The use of patterned stimulation for reducing fatigue in FES systems

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Abstract: The rapid onset of muscle fatigue is one of the major problems when using electrical stimulation to restore functional movement in individuals with a neurological deficit. It has been proposed that a variable frequency train (VFT) of stimulus pulses (consisting of repeated doublets) can produce higher force output than a constant frequency train and that this results in reduced muscle fatigue. The aim of this study was to test this hypothesis. Experiments were conducted on non-impaired subjects and spinal cord injured subjects. It was shown that a VFT produces an increase in muscle output and was optimal for doublets with an inter-pulse interval of 5ms. However this effect was highly dependent on the intensity of stimulation and there was no benefit in using a VFT at high intensities. We propose that any benefit shown using a VFT is due to change in motor recruitment, resulting from oscillations in muscle output when using the VFT, and is not an intrinsic property of the muscle. Our results show that there is little benefit of using VFTs for alleviating the problem of fatigue in functional electrical stimulation systems.

I. Introduction: It has been proposed that a variable frequency train (VFT) of stimulus pulses (consisting of repeated doublets) can produce higher force output than a constant frequency train (CFT) stimulation[1,2]. The aim of this study was to investigate the validity of the above suggestion under diverse stimulating conditions and to investigate inter-subject variability.

II. Methodology: Fifteen non impaired subjects (12M, 3F, mean age 26 and age range of 20-36 years) and one spinal cord injured subject (C5/6 incomplete lesion) were recruited. The participants were tested in an adapted wheelchair with one knee held flexed at 60 degrees by strapping the shank to a strain gauged cantilever bar fixed to the wheelchair. Surface stimulation was applied to the quadriceps muscles of the subjects to generate isometric contractions, using circular (75mm diameter) self adhesive stimulation electrodes. The active electrode was located over the femoral triangle and the indifferent electrode was placed 3cm proximal to the patella. The moment around the knee was measured during the contraction and the resulting signal from the strain gauges was amplified and sampled by a 12-bit A/D card fitted to an IBM compatible PC which also controlled the stimulation.

III. Protocols: Two main protocols were applied.

Protocol 1: Optimisation of doublet IPI. A 2 second VFT consisting of doublets with random doublet IPI followed by a 2 second rest and a 2 second CFT of the same average frequency was generated. This was applied repeatedly for different IPI values.

Protocol 2: Effect of intensity on improvement produced by VFT. Starting with high intensity of stimulation, Protocol 1 was repeated at the optimal IPI for 30 times and the intensity of stimulation was reduced between each repetition.

IV. Analysis: Maximum Moment (MM) and Force Time Integral (FTI) were calculated for each 2 second stimulus period. The ratio (VFT : CFT) for these parameters was calculated for each pair.

V. Results: There was a large degree of variation in the FTI ratio profiles between individual subjects (fig.1). In all cases there was a maximum in the FTI ratio at a doublet IPI of 5ms although this ratio ranged from 1.02 to 1.57 (VFT : CFT).

Using the VFT with optimum IPI on a particular subject showed a large improvement on MM and FTI which diminished as the intensity of stimulation increased to a feasible maximum (fig2).
By decreasing the intensity levels in a stepwise fashion there was a consequent increase in the FTI and MM ratios arising from a VFT with a doublet IPI of 5ms (fig3). As shown in figure 4, the actual moment profile generated by the VFT exhibits a considerable ripple at half the frequency of stimulation and the relative increase of the generated moment with respect to that generated by the CFT stimulation disappears as the intensity of stimulation increases.

VI. Discussion: A possible explanation for the level of improvement seen at low intensity could be related to the oscillations produced by the VFT. Because the intensity levels that were applied were low enough to activate only a fraction of the axons in the nerve bundle any slight movement would dramatically alter the recruitment of motor units. We believe that this mechanism is predominantly responsible for the increase seen in force output using the VFT at low intensity.

VII. References: