POWER IN ROWING

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The purpose of this study is to introduce the new method of the power determination in rowing and to give values of the total and body segments power in different rowers' groups. The method uses footstretcher force and boat velocity in addition to traditional handle force and oar angle and gives on average 16.8% higher power values. On average only 52.8% of total rowing power was applied at the handle and 47.2% was applied at the footstretcher. Legs execute 45.2% of total rowing power; trunk does 32.2% and arms do 22.6%.

KEY WORDS: biomechanics, rowing, power, body segments

INTRODUCTION: Measurements of athlete's power in rowing are commonly used as the main tool for identification of the athlete's energy production and technique efficiency. The traditional method of rower's power (*P*) calculation consists of multiplying the momentum applied to the oar handle *M* by angular velocity of the oar rotation ω or handle force *F* by linear velocity *v* of the point of force application (ex. Fukunaga et al., 1986, Dal-Monte and Komor, 1989, Zatsiorsky and Yakunin, 1991):

$$P(t) = M(t) * \omega(t) = F(t) * R * \alpha(t) / dt = F(t) * v(t) \qquad (1)$$

where R is the length of inboard oar radius between the gate pin and the point of force application. There are other modifications of this method when force was measured at the gate and handle moment was derived using inboard/outboard ratio (ex. Staniak et al., 1994). Although this method is applicable to the stationary devices (rowing tanks, pools, stationary ergometers), it cannot be used in the real on-water rowing because the reference point of the system (gate pin) moves with acceleration together with the boat shell and Newton laws are not applicable in this system.

Another method of rower's power calculation was introduced using power output at the oar blade (Kleshnev, 1997). It gave 11.2% higher power values in comparison with traditional methods, but it was developed on the special rowing simulator.

An interesting point is the power production of the body segments that can be used for identification of rowing styles and connected with strength and conditioning of the rowers. A number of studies consider transfer of internal energy between segments (ex. Sanderson and Martindale, 1986), but only a few of them derived mechanical power of body segments (Kleshnev, 1995).

The purpose of this study is to introduce valid methods of the rowing power calculation and to give some example values of the total and body segments power in rowers' groups.

METHODS: The measurements were undertaken during on-water rowing in competitive singles, pairs and doubles using a radio telemetry system. Boat shell acceleration along horizontal axis was measured using a piezoresistive accelerometer. An electromagnetic sensor (Nielsen-Kellerman Co.) measured boat velocity.

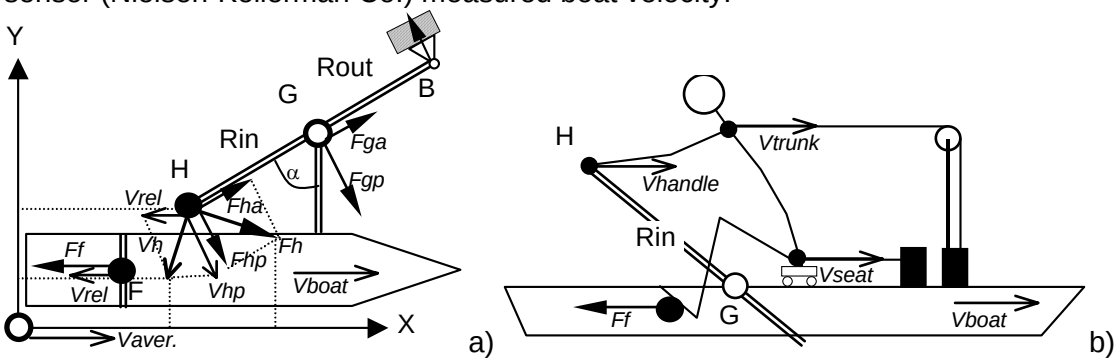

Figure 1. The simplified 2D models of the oar-boat system in horizontal (a) and vertical (b) plane.

