Facilitating Early Onset of Therapy after Stroke: An Arm Glove Design for Self-Regulation of Muscle Activation

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ABSTRACT

Rehabilitation of hand function after stroke is known to be more effective if the patients are able to start therapy as early as possible in the acute phase. The solution may be a system with biofeedback capabilities that guides the patient in practicing hand movements while recording important data for tracking progress at biomechanical levels.

The arm glove that is described in this paper is part of a wider project to develop a unified EEG/SEMG platform for stroke rehabilitation. The SEMG electrodes used inn the glove were gel-free, thus reducing set-up time. Signal distortion was found to be within acceptable limits. Various hand actions in healthy subjects were successfully detected with sufficient differentiation. The muscle activation SEMG threshold for triggering the biofeedback games was found to lie within a comparable range for most subjects. The system could be calibrated for all subjects to enable them to respond to the biofeedback games and reduce incorrect muscle activation. This may be useful to stroke patients in acute phase since they can start active therapy sitting up or lying down.

General Terms

Design, Human Factors.

Keywords

surface electromyography, SEMG, stroke, arm glove, orthosis, unified platform.

1. INTRODUCTION

The number of deaths and discharges for stroke from Singapore hospitals has been steadily rising over the past 30 years. There was more than a two-fold increase in the number between 1986 and 1996 [1]. Every 45 seconds someone in the USA suffers a stroke [2]. With rising numbers of stroke patients, there will be an increased demands on rehabilitation therapists. This will subsequently raise their duties and responsibilities and affect attention given to patients, especially in the crucial acute phase.

Most of the recovery in hemiplegia after stroke takes place in the 4 weeks immediately after stroke [3]. The earlier therapy starts, the greater the chances of full recovery [4]. Therapy is usually in the form of passive motion and is manually conducted by the therapist, who constantly encourages the patient to try to use his muscles and residual strength. Early start of such "active" therapy minimizes the learned non-use of the affected arm.

2. SYSTEM DESCRIPTION

The Biofeedback Arm Glove is a 8-channel surface electromyography (SEMG) acquisition system that can be ramped up to 16 channels if required. The same glove can be modified to be usable on both arms if necessary. The current prototype is made from medical-grade fabric anti-edema tubing and is constructed in two layers. The lower layer which is in contact with the skin contains the contact electrodes and the upper layer provides support and houses the electrode cables as they travel along the length of the arm to the data acquisition circuit which is housed below the table for this experiment set up.

The contact electrodes are 10mm diameter button type Ag/AgCl discs and used in combination with shielded electrode cables (Bio-Medical Inc. USA). The electrode is directly in contact with skin with no pre-gelled adhesive patch used. This makes the glove very easy to put on. No electronic components are mounted on the electrode. The differential signal is detected with the two electrodes being 28 mm apart in this case for most of the muscles except at the thumb flexor where we space the two electrodes at 20mm. This seems to give reliable and detectable signals in nearly all the cases tested with this type of "dry" setup. Thus, we found that we had to deviate from general recommendations for electrode spacing as per SENIAM standards [5]. The only electrode where we used an adhesive pre-gelled patch was the ground reference electrode positioned at the elbow. The arm glove is shown in Fig. 1. The inter-electrode distance is maintained by templates. Hence the inter-electrode distance does not change as the glove stretches. The same glove gave reliable signals for a hand with large and small wrists and elbows. Male and female subjects all used the same glove on the right hand.

It has been established that bio-potentials like SEMG and electroencephalography (EEG) require faithful amplification before they can be analyzed [6]. The bio-potentials (SEMG) from the patient are picked up by the electrodes and passed through a protection circuit. Ag-AgCl electrodes are chosen since they provide a stable transition with low noise and are available commercially [7]. The protection circuit guards the user and also isolates the circuits downstream from electrostatic discharge [8], [9], [10]. There are capacitors which suppress radio-frequency signals that might enter the cable. A network of double-diodes and resistors perform the protective functions. After the protection circuit, the bio-signal gets amplified with a gain factor by a high quality instrumentation amplifier (TLC279 LinCMOS precision quad operational amps) from Texas Instruments Inc. USA). One of the problems of recording SEMG is that the measured signals are often corrupted by low and high frequency interferences [11]. Amplification is carried out in several stages, as a result of which the design of the first stage becomes crucial. If it is not designed well, the system will pick up more noise which will be amplified further by the following stages. This will cause highly undesirable distortion of the signal to be monitored. An instrumentation amplifier is hence used in the first stage due to its various advantages suitable for medical instruments [11]. The detailed design of this circuit was reported by the authors earlier [12],[13].

