FIELD MEASUREMENT OF BIOMECHANICAL PERFORMANCE

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The time course of joint moments and powers during competitive performance are helpful variables for pinpointing the involved major muscle groups, estimating total mechanical energy expenditure and mechanical efficiency, and identifying the magnitude and timing of unnecessary joint power absorption. These measures are also useful for understanding the mechanisms of injury and thus planning and training for their minimisation. Simulation of sporting movements in the laboratory is useful but never reaches the validity of testing in field conditions. However, field instrumentation must meet additional criteria imposed by the environment and the necessity to minimize interference with the athlete's performance. This session will propose some solutions for field testing of athletes.

KEYWORDS: field measurement, motion analysis, technology, inverse dynamics

INTRODUCTION & OVERVIEW:

Background: The combination of biomechanical theory and measurement tools enables biomechanists to describe sporting movements in detail and deduce mechanisms of high performance. Potentially, with adequate measuring equipment, the sport scientist can output time series net joint moment and power data for all important joints of the body. Power generation and absorption can be pinpointed and mechanical efficiency calculated. Once the mechanisms are known, evidence-based training programs can be designed to produce more efficient or effective performance. For example, once it is known that the knee exerts a flexion rather than extension moment in the middle of the rowing drive phase (Smith & Milburn, 1996), the deadlift is exposed as a non-specific strength training modality for the lower limbs. This evidence could only be obtained from inverse dynamics or electromyographic analysis. The issue of what information and how this should be fed back to the coach and athlete will not be dealt with here.

Sports: Track and field events may be performed indoors and more laboratory-oriented measurement systems can be employed. Nevertheless, the SESAME project (http://www.sesame.ucl.ac.uk/) shows how unconventional this can become. Equestrian, cycling and aquatic sports do not lend themselves easily to traditional biomechanical measurement systems and it is in these areas that new technologies will have the highest impact. Further, cycling, rowing, flatwater kayak, canoe, dragon boat feature one or more fixed connections between the athletes body and the vehicle creating the possibility of utilizing these constraints to simplify the measurement system without losing accuracy.

Technology: Developments in microelectromechanical systems, GPS, wireless, microprocessors, batteries, standardisation of communication protocols and software support have opened up a vast array of possibilities for unobtrusive but detailed biomechanical measurement of many sporting movements. Commonly available GPS is now capable of a data rate of 10 Hz and position accuracy of 2.5 m in a 9g 22 x 22mm package.

The aim of this paper is to describe some useful technology for motion analysis in the field and give some examples of its successful application.

METHODS:

Orientation and Position: Inertial measuring units (IMUs) are now low cost (~US$100), accurate (± 1°) and have a high angular velocity rating (1200 °/s). They can be three dimensional and output acceleration, angular velocity, and heading or angular position and linear position. They are small and light and can be conveniently attached to body segments as small as the hand. They can be wireless (appropriate for one or two). From practical experience, a fifteen segment system should be hard-wired to a central wireless transmitter in a harness or attached to the athlete by a belt.

If the segment is expected to rotate through more than 180º, quaternions could be used rather than Euler angles to avoid the gymbal lock problem. The quaternions can be transformed back to Euler angles once the data has been collected.

Force: Portable force platforms can be constructed from three dimensional transducers sandwiched between two carbon fibre sheets. Our most recent attempt had an accuracy of <1% for all dimensions but required a minimum of four transdcuers. Centre of pressure can also be computed.

The problem is much simpler if one dimension is required. There are many small and light one-dimensional transducers available.

For sweep rowing particularly, three dimensional force sensing is desirable especially for the pin force. However, in flatwater kayak the footbar and seat force are adequately measured in the propulsive direction only. For cycling, there are a number of crank torque transducers available.

Telemetry: On-body and/or on-board telemetry can be combined to provide a minimally wired system. Bluetooth can be used for short range and Wifi 802.11b/g/n for distances up to a km or two (Figure 1.).

