Does FES of Triceps Surae affect the Activation Patterns of other lower leg muscles? A healthy subject pilot study

Monaghan CC 1, Veltink PH 1, Tenniglo MJB 2

1 University of Twente, Enschede, the Netherlands
2 Roessingh Rehabilitation Centre, Enschede, the Netherlands

Email: c.c.monaghan@utwente.nl

Abstract

Until now, research into the effects of FES has focussed on biomechanical changes. However, questions remain unanswered, as to how the stimulation of one muscle group effects the muscle activation patterns of other leg muscles of not only the stimulated side, but also the other side of the body. The purpose of this abstract is to give some preliminary insight, and to highlight that even with healthy subjects the muscle activation patterns of both legs are affected, when FES has been applied to the tibial nerve during gait.

1 Introduction

Much research has been carried out during functional electrical stimulation (FES) of the leg muscles, the most commonly known is the drop foot stimulator. So far, many researchers have approved or disapproved of stimulation techniques due to the change in gait pattern, improved angle ranges, and even the physical cost index. However, in literature no investigations have been carried out of the effects of FES on the activation patterns of other muscles.

With CVA subjects, until very recently, EMG was measured only of the paretic leg. Work of Shiavi [1] has concentrated on observing how activation patterns of muscles from both legs change during stroke recovery, with results indicating that the “healthy” leg muscles change their activation patterns as well as the paretic side. With this being the case, if FES is applied to the plantarflexors of the paretic leg of CVA subjects, to improve push-off, how does the muscle activity of the paretic leg muscles, and the non-paretic leg muscles change? The long-term goal of this current research is to answer this question.

In the short term, this abstract presents the findings of the effect of surface FES on the plantarflexors of a healthy subject with surface stimulation on the tibial nerve, at the popliteal fossa region behind the knee. This paper will demonstrate that preliminary findings suggest that the leg muscles of both legs have been affected by FES of one muscle group.

2 Methods

2.1 Equipment

EMG system: Porti-5 16 channel unipolar EMG from TMS International. The configuration used allows bipolar signals to be measured in real time. Sample frequency: 2048Hz. Amplitude range: 22bit, resolution 71.9nV. Gain: 20x CMRR: > 90 dB. Input impedance: > 10^12 Ohm Noise: < 1.5µVpp. Recorded using the ambulant-setup with a PCMCIA card to allow subject to walk freely.

Arbo solid gel EMG electrodes, oval shaped, 22mm x 35mm, interelectrode distance of 20mm.

MT9 inertial sensors and Xbusmaster from Xsens Motion Technologies B.V., sample frequency of 100Hz, baudrate of 115k2bps. One MT9 sensor contains (3x) accelerometers, gyroscopes, magnetometers (arranged such that 3D acceleration, angular velocity and magnetic field are measured) and one temperature sensor. Recorded using bluetooth configuration allowed the subject to walk free of constraints.

Custom-built custom-programmed 8-channel bi-phasic electrical stimulator with an imbedded controller to control stimulation timing. Stimulation parameters were modified via bluetooth for safety reasons; the stimulator must not be physically connected to a mains supply. The stimulator and busmaster were connected serially to allow real-time accurate timing of the stimulation [2].

2.2 Subject Preparation

During the experiment, EMG was recorded from 8 muscles although in this abstract, only 4 will be discussed. Muscles measured were rectus femoris (RF), semitendinosus (ST), tibialis anterior (TA) and gastrocnemius
mediialis (G) of both legs. EMG electrodes were applied according to SEMIAM [1] recommendations. The area to be measured was shaved, then cleaned abrasively with alcohol. When dry, self-adhesive Ag/AgCl electrodes (details above) were applied. An MT9 sensor attached to a Perspex strip, in order to avoid skin motion artefact, was then fixed to the lateral shank for stimulation control.

2.3 Experimental Procedure
The experimental procedure involved A) "Without stimulation" gait trials. The subject walked back and forth over a force plate in the gait lab approximately 10 times. Approximately 5 steps were taken per recording. Timing parameters required for stimulation were noted from the MT9 measurements. B) Stimulation Optimisation: Subject stood on a force plate, stimulation parameters were optimised i.e., a noticeable force and movement were generated. Stimulation was applied to the popliteal fossa region behind the knee. C) Stimulation gait: the subject walked across the force plate, as in part A, but with stimulation applied at every step. This cycle of “A-B-C-5 minute break” was repeated, until three stimulation times were measured. The stimulation time to be discussed in this abstract is 10° after heel strike [2]. The “A” trials (after the first batch) were reduced to 5 times back and forth to reduce the chance of fatigue.

2.4 EMG processing
EMG data was band passed filtered, with a high-pass filter of 5Hz and a low-pass filter of 2kHz, then processed in Matlab. The values given are the band-passed signal standard deviations. To assist in finding the burst times, the signal was full-wave rectified and smoothed. When either the raw or the enveloped data was above 50µV, a burst was assumed, and the standard deviations and burst times of the raw EMG were taken. N.B., the standard deviation was not calculated while stimulation artefact was present, as this would change the standard deviation values.

2.5 Statistical Analysis
The standard deviations and burst durations were put through an ANOVA test (P<0.05). Empty cells, were treated with the Tukey All pairwise multiple comparison procedure.

