

Effects of Regent Suit on Lower Limb Electromyographic Patterns of hemiparetic subjects

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Abstract – During human walking, the muscle activity of the lower extremities needs to be well coordinated to provide support, dynamic balance, propulsion, and foot clearance. Clinical aspects of patients who are hemiplegic as a result of stroke vary according to the damaged region of brain tissue, its size, and the cause of damage. Functional recovery of limb mobility of patients with spinal or cerebral injuries can take great advantage of the basic role played by sensorial and proprioceptive stimulations. On this base the Institute of Biomedical Problems of the Russian Academy of Sciences have recently developed the “Regent Suit” (RS), an experimental medical device derived from a suit worn by astronauts for therapeutical purposes during space flights. Although preliminary studies describe rehabilitation outcome of the RS in stroke, EMG changes induced by the suit are not known. Aim of the paper is to describe the effects of RS on lower limb EMG patterns on hemiparetic subjects.

I. INTRODUCTION

In healthy subjects, the temporal characteristics of gait related to muscle activity follow rather stereotyped patterns. As consequence of cerebral injury, such as hemiparetic disease, the temporal order of muscle activity during walking is often disrupted, either through impairments in the central control of the timing of muscle activity, or through the development of compensatory neuromuscular strategies [1]. Clinical aspects of patients hemiplegic as a result of stroke vary according to the damaged region of brain tissue, its size, and to the cause of damage. Gait of hemiparetic patients is characterized by several abnormal features. Among the more common timing abnormalities found in hemiparetic gait are the absence or reduced amplitude of specific components of the activation pattern (e.g. the burst around the transition from swing to stance in Tibialis anterior) [2;3], abnormal muscle tone such as lower limb hyposthenia and abnormal muscle activation patterns, mostly affecting the paretic side [4;5]. Moreover one of the most frequent

clinical outcome following traumatic brain injury is represented by an asymmetric gait. In particular the hemiparetic gait is characterized by slow and asymmetric steps with poor selective motor control, delayed and disrupted equilibrium reactions and reduced weight bearing on the paretic limb having a shorter stance time and step length than that of the non-paretic limb [6-8]. These impairments limit mobility, increase risk of falls and impose higher energy demands for basic daily living activities [9].

Recently, studies have correlated these pathological motor disturbances to those observed in astronauts exposed to the long-term negative effects of the absence of gravity caused to the neuro-muscular-skeletal system during space flights. On this base the Institute of Biomedical Problems of the Russian Academy of Sciences in Moscow developed the “Regent Suit” (RS), an experimental medical device specifically designed for neurological patients’ rehabilitation and derived from a special suit worn by astronauts for therapeutical purposes during space flights[10]. RS is used for repeated rehabilitation sessions of patients with movement disorder of central genesis in the form of hemiparesis, tetraparesis and ataxis disorders due to strokes as well as craniocerebral injuries. Several electromyographic studies have been conducted to obtain information on the patterning of lower extremity muscle activity in hemiparetic gait but literature reports only preliminary studies describing outcome of intensive rehabilitation application of the RS in stroke patients [11]. So, the understanding of the changes induced by the use of the suit on the electromyographic (EMG) pattern is poor and no previous papers addressed such issue, whose analysis would be a basic prerequisite for a correct therapeutic use of the device. The diagnostic information offered by EMG gait analysis is mainly related to functional and pathophysiological characterization of gait disturbance, representing the sole opportunity for a direct analysis of locomotor commands issued to individual muscles responsible for progression and dynamic stabilization of

axial segments.

The aim of this paper is to describe the effects of RS on lower limb EMG patterns in hemiparetic subjects modelling the electromyographic linear envelope as summation of un-normalized Gaussian pulse.

II. MATERIALS AND METHODS

A. Experimental set-up

We studied 4 hemiparetic patients. (3 males, 1 female, mean age 41 yo). All subjects underwent a session divided in two phases, each consisting of four recordings of a straight walk of 10 steps.