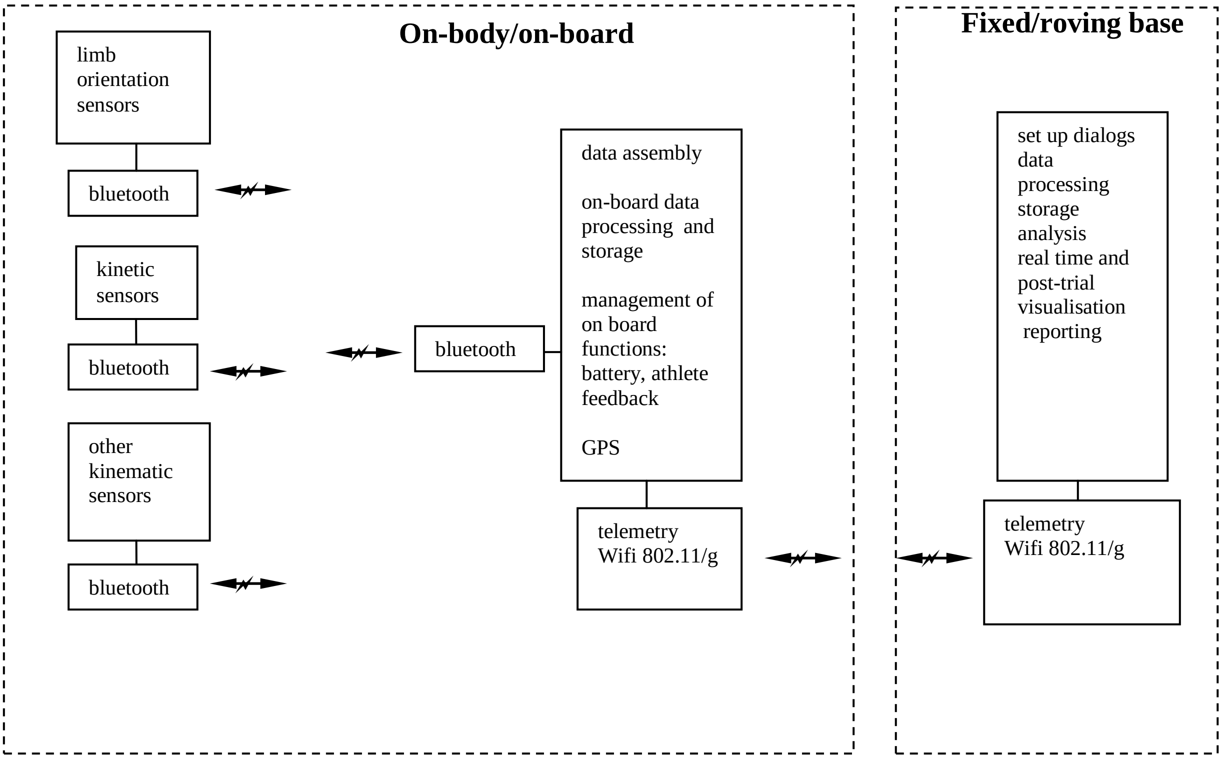

Figure 1. Configuration of wireless motion capture and analysis system.

RESULTS:

Dragon Boat: Elite dragon boat paddlers have more efficient paddle strokes than sub-elite paddlers (Figure 2.) (Ho et al., 2009). The data for this result was obtained using calibrated strain gauge transducers mounted on the inside of the paddle shaft. Equation 1 was used to calculate the efficiency.

$$Efficiency = \frac{\Sigma\left(\Delta \mathrm{Energy}_{\mathrm{propulsive}}\right)}{\Sigma\left(\Delta \mathrm{Energy}_{\mathrm{total}}\right)} = \frac{\Sigma\left(\mathrm{Force}^{\mathrm{blade}}_{\mathrm{propulsive}} \times \Delta \mathrm{Distance}^{\mathrm{blade}}_{\mathrm{propulsive}}\right)}{\Sigma\left(\mathrm{Force}^{\mathrm{blade}}_{\mathrm{normall}} \times \Delta \mathrm{Distance}^{\mathrm{blade}}_{\mathrm{normal}}\right)} \qquad \text{(equation 1)}$$

The paddle strain gauge outputs were conditioned electronically and input to an analog to digital module before sending to a custom telemetry device operating in the 900 MHz band.

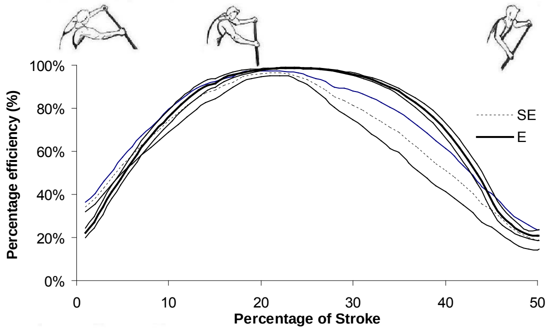

Figure 1. Average (±95% confidence interval) dragon boat paddling efficiency of sub-elite (SE) and elite (E) groups during the drive phase (normalised to one stroke).

