($T = 257$, $p < .001$, $r = -.47$ and $T = 583$, $p < .001$, $r = -.58$), SS.3, wrist extensor ($T = 351$, $p < .001$, $r = -.67$), SS.5, supinator ($T = 23$, $p < .001$, $r = -.61$), and SS.7, thumb flexor ($T = 49$, $p < .001$, $r = -.61$). This significant difference shows that all stroke subjects used more than one group of muscles to extend and flex their wrist. Other than SS.4 and SS.7, the rest of the stroke subjects used the theoretically correct muscle group, wrist extensor, more often while attempting wrist extension. For wrist flexion, none of the stroke subjects used the theoretically correct muscles group, wrist flexor, dominantly. This seemed to indicate that wrist extensors were more intuitively controlled (although weak in terms of force generation) while wrist flexors were actually poorly isolated although most stroke subjects should better flexion movement when compared to extension.

Co-contraction of muscles was present in both healthy and stroke subjects. No subject (stroke or healthy) used only one corresponding muscle group specifically to elicit the corresponding action. Seven out of nine stroke subjects used correct muscle groups initially as compared to seven out of eight healthy subjects. For flexion, the number of healthy subjects was the same while none of the stroke subjects used the flexors predominantly. This points out that using compensatory muscle activity to elicit the intended motion is not restricted to hemiplegic patients alone; there are healthy individuals who engage in compensatory muscle activity as well, which is not age dependent. Further, stroke subjects were able to target flexor muscles poorly compared to extensors, which was surprising.

In the sample SEMG profile in Fig 2(A), second extension shows a better differentiation compared to first extension peak, while flexion shows poor muscle recruitment. Stroke patients with significantly impaired movements showed symptoms of exhaustion - panting or heavy breathing. For these stroke subjects, SEMG revealed the activation of all muscle groups (agonist and antagonist) for all actions attempted. Thus general patterns of co-contraction were high. For moderate and mild stroke subjects and healthy subjects, where exhaustion was not evident, SEMG revealed a distinct alternation in activation of agonist and antagonist muscle groups for opposing actions done alternatively as shown in Fig 2(B). Several moderate and mildly impaired subjects were able to improve from a profile similar to Fig 2 (B) to a profile closer to Fig 2

(C) in a single session of therapy using the SynPhNe platform. Notable among these was subject SS5, who progressed to lifting up a bottle filled with water. Although it is known that stroke patients may show true recovery (same muscles used for specific actions as pre-stroke) or behavioural recovery (through the use of compensatory muscles), current clinical rehabilitation practices cannot make a visual distinction of true and maladaptive strategies [5]. Such a differentiation was clearly visible in this experiment as illustrated by Fig 2. The subjects could also use this feedback to improve their SEMG activation profiles.

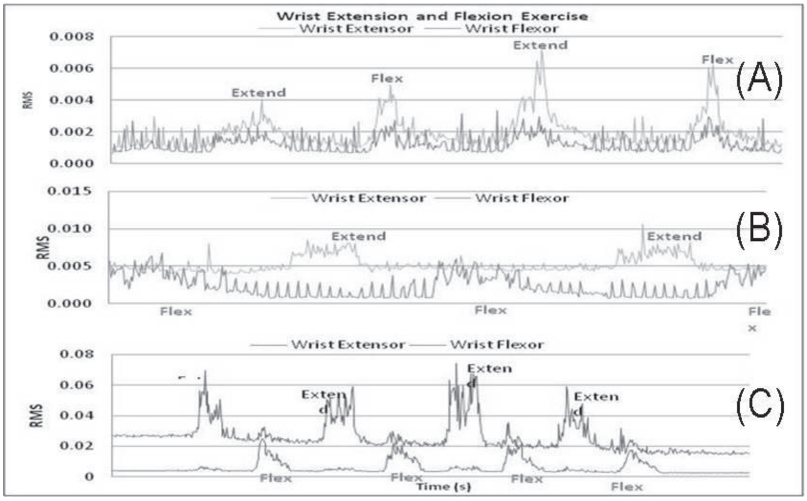

Fig 2. Sample agonist-antagonist SEMG RMS plot for wrist extension and flexion (A) high co-contraction in wrist extension (B) moderate co-contraction in wrist extension (C) functionally differentiated agonist-antagonist action.