The angle between oar and boat in a horizontal plane (α on Figure 1,a) was measured using a servo potentiometer. Two forces applied to the oarlock were measured using instrumented gate: a perpendicular (*Fgp*) and an axial ones (*Fga*) to the oar shaft. The perpendicular handle force (*Fhp*) was derived using *Fgp,* inboard and outboard length of the oar. The force applied to the footstretcher along the boat axis (*Ff*) was measured using special construction with strain gauges. Linear velocities of the seat (*Vseat*) and top of the trunk (*Vtrunk*) were measured using low stretchable fishing line and potentiometer devices (Figure 1,b). The joint of *Sternum* and *Clavicle* was used as the point of top of the trunk. Linear velocity of the handle was calculated using angular velocity and the inboard radius of the oar.
The total number of 88 elite athletes took part in the measurements (Table 1). Every crew performed a set of the four-six test trials per one minute each with unlimited recovery time. The stroke rate increased in each trial on 4 min^{-1} and was in a range of 16-40 min^{-1} for the whole sample.

Table 1. Parameters of the rower's groups (mean ± STD).

	Men Sweep	Men Scull	Women Sweep	Women Scull
N	28	20	24	16
Height (m)	1.91±0.06	1.88±0.05	1.80±0.03	1.76±0.07
Body mass (kg)	85.6±9.0	83.7±8.9	73.9±3.4	67.3±8.7

The data was collected and stored in a PC and then processed using special software. Typical patterns of biomechanical parameters of athlete's cyclic movements were produced. Then the patterns of derived parameters and the average patterns of the crew were calculated and used for analysis.

RESULTS AND DISCUSSION: **Method of the power calculation**. The rower's body was assumed as a rigid one. A 2D coordinate system was chosen in the horizontal plane with the reference point that moves in parallel to the boat course at constant velocity equal to the average boat speed (*Vaver.*, Figure 1,a). The x-axis was directed parallel to the boat axis.
The rower applies power at two points only: at the oar handle (*H*) and at the footstretcher (*F*). The resulting handle force (*Fh*) was calculated as a vector product of the perpendicular (*Fhp*) and axial (*Fha*) forces. The resulting handle velocity was calculated as a vector product of the handle velocity perpendicular to the oar shaft (*Vhp*) and relative boat velocity (*Vrel*). The instantaneous handle power (*Ph*) was derived as a scalar product of *Fh* and *Vh*.

$$Ph = Fh * Vh * \cos(\varphi) \qquad (2)$$

where φ is the angle between *Fh* and *Vh* vectors. Another method of *Ph* calculation could be used which is simpler in practice and gives the same results. It consists of deriving projections of forces and velocities vectors on axis X and Y and of calculation of products of sums

$$Ph = Ph_x + Ph_y = (Php_x + Pha_x) * (Vh_x + Vrel) + (Php_y + Pha_y) * Vh_y \qquad (3)$$

The footstretcher power (*Pf*) was calculated as a scalar product of the footstretcher force (*Ff*) and *Vrel*.

$$Pf = Ff * V\,rel \qquad (4)$$

The total power exerted by a rower into an external environment was derived as a sum of *Ph* and *Pf*:

$$P = Ph + Pf \qquad (5)$$

The segments powers were derived as scalar products of corresponding force and velocity:

$$Plegs = Ff * Vseat \qquad (6)$$

$$Ptrunk = Fhp * (Vtrunk - Vseat) \qquad (7)$$

$$Parms = Fhp * (Vhp - Vtrunk) \qquad (8)$$

Work done (W) and average power (Pav.) were derived using standard equations:

$$W = \int P(t)\,dt \quad (9); \qquad Pav. = W / t \quad (10)$$

Power patterns and values. The difference between rowing power calculated using old and new methods could be explained by footstretcher power applied at the beginning of the drive phase (Figure 2, a, c). On average the new method gave 16.8±7.0% higher power values and the difference did not depend on the boat type, rower's gender or stroke rate.