In the first phase, subjects have been instrumented by surface EMG electrodes and footswitches. Four EMG channels have been acquired by a wireless BTS Freemg 300 system with variable geometry mounting clip surfaces electrode, 16-bit resolution, 1 kHz sampling rate, in the 20-400 Hz frequency band, over the main muscles involved in walking and exactly: Soleus (SL), Tibialis Anterior (TA), Semitendinosus (ST) and Vastus Lateralis (VL). All surface EMG recordings have been performed according to related SENIAM recommendation [12]. With a fifth wireless channel, the gait cycle (GC) has been recorded by four BTS Freemg300 system footswitches, applied under the soles of the feet.

In a second phase, subjects have been assisted in wearing the suit, paying attention to the previous placement of the electrodes. RS has been mounted in the same standard configuration for all subjects, regulating by locking buckles similar elastic loading elements (ELE) pre-indentation tension amount measured by a digital hand-held tension meter.

The therapeutic effect of RS is based on the creation of premeasured amount of afferent proprioceptive stream (principle of dynamic proprio-correction). Sanogenetic effect of therapeutic suit is realized via mechanical impact on the patients' body effected by ELE which create a central load on the musculoskeletal system causing specific mobilization of certain muscle groups. RS is composed by four main supporting elements: vest, shorts, knee-caps and straps, mutually interconnected by means of a set of six types of ELE (Figure. 1)



Figure 1. a) RS configuration and b) wireless EMG electrodes positioning

B. Emg Signal Processing

EMG analysis has been offline performed by LEG-Lab, a Matlab software package developed by authors and specifically designed for EMG gait analysis. LEG-Lab provides automated functionality of signal pre-processing, features extraction by Gaussian decomposition and final data reporting of recorded sessions of gait analysis independently for each muscle signal.

Pre-processing consisted of several main steps; at first it has been extracted the linear envelope (LE) computed rectifying and filtering signals via a low-pass Butterworth 8 poles filter with 10 Hz cutoff frequency [13]. In Figure 2 is shown the LE of the EMG signal of TA muscle for one of the subjects studied.

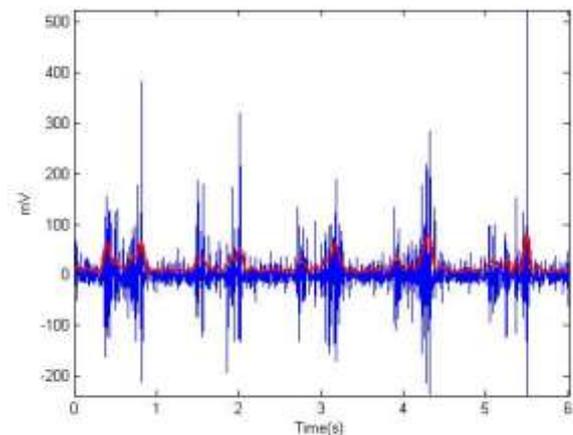


Figure 2. LE of the left TA EMG signal.

Then the analysis has been performed by means of the following steps:

- 1) LE segmentation in gait's epochs (LES) on the base of automatic recognition of the beginning of the steps via the signal provided by footswitches; 2) first and last two LES removal, in order to exclude accelerating or decelerating steps, limiting the analysis from the third to the eighth step; 3) time normalization of LES (TNLES) by linear interpolation or decimation to reconstruct each signal epoch with the same number of 1024 data points; 4) amplitude normalization of all TNLES (TANLES) by peak dynamic method [14], namely expressing each step as a percentage of its maximum value, to get EMG signals comparable between muscles and subjects and improve their sensitivity as diagnostic tool in gait analysis [15] and finally 5) overall averaging of all TANLES (ATANLES).

Although the ATANLES describes the overall muscle activation profile over the step, this curve is often too complex to clearly identify activation patterns and more concise temporal features have been considered. First, macro activations have been automatically detected as intervals on ATANLES exceeding three times its

standard deviation for at least 50 ms and therefore identifying EMG ON-OFF times. Then, ATANLES has been modeled as summation of un-normalized Gaussian pulses of various length [16]. Aim of this decomposition is to identify the various phases of envelope so that the latter could be expressed in mathematical terms according to the expression:

$$y(x) = \sum_{i=1}^M \frac{\alpha_i}{\sqrt{2\pi\sigma_i^2}} \exp\left[-\frac{(x - \mu_i)^2}{2\sigma_i^2}\right] \quad (1)$$

where α_i is the amplitude of the basic function, μ_i and σ_i are respectively the mean and standard deviation of the Gaussian function and the Expectation–Maximization algorithm [16;17] was used for parameter estimation.