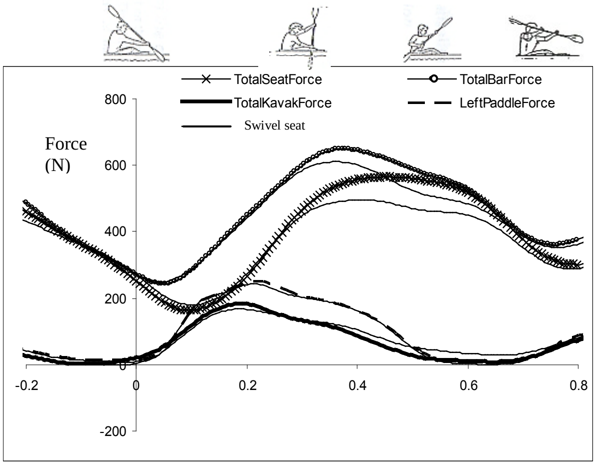

Figure 2. Flat water Kayak paddling. One stroke with the left paddle in the fixed seat compared with the swivel seat (thin solid lines).

Flatwater Kayak: The net propulsive force on a single kayak was measured on-water while the paddler was using a fixed seat then a swivel seat (Figure 2.). The footbar force, seat force and the normal paddle force were measured in one dimension. The average force on the footbar and seat is less for the swivel seat. The knee extension muscle force would be less on average and leads to a greater capacity for power output for a given metabolic cost (Michael et al., 2010).

Rowing: The transverse pin forces in a pair boat cause an unbalanced moment about a vertical axis which potentially would cause boat yaw. The on-water instrumentation system reveals that pair rowers minimize boat yaw by compensating for the unbalanced horizontal plane moment by differentially manipulating the magnitude of the propulsive force on the pins (Figure 4) (Smith and Loschner, 2002). Three dimensional piezoelectric force transducers were used at the pin. The outputs were electronically conditioned and input to an analog to digital module that provided serial output to a custom telemetry unit. Total power output to the boat can be calculated (Figure 5).

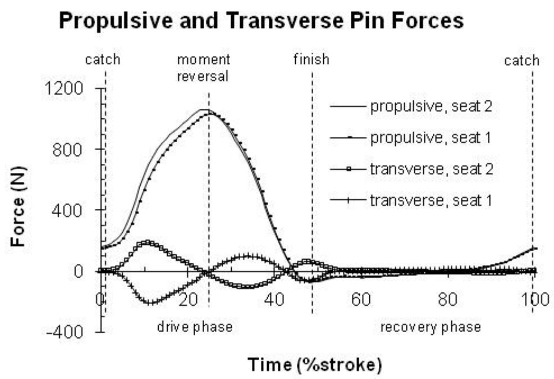

Figure 4. Propulsive and transverse pin forces for elite rowers in a pair boat. The unbalanced moment caused by the transverse forces is compensated for by the magnitude and timing of the propulsive force.

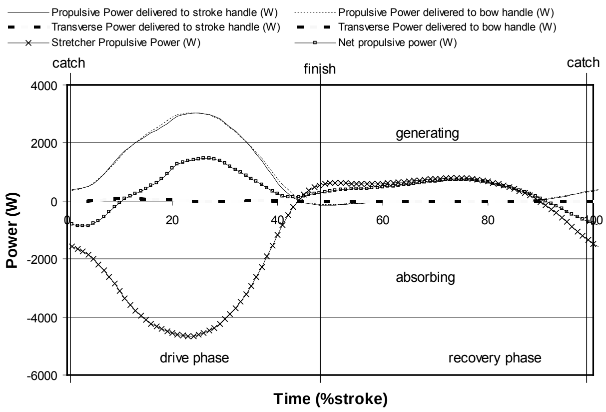

Figure 5 Ensemble average pair power output time series at 30 strokes per minute.

PRACTICAL APPLICATIONS:

The information gathered by the described systems can be used for crew selection as part of a performance tracking system or individually tailored for individual athletes and their coaches. Particular aspects of the athletes technique can be targeted, a plan made for the changes required and further measurements conducted to see if those changes have been learned.

More research work needs to be carried out into the selection of information that is used for feedback to the coach and athlete and into the different methods of providing the feedback. The systems described in this paper have the potential to provide real time feedback of raw and calculated data for both athlete and coach. For example a single number could be calculated that is an estimate of the efficiency of the rowing stroke at the completion of each stroke. Alternatively the time series of force(s) or angle(s) could be presented in real time. No research has been conducted yet which helps with this decision-making process.

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