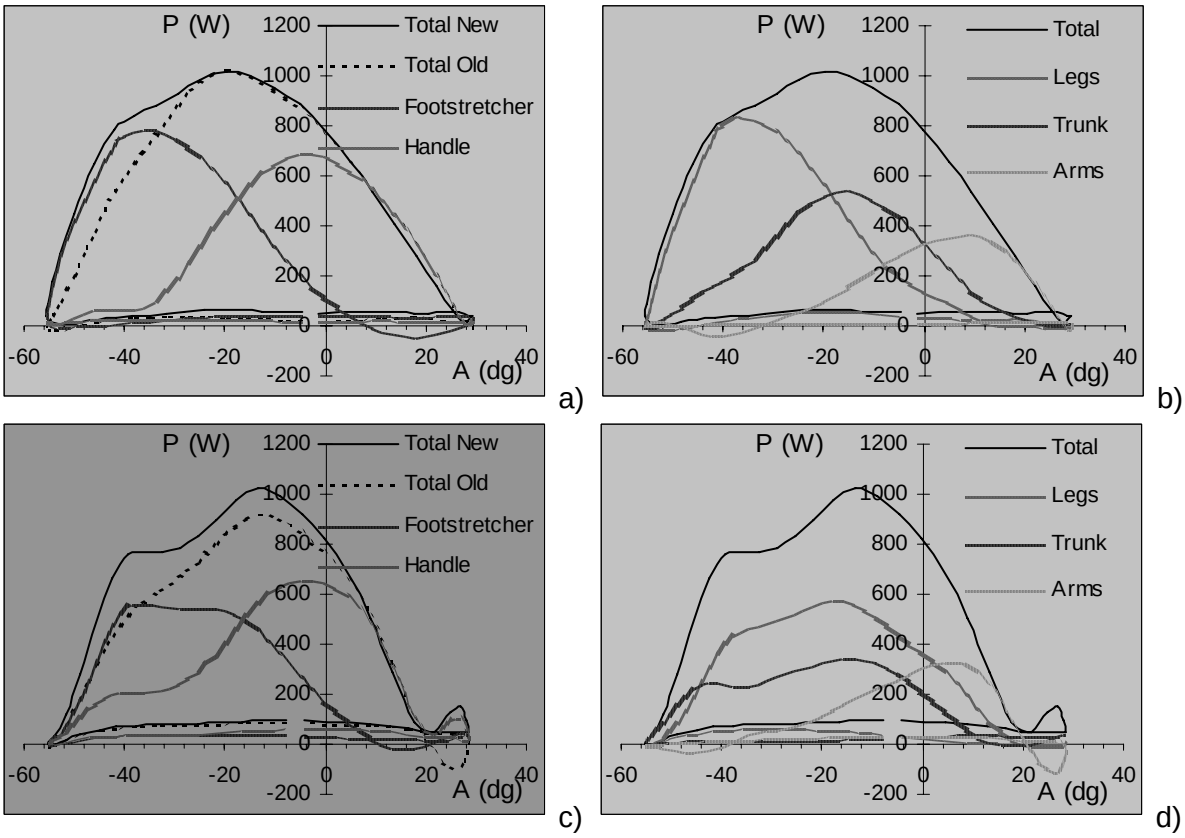

Figure 2. The typical patterns of the instantaneous powers applied by the rower at the handle and footstretcher (left column) and the segments powers (right). X-axis is the oar angle relative to the boat perpendicular.

The patterns of the instantaneous powers of the body segments (Figure 2, b, d) show examples of the rowing styles with sequential (upper row) and simultaneous segments work. The first one could be related to Rosenberg style (Klavora P., 1976) and the second one to DDR style.

In the whole sample 47.2±4.1% of the total power applied to the footstretcher and 52.8±4.1% applied to the oar handle (Table 2). Sweep rowers applied more power at the footstretcher (48.5±3.8%) than scullers (45.2±3.8%, $p < 0.01$) and correspondingly less power at the handle. There was no difference in these parameters between male and female rowers.

Table 2. Footstretcher and handle shares in rowing power (mean ± STD).

	Men Sweep	Men Scull	Women Sweep	Women Scull	All Rowers
Footstretcher Power (%)	48.9±3.5%	45.9±3.9%	48.2±4.1%	44.3±3.5%	47.2±4.1%
Handle Power (%)	51.1±3.5%	54.1±3.9%	51.8±4.1%	55.7±3.5%	52.8±4.1%

No significant differences were found in the segments shares between rowers' groups (Table 3) except male scullers that had lower trunk power share and higher arms power.

