Kinematics of the upper and lower extremities in three-dimensions during ergometer rowing

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Introduction

Although the two-dimensional kinematics of the lower and upper extremities and trunk during ergometer rowing has been studied by many [(Nelson & Widule, 1983) (Martindale & Robertson, 1984) (Kaya et al., 1995) (Kaya, 1996) (Kyröläinen & Smith, 1999) (Pudlo, 1999) and (Hawkins, 2000)], the anatomical segment paths and ranges of motion are not reported explicitly in the literature. Nelson and Widule (1983), Martindale and Robertson (1984), and Kyröläinen and Smith (1999) present the results of work, energy and power analyses only. In Hawkins’ (2000) development of a dry-land rowing system which can provide feedback to the rower, he describes the attachment of four single degree-of-freedom electrogoniometers to a rower’s hip, knee, ankle and elbow, but he does not report any angular data.

Documented kinematic ranges of motion can be found only in two unpublished theses: one in Japanese from Keio University (Kaya, 1996), referred to in an abstract (Kaya et al., 1995); the other in French from L’université de Valenciennes et du Hainaut-Cambrésis (Pudlo, 1999). Kaya (1996) collected the two-dimensional trajectories of ten markers on the right side of the body. The results show the hip joint of the skilled rowers to have a range of 80º flexion and that of the non-skilled rowers to have a range of 60º flexion. The results at the knee for both the skilled and non-skilled rowers showed a range of motion of 100º flexion. Pudlo (1999) collected sagittal-plane kinematic data for the wrist, elbow, shoulder, ankle, knee and hip. The results show the elbow to have an average range of motion of 100º. There are no wrist and shoulder ranges presented. In the lower limb, the hip has a range of 50º, the knee a range of 120º, and the ankle a range of 50º.

The aim of the present study is to document the three-dimensional kinematics of the whole body during ergometer rowing. Such data is important not only for studies of rowing technique and performance, but also for use as input to models of the musculoskeletal system which can calculate the forces in the anatomical structures of the joints and limbs. Our particular motivation is to gain further insights into normal rowing so that we may development new control strategies for rowing after spinal injury by means of computerised functional electrical stimulation.

Methods

A twelve-camera Vicon 524 motion analysis system (Vicon Motion Systems, Oxford, UK) was used to capture kinematic data at 120 Hz. Eighty-one passive retroreflective markers of 14 mm in diameter were attached to the subject (Figure 1). These markers define the body embedded co-ordinate systems (BCS) and anatomic co-ordinate systems (ACS) of seventeen segments plus the ergometer. In a static standing trial all markers were attached, and transformation matrices between the ACS and BCS were calculated using a least-squares algorithm (Veldpaus et al., 1988). This same algorithm was used in the rowing trials to calculate the movements of the seventeen segments relative to their standing anatomic position. Flexion-extension, abduction-adduction and internal-external rotation kinematics of the joints of the upper and lower extremities were calculated using the joint co-ordinate system (JCS) (Cole et al., 1993).

Five healthy male rowers aged between 22 and 34 with between three and five years of university rowing experience were tested. The rowers had the kinematic markers attached and their heart rate was taken. The static trial was captured as the rowers stood in the anatomic position (Figure 1). A warm up at 20 strokes per minute (spm) was performed for five minutes and the heart rate was allowed to return to within five beats of resting. Rowers stroked at 16, 20, 24, 28 and 32spm in a randomised order. At least four trials of at least three successive strokes were captured for each rower. Between different stroke rate
trials, the heart rate was allowed to return to within five beats of resting to ensure that all data collection was obtained in the absence of fatigue.

The start and end of each rowing cycle was determined from the anteroposterior velocity of the marker on the right lateral femoral condyle. For the data analysis, each rowing cycle was time normalised to 0-100%, with drive starting at 0% and recovery finishing at 100%.

![Figure 1](image)

**Figure 1**: Marker placement for three-dimensional kinematic measurement.

**Results & Discussion**

Figures 2 and 3 include the ensemble averages ± one standard deviation of the lower extremity motions of one trial from four rowers and the upper extremity motions of one trial from two rowers, all rowing at 24 spm. Results are presented for one stroke rate only since the three-dimensional kinematics of ergometer rowing did not change significantly at different cadences (p<0.01). The joints of the lower limb all have significant out-of-plane movements, particularly long-axis (internal/external) rotations (Figure 2). The joints of the upper limb also undergo motion in all three dimensions (Figure 3). The patterns of motion reported here are comparable to the two-dimensional ones previously documented (Kaya, 1996) (Pudlo, 1999), although the ranges of motion reported here tend to be larger. It is possible that the shoes worn by our rowers influenced marker motion at the ankle and forefoot, resulting in an overestimation of their ranges of motion. It is also possible that previous analyses have underestimated the hip, knee, ankle and elbow actual motions by assuming only two-dimensional motion.

**References**

Kaya, M. Master of Science thesis, Keio University, Japan, 1996.
Figure 2: Three-dimensional kinematics of the lower extremity ensemble averaged for 0-100% of the rowing cycle from four rowers at a cadence of 24 spm.

Figure 3: Three-dimensional kinematics of the upper extremity ensemble averaged for 0-100% of the rowing cycle from two rowers at a cadence of 24 spm.

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