3 Results
Figure 1 shows an example of two trials; figure 1A shows the gastrocnemius (dark line) and the tibialis anterior (grey line) of the ipsilateral leg. Figure 1B is the gastrocnemius and tibialis anterior of the contralateral leg, over the same time interval. Figures 1C and D show the same muscles, measured with stimulation applied at each step. The overall duration has been kept constant, (5s) although as it is a different trial, obviously the actual time differs. The figure indicates two individual trials, but are consistent with all recorded trials. The figure highlights the agonist/antagonist activity of the gastrocnemius and tibialis anterior. Figure 1C shows that the electrical stimulation is present when the ipsilateral gastrocnemius (heavy black line) is most dense. From this block of stimulation, it can be seen that stimulation was applied too early and that the physiological burst of the gastrocnemius came when the stimulation effect had gone. The bursts clearly show that the amplitude has significantly increased, while the burst duration has significantly decreased. This is highlighted quantitatively below.

Table 1 shows the average of the calculated standard deviations and Table 2 shows the average burst times, for the ipsi- and contra-lateral gastrocnemius and tibialis anterior, with and without stimulation. Contra and ipsi-lateral T.A. standard deviations failed the equal variance test, so ANOVA was not possible with these values.

Table 1: Shows the Values for Mean Standard Deviations without stimulation and with stimulation 10 degrees after heel strike.

<table>
<thead>
<tr>
<th></th>
<th>NO STIM 1</th>
<th>STIM 1</th>
<th>NO STIM 2</th>
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<tbody>
<tr>
<td>Ipsi- G</td>
<td>190 ± 23</td>
<td>220 ± 33</td>
<td>194 ± 10</td>
</tr>
<tr>
<td>Ipsi- TA</td>
<td>98</td>
<td>102</td>
<td>100</td>
</tr>
<tr>
<td>Contra- G</td>
<td>195 ± 27</td>
<td>241 ± 31</td>
<td>174 ± 11</td>
</tr>
<tr>
<td>Contra-TA</td>
<td>116</td>
<td>123</td>
<td>122</td>
</tr>
</tbody>
</table>

Table 2: Shows the Values for Mean Burst Durations without stimulation and with stimulation 10 degrees after heel strike.

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<thead>
<tr>
<th></th>
<th>NO STIM 1</th>
<th>STIM 1</th>
<th>NO STIM 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ipsi- G</td>
<td>0.37 ± 0.05</td>
<td>0.2 ± 0.03</td>
<td>0.36 ± 0.03</td>
</tr>
<tr>
<td>Ipsi- TA</td>
<td>0.59 ± 0.05</td>
<td>0.52 ± 0.03</td>
<td>0.58 ± 0.03</td>
</tr>
<tr>
<td>Contra- G</td>
<td>0.39 ± 0.04</td>
<td>0.38 ± 0.04</td>
<td>0.38 ± 0.03</td>
</tr>
<tr>
<td>Contra-TA</td>
<td>0.59 ± 0.07</td>
<td>0.41 ± 0.09</td>
<td>0.54 ± 0.04</td>
</tr>
</tbody>
</table>

Table 1 shows that with the onset of stimulation, the mean standard deviation of the stimulated gastrocnemius increased significantly from 190 to 220µV. When
stimulation was removed, the mean standard deviation became 194\(\mu V\), this decrease is not significant. Table 2 shows that this pattern of activity occurred over a significant burst-width change from \(~0.4s\) to \(0.2s\) and re-increased to \(~0.4s\) with no stimulation.

The ipsilateral tibialis anterior activity changed from 98 to 102 to 100\(\mu V\), this is not significant. Table 2 shows that the TA pattern change was over a significant change in burst time, from \(~0.6s\) to \(~0.5s\) to \(~0.6s\).

The activity of the contralateral gastrocnemius increased significantly from 195 to 241\(\mu V\) and subsequently decreased to 174\(\mu V\) with stimulation removal. This change was not related to a change in burst duration (table 2).

With the contralateral tibialis anterior activity, the standard deviation did not change significantly (table 1) but the burst duration significantly decreased from \(~0.6s\) to \(~0.4s\) and again back to \(~0.5s\) when stimulation was removed.

4 Discussion and Conclusions

The results above indicate that FES of the triceps surae, as expected effects not only the activation pattern of the stimulated muscle, but also the activation patterns of other leg muscles of both legs. It can be said that the effect is strongest in the stimulated leg muscles, because both burst duration and standard deviation of activity of the gastrocnemius was changed with application of the stimulation. To a lesser degree, the muscles of the other leg muscles have been effected, demonstrating changes in either burst width or standard deviation of the burst.

Future processing of the EMG will entail matching gait-cycle events. A major drawback of this work is that this was not done here. The investigation into this FES application in stroke subjects is the main question where this pilot study has relevance. As stroke subjects already exhibit asymmetry in their gait patterns and EMG patterns, it will be interesting to explore the effects of stimulation on the triceps surae on the gait patterns and their EMG patterns. It is also necessary to investigate the effect of randomising the stimulation patterns (with and without stimulation as well as randomised timing) to determine the rate of change of muscle activation patterns, which is the next step of this research.

References


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