ESTIMATION OF CONTROL STRATEGIES ADOPTED BY ELITE FES ROWERS

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INTRODUCTION

Functional electrical stimulation (FES) rowing was initially proposed as an alternative form of total body exercise for paraplegics in order to increase fitness and reduce mortality due to cardiovascular disease (Wheeler 2002). It has developed to a stage where teams regularly compete in national and international indoor competitions, and FES sculling on water has been successfully demonstrated. The effectiveness of FES rowing as exercise is well established (Hettinga and Andrews 2007; Velleren et al. 2007).

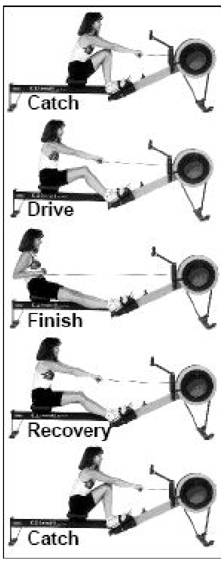

Figure 1: Phases of a complete FES rowing cycle.

The FES rowing cycle, shown in Figure 1, is performed by the coordination of voluntary upper body movements with FES generated movements of the rower's paralysed legs. While athletes have trained themselves to perform very effectively by developing rowing cycles through practice, until recently there has been little experimental data objectively detailing the control strategies they adopt. To address this, we have developed a data acquisition system to measure the many relevant variables and used it to study the performance of an elite FES rower (age = 51yr, bodyweight = 70kg, injury level = T4/ASIA A, time since injury = 6yr, total FES rowing training = 4yr), by phase plane analysis, the results of which we present here.

METHODS

A Concept 2 indoor rowing machine has been modified to provide increased trunk support, constrain leg motion to the sagittal plane and protect knee joints against impact. Shock absorbers are fitted to the seat safety stops in order to dampen impact and assist in momentum transfer from one phase to another (Hettinga and Andrews 2007). A single rower operated push switch controls 4-channels of electrical stimulation to the rower's leg muscles. When the control switch is closed the stimulator activates the quadriceps causing leg extension. Similarly, when open the switch allows stimulation of the hamstrings causing leg flexion.

String (potentiometer) sensors provide seat and handle position data. A National Instruments NI USB-6008 12 bit data acquisition unit, in conjunction with a PC running custom software developed in LabVIEW, simultaneously records seat and handle position data together with the state of the control switch. The software also calculates seat and handle velocity values from the corresponding position data using a Savitzky-Golay algorithm.

RESULTS AND DISCUSSION

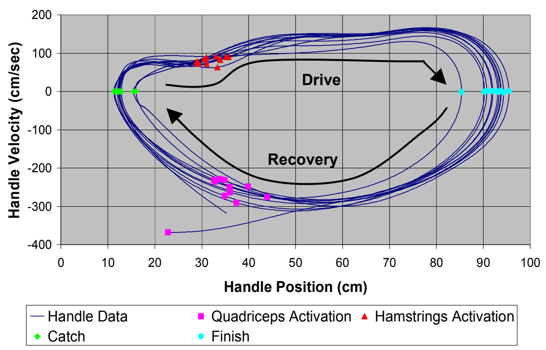

Figure 2: Handle velocity v handle position.

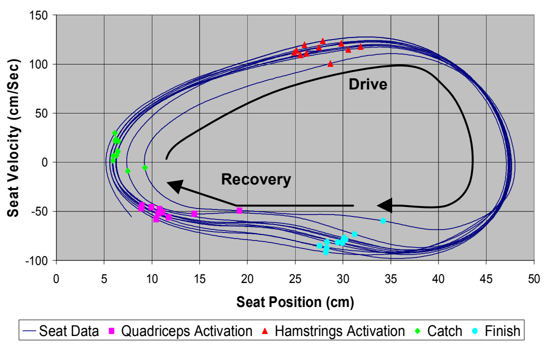

Figure 3: Seat velocity v seat position.

Phase plots of velocity against position for the handle and seat respectively over 10 complete rowing cycles are shown in Figures 2 and 3.

Table 1: Mean time taken and variance of rowing phases

Phase	Mean Time	Variance
Drive	0.811 sec	0.000903
Recovery	0.481 sec	0.000931

It can be seen that the rower switches at regular points on the cycle with very low variance. The curves are smooth with no sudden zeros in velocity. It is also noted that the switching points (i.e. quadriceps and hamstrings activation) occur before the extremes of motion (i.e. catch and finish).

SUMMARY/CONCLUSIONS

The subject appears to use anticipatory control, a learned skill in which the subject continuously predicts the system dynamics and state of fatigue of the stimulated muscle. The legs extend under load applied via the handle. In each stroke the rower loads the legs through the handle force to control the speed of the drive. If too much handle force is applied against the stimulated quadriceps the motion will be sluggish or may stall. As the quadriceps strengthen with use, the rower will impose increasing levels of handle force to regulate the motion. Thus the quadriceps always work under maximal loading. Furthermore, FES activation of quadriceps during late "recovery" will first cause an eccentric contraction (where the quadriceps are lengthening whilst contracting and act like springs) to decelerate the forward motion, then concentric contraction during "drive". Eccentric force actions will generally involve greater force actions than concentric contractions for the same FES stimulus intensity. This pattern of loading may have implications in training the quadriceps muscle properties and may explain long term changes (>1 yr) we have observed.

REFERENCES

Hettinga D., Andrews B.J. (2007). *Neuromodulation* **10**, (3), 291-297.

Verellen J. et al. (2007). *Disability and Rehabilitation: Assistive Technology* **2**, (2), 127-132.

Wheeler, G.D. et al. (2002). *Archives of Physical Medicine and Rehabilitation,* **83**, 1093-1099.