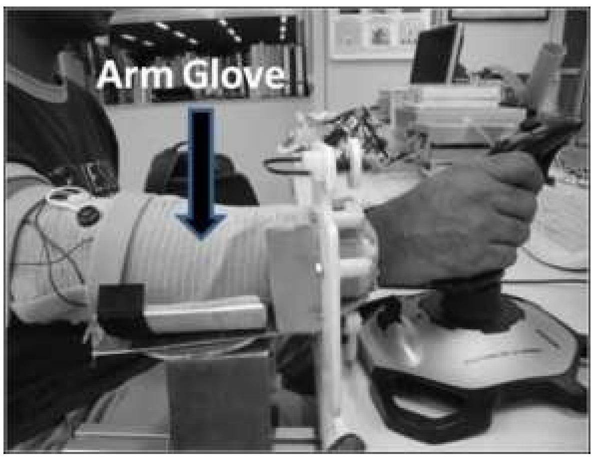

Figure 1. Table top set up of arm glove with joystick

Software issues were greatly reduced by adopting LabView 8.0 (From National Instruments Corporation, USA) as a development platform for the entire project. This circuit, which will receive bio-potential signal, will be connected with NI-USB 6259, a multi I/O interface (National Instruments Inc. USA), which interfaces with the computer.

The USB-6259 has as many as 32 analog input terminals, 4 analog output terminals, 32 digital pins, 16-bit A-D converters and two 32-bit counters [14]. 8 of the analog input terminals are used for connecting to the interface circuit (2 sets of 4 channel circuits). 8 digital output pins are also connected to the interface circuit to control the working mode (SEMG or EEG) of each channel. This feature has been incorporated to make it possible to record both SEMG and EEG simultaneously for future experiment as part of the Unified Platform concept [12]. The block diagram explaining the setup is shown in Fig. 2.

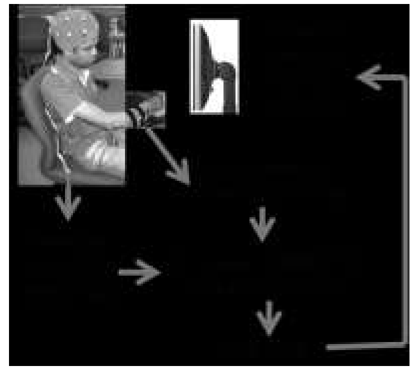

Figure 2. Unified platform setup showing SEMG glove and signal flow path up to the monitor which displays the biofeedback.

Once the signals are acquired into LabView, the triggers (thresholds) for use in the guided therapy games can be calibrated for the user. This calibration may involve further gain and trigger setting for each channel separately for an individual. After the calibration, the GUI takes over to guide the user through movements involving isometric, single joint and multiple joints. The GUI enables the patient or therapist to set intensity levels, number of repetitions, audio cues, visual assist, video guidance. The game set up is shown in Fig. 3.

Figure 3. Gaming setup with biofeedback arm glove

3. RESULTS

A trial equipment test was conducted by generating signal in LabView 8.0 (running on Windows XP, Pentium 4 PC with 1.5 GB RAM) and give input to the circuit through the analog outputs of the USB-6259. The frequency of this signal was varied over a range which covers the expected range of SEMG signals. The outputs from the circuit were measured and gain calculations were made in LabView. The frequency response of the circuit boards was then plotted in LabView (Fig. 5).

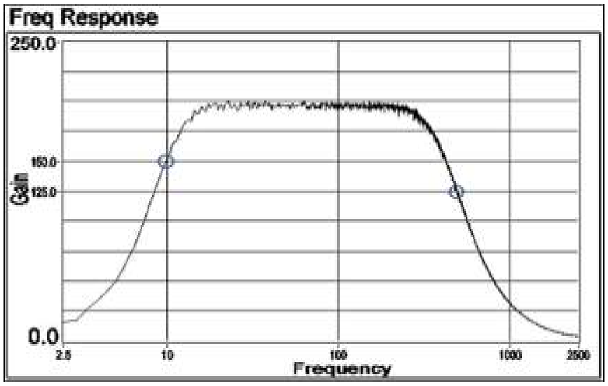

Figure. 5. Frequency response of actual PCB in SEMG mode

A negligible amount of distortion was observed in the curve, due to the effects of real-world measurement conditions like sampling noise of digital-analog converter in the USB-6259 and random environmental noise. The cut-off frequencies are indicated by the circles on the graph in Fig.3. The gain at the lower cut-off frequency (10 Hz) is approximately 150, while at the higher cut-off frequency (500 Hz) it is about 125. Between them, which is the expected range whereby the SEMG signal would present (10Hz – 500 Hz), gain of the system is approximately 200. This is an acceptable performance for SEMG measurements [14]. Details of the EEG mode response have been reported earlier by the authors [15]. The EEG recording helps to monitor important neurological parameters for progress monitoring and biofeedback.

