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Towards the Development of Full Motion FES Rowing with Accurate Ergometry: RowStim IV

Brian J. Andrews, Robin Gibbons, Simon Goodey, Adrian Poulton and James Shippen

Abstract A FES Rower is presented that is closer to normal rowing. The system uses the Concept2 ergo but, based on our error analysis, the performance monitor that estimates distance rowed from measured power may not be accurate enough for competitive events.

I. INTRODUCTION

FES Rowing involves electrical activation of the paralyzed legs of individuals with spinal cord injury. In its present form, based on an adapted Concept2 (C2) air damper ergometer, this was developed at the University of Alberta in the early 1990s, [1]. The RowStim series has been developed to improve both cardiovascular and bone health for individuals with spinal cord injury in one physical exercise. Variants have also been developed both for international indoor rowing competitions (BIRCs and CRASH-Bs) and for on-water demonstrations [1].

FES rowing represents a significant cybernetic control challenge, in which there is a close man-machine interaction in which human energy is transferred to the machine to achieve therapeutic and performance goals. Presently, in the RowStim III, only an approximation able-bodied rowing styles can be achieved - the kinematics are visibly quite different, mainly because the rower's trunk is fixed by mechanical constraints.

Performance goals have, in part, driven our continued development of the RowStim series ergo mechanics and FES control systems to ever closer approximate normal rowing styles. Performance has been monitored using the existing and widely adopted C2 performance monitor that is embedded into the C2 ergo. Medals are awarded on the basis of performance in competition. Training is also based on performance monitoring. Performance is measured quite differently in on-water and indoor rowing events.

In on-water rowing events it can usually be seen visually who the winners are. However, sometimes it is only fractions of a second that separate gold from silver. Accurate performance measurement is therefore critical in order to resolve medal placement for these events. On water rowing relies on accurate timing, better than 0.01s, and very accurate photo finish. For example, in the Rio Olympics, in the men's 2,000m single sculls 0.001s, about 4.2cm, separated the gold and silver medalists with the decision being based on a photo

finish.

Indoor rowing events use stationary ergometers, usually the C2 type, and medal placement relies on estimates made on distance rowed by each competitor as the event proceeds. In the C2 ergometer, distance is calculated from velocity which in turn is estimated from the measured power. The accuracy of the C2 power measurement, is subject to error [2]. However, despite the widespread adoption of the C2 and its performance monitor for indoor rowing events, the authors are unaware of any accuracy specification or error sensitivity analysis. FISA regulates both on water and indoor rowing events and regulation 14.2.2 specifies the ergometer monitor, however, there no consideration is given to its required accuracy [3].

Here we present our progress in FES rowing in the development of a new prototype rower (RowStim IV) and an initial assessment of the C2 performance monitor for its accuracy in FES rowing.

II. METHODS

A. Trunk Rotation and the prototype RowStim IV

Normally the trunk is free to rotate during rowing. Rotation produced by hip and spine motion has the effect of increasing stroke length as illustrated in Fig. 1. The sagittal angulation is normally between 60-80 degrees, corresponding to an increase in stroke of $L \cdot \sin(70)$ where L is the trunk length (hip shoulder joints).

Fig. 1. A graphical illustration of the increase in stroke length as a result of sagittal trunk angulation.

In able bodied rowing power is contributed by the arms trunk and legs in the proportion arms 22.4%, legs 46.4% and trunk 30.9% [4]. In FES rowing using the RowStim III the

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corresponding figures are arms 80%, 20% legs and the trunk making no contribution.

A new FES rowing system is being developed as part of the RowStim series, in which the trunk is not fixed but can rotate in the sagittal plane. This can accommodate the full range of motions for the four basic styles of rowing [4]. The trunk and legs are stabilized medio-laterally and the stroke normalized in terms of length and stroke rate. This arrangement enables the hip extensors to usefully contract using FES. The trunk musculature may also be activated.

Fig. 2. Prototype of the new RowStim IV. The seat backrest allows full range of anterior posterior trunk rotation. The trunk and legs are stabilized mediolaterally using a telescopic support.

B. Error Analysis for the C2 Performance Monitor

Indoor rowing competitions use an estimate of the distance rowed to determine the award of gold, silver or bronze medals. In the C2 performance monitor distance rowed is based on a measurement of mechanical power using an assumption expressed in equation (1). The exact methods used by C2 are proprietary, however, Van Holst [5] suggests a plausible derivation of this relationship based on the physics of ergometer rowing. Assuming that the relationship between the power P and the speed of the boat v holds then:

$$v = 0.71\sqrt[3]{P} \dots (1)$$

If the distance of the rowing event is D , the duration, t will be

$$t = D/0.71\sqrt[3]{P}$$

the sensitivity, dt/dP , of the duration to the power is:

$$\frac{dt}{dP} = \frac{D}{2.13P^{2/3}} \dots (2)$$

Fig. 3 Error sensitivity for equation (2) over a range of average powers for various rowers, including FES rowers.

In FES rowing, using the RowStim III, individuals with SCI have attained up to approximately 75W [1]. It can be seen that the sensitivity to error increases over this lower power range.

For example, if the error in measuring power is say 10%, then FES rowing at say 75W, would observe an error of $75 \times 0.1 \times 2.96 = 22.2s$, which we consider too much.

III. DISCUSSION

The prototype RowStim IV is visually very close to able bodied rowing. The seat mechanism allows for full sagittal trunk motion, with medio-lateral support. The stroke length and rate of FES rowers can be normalized. It remains to be determined if computer controlled electrical stimulation of the hip and ankle extensors, in addition to the presently used quadriceps, can increase performance over 2,000m. However, adding bulk to the hip extensors should help to reduce pressure sore risks and the extra muscle activity should further improve cardiovascular and bone health benefits.

Estimating rowed distance using equation (1) is sensitive to measurement error, particularly in the lower power ranges that includes FES rowing. This suggests a need to develop a more accurate ergometer performance monitor, so that medal placements can be made with similar accuracies used in on-water events.

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