COMPARISON OF ON-WATER ROWING WITH ITS SIMULATION ON CONCEPT2 AND ROWPERFECT MACHINES

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The purpose of this study was to identify biomechanical differences and similarities between on-water rowing and its simulation on Concept2 and RowPerfect rowing machines. Handle force, positions of the handle, seat and trunk, shell acceleration were measured in single scull and on both machines in five female rowers. It was found that the rowers applied 30% - 40% higher handle force on both machines than on-water. Stroke length was 11%-12% shorter on both machines, which mainly occurred by means of 30% shorter arms drive. Legs drive was 4% - 6% longer on Concept ergo-meter than on both RowPerfect and on-water. Significant differences were found in the handle velocity and shell acceleration profiles. Machines should be considered as a cross-training for rowers and can not replace on-water rowing.

KEY WORDS: rowing, biomechanics, ergometer, comparison

INTRODUCTION: Rowing machines are widely used for cross-training and physiological testing in rowing. Concept2 rowing ergo-meter became the most popular machine during the last decade. Providing obvious visual similarity with on-water rowing, exercise on machines has significant mechanical differences (Martindale & Robertson, 1986, Lamb, 1989). The main difference is stationary position of the foot-rest that dramatically increases inertia forces during shuttle movement of the rower on the sliding seat. Moreover, rowing on stationary machines like Concept2 increases probability of knee and low back injury (Bernstein et al., 2002).
ROWPERFECT rowing simulator was invented to overcome these problems (Rekers, 1993). This machine has a mobile foot-rest connected to a power absorption unit (aero-brake). A number of world class rowers achieved good results using ROWPERFECT for cross-training. The study of Elliott et al., 2002 attempted to prove similarities between rowing in the boat and on ROWPERFECT machine. The study found similarities in individual force profiles and differences in kinematics of the legs movement. However, it did not noticed differences in magnitude of the handle force and the handle velocity profile.
The main purpose of this study was to reveal and explain biomechanical differences between on-water rowing and its simulation on Concept2 and ROWPERFECT machines, which can affect the rowers motor control pattern and their on-water rowing technique.

METHODS: The measurements were conducted using RowBot-3 data acquisition system (12 bit, 25 Hz).The handle force in the boat was measured using a custom made strain-gauged transducer mounted on the oar shaft. On both rowing machines the handle force was measured using modified E-Row system (WEBA Sport, Austria). All force transducers were dynamically calibrated using SB0-200 load cell (Davidson Measurement, Australia) connected in parallel to the RowBot3 system.
Oar angle during rowing in the boat was measured using conductive-plastic potentiometer (6538, Bourns). Handle position ***L*** was derived from the oar angle ***A:***

$$L = A\ Rin.a \qquad (1)$$

,where ***Rin.a*** is actual inboard length of the oar, equal to

$$Rin.a = Rin. - HL/2 + GW/2 \qquad (2)$$

,where ***Rin.*** is a real inboard (0.88m), ***HL/2*** half of the handle length (0.06m), ***GW/2*** half of the gate width (0.02m).
Seat and trunk positions were measured using custom made transducers, which were based on spring-loaded multi-turn potentiometer (3590, Bourns) and pulley connected with low-stretchable line to the seat or trunk at L1-C7 level.

Accelerations in longitudinal axis of the boat and mobile unit of the ROWPERFECT machine were measures using accelerometer ADXL202 (Analog Devices) inbuilt in the RowBot3 unit. The data was stored in a portable PC in real time. Pair of radio-modems was used for transmitting the data during on-water measurements.
Five female rowers participated in the study. The average height of the rowers was 1.80 ± 0.4 m, body mass 72.2 ± 3.6 kg.
The rowers performed the similar tests on-water in single sculls, on RowPerfect and on Concept-II rowing machines. Two 90 sec samples of data were collected during each test session:

- the first sample at a training stroke rate around 20 str/min,
- the second sample at a racing stroke rate around 32 str/min.

Analysis Methods: The collected data was normalized in time and typical biomechanical parameters were produced (Kleshnev, 1996). Derivative numerical values were derived using the typical parameters (Table 1). Finally, typical biomechanical parameters were averaged in all five rowers for evaluation of the differences between exercises (Figure 1).

RESULTS: Maximal force applied to the handle on both rowing machines was 27% - 30% higher at the training stroke rate and 34%-40% higher at racing stroke rate. Average force on ergo-meters was 19% - 22% and 25% - 26% higher, correspondingly. There were no significant differences found between Concept and RowPerfect ergo-meters.
Rowers executed 11% - 12% shorter stroke on stationary ergo, which mainly occurred by means of 30% shorter arms drive. Legs drive was 4% - 6% longer on Concept ergo-meter than on both RowPerfect and on-water. Differences in the trunk travel were insignificant.