For performance verification, it was decided to measure the SEMG response of wrist extension. Wrist extension is one of the major challenges for those with post-stroke hemiplegia. The electrode positions for measuring extension were set up as suggested in [5]. It was found that the triggers were more distinct and repeatable when the inter-electrode distance was maintained as mentioned earlier. Fig. 6 shows the SEMG response measured by a 9V battery operated version of the proposed prototype. It can be clearly seen that the proposed system can produce triggers which are stable and sensitive.

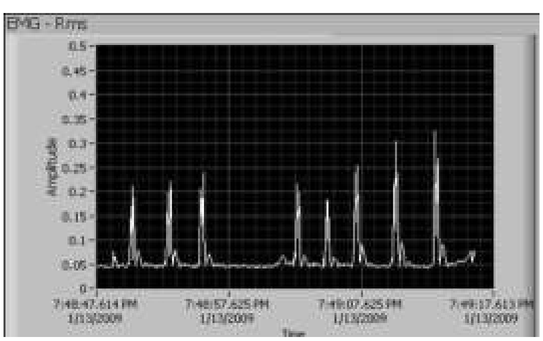

Fig.6. Front panel of LabView Program for Active Mode Rehabilitation

SEMG signals from five healthy persons were measured, and it was found that the system was sensitive enough to detect even small finger movements and isometric contractions. Gain could be adjusted if the SEMG signals were weak. Or else, the threshold could be lowered in any channel to assist in achieving the trigger. Once this was established, we proceeded to extend the glove to a two layer 8-channel system. The muscles targeted for standard therapy exercises are listed in Table I.

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

	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 next set of experiments with 10 healthy subjects in the age group 25-74 involved recording 8-channel SEMG in resting state, in a relaxation state and then during hand and arm movements. Movements were categorized into single joint and multiple joint movements. This was followed by task practice which included two-finger pinch, cylindrical grasp and four finger pinch.

Table II. Additional software gain and average thresholds set for healthy subjects in the age group ranging 25-74 years

	Muscle	Gain Range	Average Threshold Amplitude (Gain=1)
1	Extensor carpi ulnaris	1-2	0.02 V
2	Flexor carpi ulnaris	1-4	0.02 V
3	Extensor digitorum	1-8	0.015 V
4	Flexor digitorum profundus	1-8	0.02 V
5	Pronator teres	1-2	0.02 V
6	Supinator	1-4	0.02 V
7	Opponens pollicis	1-2	0.02 V

Table II shows the average trigger thresholds of the SEMG signals which were found for the concerned muscles as well as the gains that were required in the software, over and above the fixed gain provided in the hardware circuit. For subjects exhibiting involuntary co-contraction, the thresholds could be modified to still give unique triggers.

As seen from the table, additional gain was required in some cases, particularly the finger extensors and the supinator. These two muscles seemed to be bypassed and compensated for either by a different set of muscles or by exaggerated medio-lateral elbow movement. In all except one, after a few trials, the required muscle could be engaged and relaxed using the biofeedback. Unexpectedly, signals were found to be clearer in case of healthy elderly subjects as compared to some younger subjects. This may be due to thinning of skin due to old age among other reasons. This will be an advantage since a large majority of the stroke patients are elderly. The elderly subjects were physically active and engaged in manual work, which could also contribute to well differentiated signals. Most subjects found some difficulty to activate the pronator and supinator muscle. A compensatory elbow movement was used. Under resistance, the said muscle activation was detected by the system. In the elderly subjects, there was some difficulty in wrist extension during time of assessment prior to experiment. However, after seeing the feedback on the computer screen, they were able to activate the wrist extensor sufficiently to achieve the same trigger threshold as the younger subjects.

This paper is primarily to explain the construction of the arm glove. Detailed experimental results related to task based SEMG of healthy and stroke patients will be reported in subsequent papers.

4. CONCLUSION

The primary objectives of versatility, low-cost and portability for the 8-channel SEMG system were satisfied by the prototype. The signals from the various muscle channels were repeatable and the same electrode locations on the glove could accommodate a wide variety of hand sizes. This glove prototype excludes the need for supervised electrode set-up and multiple cables, if one needs to track functional tasks in therapy. Being light, it can facilitate early start to therapy and teach the patient to minimize compensatory muscle activity in the early stages of post-stroke recovery. The development of a compact I/O card to replace the USB-6259 will further lower the price and increase portability.

5. ACKNOWLEDGMENTS

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