A precise reconstruction of the EMG LE requires a large number of component phases. The phases which correspond to a significant proportion of activity in the EMG LE are defined as dominant phases while the others as non-dominant. A threshold was computed as area under the envelope between ON and OFF timing divided by the number of components minus one. Then, phases with area greater than this threshold were identified as dominant phases and the one having the highest amplitude is called the peak phase. The position μ_i of the peak phase (defined in percentage of the whole GC) was considered as a temporal identifier of muscle activation and compared to the EMG LE peak (as can be seen in Fig. 2), results more robust with respect to outliers, involving a considerable underlying muscle activity [18;19].

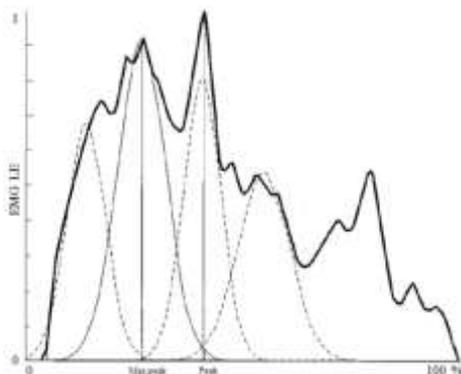


Figure 3. Example of the analysis over the gait cycle. EMG LE represented with black thick line. Peak phase in continuous line and other dominant phases as dashed Gaussian.

III. RESULTS AND DISCUSSIONS

EMG gait analysis has been performed on 16 pairs of recordings, with and without regent suit. 4 of them have been discarded from results, due artifacts on EMG signal caused by movements of parts of the suit over the electrodes.

Due to skewness of data distributions (positions μ_i in the two groups of recordings, without and with RS),

differences between medians have been tested by Wilcoxon matched-pairs signed rank test (WLC).

Results shown in the table I allow to get the three following findings. The proprioceptive stimulation of the RS delays both TA and ST activation timing toward more physiological values of the late GC phase, although this effect showed a statistical significance between medians only for the ST (WLC $p < 0.005$). The effect on SL mainly appeared as synchronizing; medians of activation times without and with RS do not differ, but the whole distribution converge towards more physiological values of about the 40% of the GC. Data on VL have been correctly analyzable only in 8 recordings. However, results showed a moderate but significant (WLC $p < 0.05$) timing anticipatory effect of the RS toward more physiological values of the early GC phase. Pairing between data is effective, and without and with RS measurements significantly vary in a coherent way (Spearman r values ranging from 0,4 to 0,7 with $p < 0,05$ for all except TA).

Table I. peak phase values for all studied muscles. data expressed as mean, 25% and 75% confidence interval

	SL		TA	
25%Perc.	6.3	26.8	4.0	58.8
Median	36.0	36.5	44.5	66.5
75%Perc.	70.5	49.0	70.3	70.5
Wilc. test	ns		ns	
RSperm	0,5(0,027*)		0,1(0,338)	

Table II. Peak phase values for all studied muscles. data expressed as mean, 25% and 75% confidence interval.

	ST		VL	
25%Perc.	4.3	49.5	4.0	58.8
Median	11.0	73.0	21.5	15.5
75%Perc.	17.5	90.5	71.8	48.5
Wilc. test	<0,001***		0.04*	
RSperm	0,4 (0,045*)		0.7(0,004**)	

RS is an innovative device which might provide a significant contribution in the gait rehabilitation process. Comprehension of its effects on EMG patterns is at the base of a correct clinical use of the device.

Preliminary results on the studied subjects showed in fact that, when RS is used, an overall shifting peak EMG timing activations towards more physiological values [20] of the GC is observed.

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