Table 3. Shares of body segments in rowing power (mean ± STD).

	Men Sweep	Men Scull	Women Sweep	Women Scull	All Rowers
Legs Share (W)	45.4±4.5%	44.8±4.0%	45.7±6.4%	44.9±3.5%	45.2±4.9%
Trunk Share (W)	32.5±5.9%	29.3±3.8%	33.5±6.8%	33.4±4.3%	32.2±5.8%
Arms Share (W)	22.1±6.4%	25.9±3.8%	20.8±6.1%	21.7±4.6%	22.6±5.8%

In contradiction with previous studies (Dal-Monte and Komor, 1989) it was found that linear trend was the best approximation of power-rate dependence (Figure 3). Determination coefficient between predicted and actual data (R^2) was in the range 0.71 – 0.82.

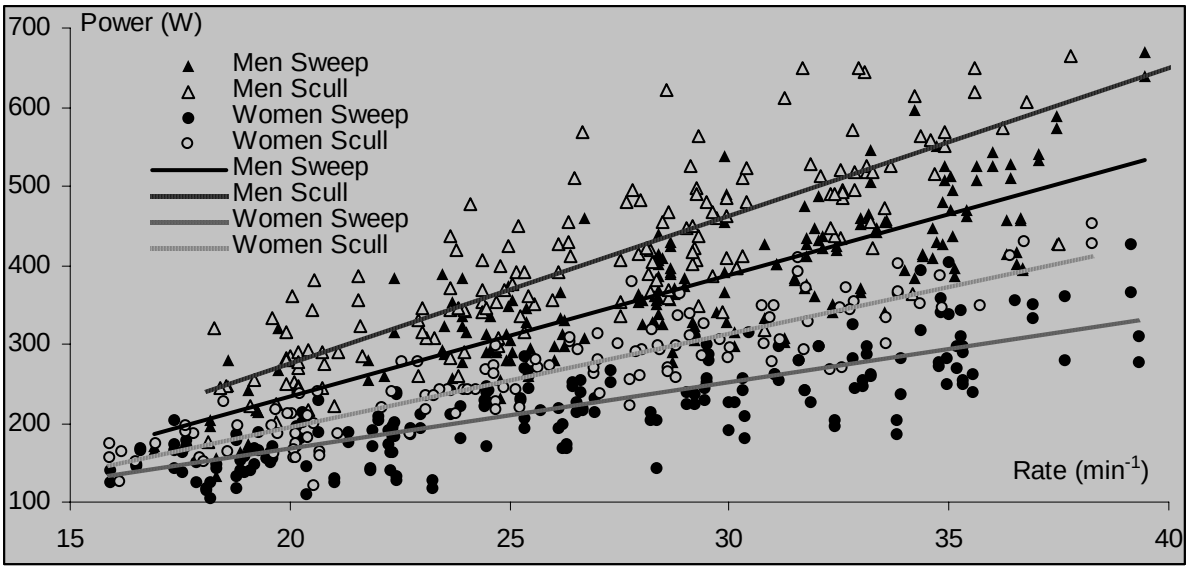

Figure 3. Dependence of rowing power on stroke rate in the rowers groups

The equations of linear regression of rowing power (y) on stroke rate (x) had the following values in the different rowers' groups:

Men Sweep:	*y = 15.3633 x - 73.5170*	*(11)*
Men Scull	*y = 18.6887 x - 98.6895*	*(12)*
Women Sweep	*y = 8.4722 x - 2.6322*	*(13)*
Women Scull:	*y = 11.9570 x - 45.1272*	*(14)*

CONCLUSIONS:

1. Calculation of the power during on-water rowing using handle force and oar angle cannot be valid due to non-stationary boat movement. It is necessary to take into account footstretcher force and boat velocity. The new method gives on average 16.8% higher rowing power.
2. Only around 53% of total rowing power was applied at the oar handle and the other 47% was applied at the footstretcher.
3. The main power in rowing executes by legs (around 45%); smaller power executes by trunk (~32%); the lowest power produces by arms (~23%).

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