The other muscle groups showed similar self-regulated changes particularly finger extensors and pronator. The supinator was the most difficult to sense clearly and also to regulate volitionally. Only subject SS7 could engage wrist flexors clearly and repeatedly. He used the platform to do increased number of repetitions on extensor and flexor muscles and decided to use the platform as an endurance trainer.

This study demonstrated that the use of SEMG was not only able to identify when compensatory muscles are being used, but also which muscle groups were adopting maladaptive synergies. The patient was consequently able to self-correct.

4.2 Therapy Outcome Observations

Visual observation of the experiments threw up some interesting results. It was found that the single session therapy of approximately one hour resulted in gains for several patients. It was decided to collate these observations to see which group of patients adapted fastest to the system and was able to "self-correct" or "self regulate" based on the biofeedback they received. The summary of these results are shown in Table III for severe, moderate and mildly impaired patients respectively.

Most of the severely affected patients with flaccid arms were unable to perform the exercises. However, every subject was taken through the entire task practice sequence. Subject SS1, with Fugyl Meyer score only 21, was able to see the weak muscle contractions in her arm and by manipulating the hand position was able to achieve a pronation, supination movement. She also managed to extend fingers by trying to achieve a higher SEMG trigger, but could not extend thumb. Thus she was able to supinate and approach a bottle for task practice but was unable to grasp. Subject SS1 was motivated to try the tasks for a full 50 minutes after seeing such immediate, incremental progress. The subject SS3 noticed that the slight movement he managed to generate was actually by using compensatory muscle strategies. He learned to arrest this tendency and reported higher motivation due to a better understanding of the muscle activation process.

Table III Summary of Single Session Outcomes – gains in various activities

Stroke subject	Impairment	Able to Induce Relaxation	Single joint movement	Multi-joint movement	Task practice
SS1	severe	no	Pronation, finger extension	Open grasp	Approach bottle with open grasp
SS3	severe	no	Corrected compensation	Restrained compensation	No gains
SS6	severe	no	No gains	No gains	No gains
SS8	severe	no	No gains	No gains	No gains
SS2	moderate	yes	Pronation, finger extension	SEMG peaks	SEMG peaks
SS4	moderate	yes	Pronation without compensation	Two finger pinch	Lifted and transferred pen
SS5	mild	yes	Pronation, finger extension	Open grasp	Grasped and lifted full water bottle
SS7	mild	no	Wrist flexion, finger flexion	More repetitions	More repetitions
SS9	mild	yes	Pronation without compensation	Open grasp, pinch	Lifted bottle, used chop sticks

In the moderately and mildly affected subjects, one of the consistent gains was the reduced SEMG baseline activity induced by the relaxation instruction. Imitating the mirror image and self-correcting based on biofeedback resulted in subject SS4 picking up a pen for the first time post-stroke. Both patients managed to execute pronation without compensatory use of the elbow after reading the biofeedback. This compensation showed up as an absence of peaks in the pronator muscle biofeedback screen. The mildly affected subjects were also able to achieve a lower SEMG baseline in the relaxation exercise. Compensation in pronation and finger extension was substantially self-corrected after 5-6 attempts. Subject SS5 and SS9 were able to attempt successfully the lifting of a water bottle filled with water and the picking up of an object with chopsticks respectively, for the first time post-stroke. This was very encouraging and both patients left the experiment room highly motivated.

5. Conclusions and future work

Several patients made visible breakthroughs in simple movements and tasks in a single session and all except two severely impaired subjects showed gains in self-regulating appropriate muscle synergies. The SEMG data analysed demonstrated that healthy and stroke subjects have an innate ability to self-regulate their muscle use strategy to improve functional outcome. The results point in favour of the hypothesis that an attempt to tap redundant neural pathways using mirror-image visual input combined with SEMG biofeedback may enable actively participating hemiplegic patients to make significant breakthroughs in motor function recovery very early in therapy. A larger study is urgently needed to further validate this theory and translate into clinical practice for stroke therapy.