Table 1 Derivative numerical values of rowing at training and racing stroke rates.

	Parameters	Boat		RowPerfect		Concept2	
	Rate	Training	Racing	Training	Racing	Training	Racing
1	Average Rate (str/min)	20.1	32.3	22.3	35.2	20.7	32.1
2	Rowing Power (W)	247	391	247	401	237	375
3	Drive Time (s)	1.26	1.00	1.13	0.92	1.21	0.97
4	Rhythm (%)	42.0	54.0	42.0	53.9	41.7	51.9
5	Drive Length (m)	1.60	1.59	1.42	1.43	1.44	1.41
6	Maximal Force (N)	634	602	803	806	826	840
7	Average Force (N)	331	342	404	427	394	430
8	Ratio Aver/Max Forces (%)	52.3	56.9	50.4	53.0	47.7	51.2
9	Position of Max. Force (%)	37.6	34.7	36.3	40.5	37.2	40.8
10	Catch Slip (m)	0.04	0.04	0.07	0.09	0.12	0.13
11	Release Slip (m)	0.22	0.20	0.24	0.25	0.22	0.21
12	Max.Handle Velocity (m/s)	2.06	2.36	1.73	1.94	1.70	1.89
13	Average Velocity (m/s)	1.28	1.59	1.26	1.55	1.19	1.45
14	Position of Max.Velocity (%)	59.4	65.2	73.5	71.4	76.4	74.1
15	Min. Acceleration (m/s2):	-3.35	-7.92	-3.46	-9.13	0	0
16	Max. Acceleration (m/s2):	3.23	3.39	2.01	2.78	0	0
17	Legs Travel (m)	0.52	0.51	0.52	0.52	0.55	0.53
18	Trunk Travel (m)	0.50	0.48	0.48	0.48	0.47	0.46
19	Arms Travel (m)	0.61	0.62	0.43	0.43	0.44	0.43

Handle force curve was more rectangular in the boat and had a more peaky shape on both machines. This can be quantified using ratio of average/maximal forces, which was higher in the boat. Peak force at racing rate achieved earlier on water.

Maximal handle speed was 18%-20% higher on-water than on both ergo-meters. This difference affects the rower's feeling of the handle acceleration and is related to the difference in gearing ratio.
ROWPERFECT machine accurately simulates negative acceleration of the boat shell at catch. Acceleration of the single during the drive was significantly (20% - 30%) higher than acceleration of the mobile unit of the ROWPERFECT. The later exceeded the boat acceleration during recovery phase.