Acknowledgements

The authors wish to thank the staff of Robotics Research Centre, NTU, Singapore, and Tan Tock Seng Rehabilitation Centre, Singapore, for the use of their facilities in the conduct of this project. The study was sponsored by grant NIG/0024/2008 of NMRC Singapore.

References

[1] Venketasubramian, N, 1999. Stroke in Singapore – An overview, Singapore Medical Journal, Singapore, 1999. 40(1). Extracted on 24.06.2012 from http://www.sma.org.sg/smj/4001/articles/4001ra1.html

[2] Cardiovascular Disease and Stroke Care, Centre of Excellence in Health Disparities, Morehouse School of Medicine. Extracted on 27.05.2012 from http://web.msm.edu/EXPORT/stroke_facts.htm

[3] "Stroke Statistics", extracted on 21.06.2012 from http://www.strokecenter.org/patients/stats.htm

[4] Lenze,E.J., Munin, M.C., Quear, T., Dew, M.A., Rogers, J.C., Begley, A.E., Reynolds, C.F., 2004. Significance of poor patient participation in

physical and occupational therapy for functional outcome and length of stay. Archives of Physical Medicine and Rehabilitation, 85, Pg. 1599–1601.
[5] Timmermans, A., Seelen, H., Willmann, R., Kingma, H., 2009. Technology-assisted training of arm-hand skills in stroke: concepts on reacquisition of motor control and therapist guidelines for rehabilitation technology design, Journal of NeuroEngineering and Rehabilitation ,6, 1.
[6] Witte, O.W., 1998. Lesion-induced plasticity as a potential mechanism for recovery and rehabilitative training, Current Opinion in Neurology, 11(6), Pg. 665-662.
[7] Kwakkel, G., Kollen, B.J., Grond, J.V., Prevo, A.J.H., 2003. Probability of regaining dexterity in the flaccid upper limb: Impact of severity of paresis and time since onset in acute stroke, Stroke, 34, Pg. 2181-2186.
[8] Van Peppen, R.P.S., Kwakkel, G., Wood-Dauphinee, S., Hendricks, H.J.M., Van der Wees, P.J., Dekker, J., 2004. The impact of physical therapy on functional outcomes after stroke: what's the evidence? Clinical Rehabilitation, 18(8), Pg. 833-862.
[9] Bach-y-Rita, P., 2001. Theoretical and practical considerations in the restoration of functions following stroke, Topics in Stroke Rehabilitation, 8(3), Pg. 1-15.
[10] Rizzolatti, G., Craighero, L., 2004. The mirror–neuron system, Annual Review of Neuroscience, 27, Pg. 169-92.
[11] Gelfand, I.M., Latash, M.L., 1998. On the problem of adequate language in motor control, Motor Control, 2(4), Pg. 306-313.
[12] Banerji, S., Heng, J., Pereira, B.P., 2012. Facilitating early onset of therapy after stroke: An arm glove design for assessment and self-regulation of biomechanics in motor function recovery, accepted at The International Conference on Rehabilitation and Assistive Technology, iCREATe 2012, Singapore, July 2012.
[13] Raichur, A., Wihardjo, J., Banerji, S., Heng, J., 2009. 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, AIM 2009, Pg. 1998-2003.
[14] Heng, J., Banerji, S., 2010. A Step towards Multi-level Human Interface Devices: A System that responds to EEG/SEMG Triggers, International Journal of Biomechatronics and Biomedical Robotics, 1(2), Pg. 93 - 98.
[15] Kaplanis, P.A., Pattichis, C.S., Hadjileontiadis, L.J., Roberts, V.C., 2009. Surface EMG analysis on normal subjects based on isometric voluntary contraction, Journal of Electromyography and Kinesiology 19, Pg. 157-171.
[16] Heng, J., Banerji, S., 2010. Low Usage of Intelligent Technologies by the Aged: New Initiatives to Bridge the Digital Divide, Jeffrey Soar (Ed.) , "Intelligent Technologies for Bridging the Grey Digital Divide", IGI Global Publishers, NY., Pg. 188-206.