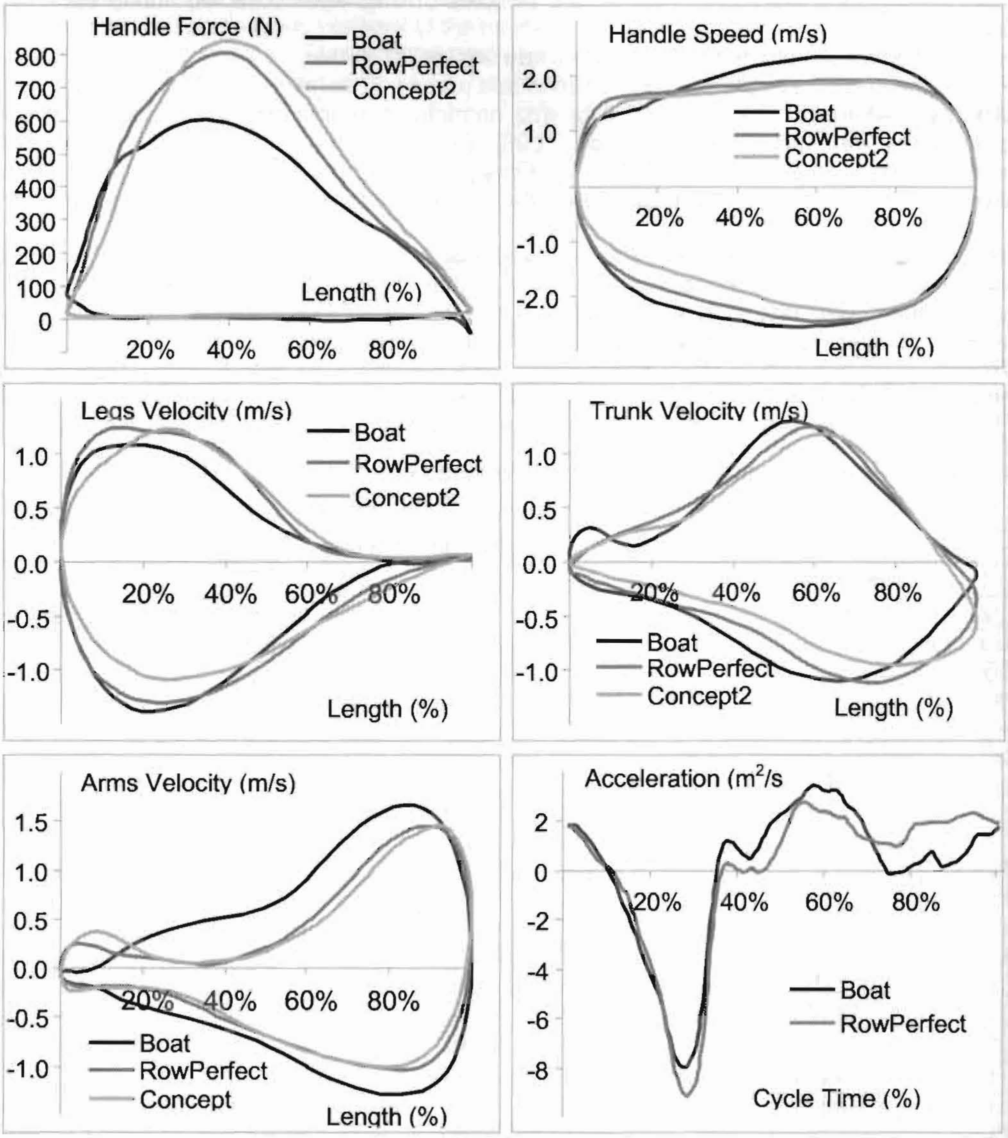

Figure 1 Average patterns of biomechanical parameters of five female rowers at racing stroke rate.

DISCUSSION: Faster increase of the handle force and legs speed in the boat and on ROWPERFECT can be explained by different magnitude of inertial forces caused by in interaction of the rower with stationary or mobile point of support. This confirms results of the previous studies (Martindale & Robertson, 1986, Lamb, 1989).

The differences in magnitude of the handle force can be explained by different gearing ratio in the boat and on rowing machines (Figure 2).

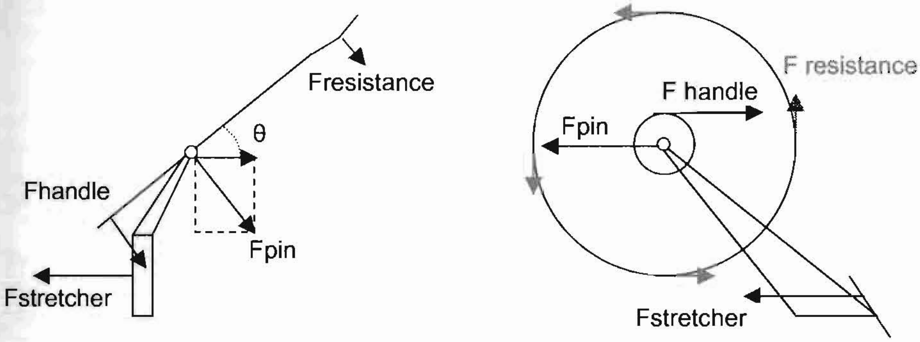

Figure 2 The main forces during rowing on water (left) and on air-braked rowing machine.

In the boat, the relationship between the handle and stretcher forces can be expressed as:

$$F_{handle} = (F_{stretcher} - F_{inert.boat}) (R_{out} / (R_{in} + R_{out})) / \cos\theta \quad (3)$$

, where ***Finert.boat*** is inertia force of the boat shell (relatively small), ***Rout*** is the oar outboard length, ***θ*** is the oar angle. On the machines, the difference between the handle and stretcher forces equal to the inertia of the mobile unit on ROWPERFECT (smaller) of the rowers mass on Concept2 (larger):

$$F_{handle} = F_{stretcher} - F_{inert.} \quad (4)$$

The rower has to apply 30%-40% less force at the handle at than the stretcher in the boat, but similar forces on the machines. This explains results of our measurements.
Moreover, gearing ratio in the boat varies during the drive, because it depends on the oar angle (equation 4). In both machines it is constant. This explains difference in the handle velocities profiles.
The difference in the length of the handle and arm travel can be explained by curvilinear geometry of the arms movement in the boat and linear path on machines.

CONCLUSION: Found differences in biomechanical structure of rowing affect the rowers' motor control pattern and rowing technique, which can not be directly transferred from a machine to the boat. Athletes with higher upper body strength and slower muscles can achieve advantage on rowing machines, while athletes with stronger and faster legs can be better performers on-water. Rowing on-water and on-machine are two different sorts of exercises and machines should be considered as a cross-training for rowing. This should be remembered when use machines for testing and selection purposes.

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