Method of analysis of speed, stroke rate and stroke distance in aquatic locomotions

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Abstract

A method was developed for evaluation of speed and distance per stroke (SD) at various stroke rates during aquatic locomotion. The method is based on equation $Fd = k\ V^2$, which describes dependence of hydrodynamic drag force Fd on velocity V in water. Equality of the mechanical work per stroke at various stroke rates was taken as a criterion for SD evaluation. Two equations were developed for calculation of "prognostic" speed $Vp = V_0\ (R_1/R_0)^{1/3}$ and $SDp = SD_0\ (R_0/R_1)^{2/3}$. Ratio of the actual values to "prognostic" was used for evaluation of the consistency of work per stroke. The method was verified using the data of biomechanical measurements in rowing, when mechanical work per stroke was measured directly. Then the method was used for race analysis in swimming. The method can be useful tool for coaches in swimming, rowing and canoeing.

KEY WORDS: Rowing, swimming, canoeing, speed, stroke rate, stroke distance.

Introduction

Average speed (***V***), stroke rate (***SR***) and stroke distance (***SD***) are fundamental variables of aquatic locomotions, such as swimming, rowing and canoeing. Relationships between these variables are defined by a number of factors. The most obvious is the athlete anthropometry and body composition (Keskinen et al., 1989, Pelayo et al., 1996). Taller and bigger athletes can produce more work per stroke that means their distance per stroke is longer. Smaller athletes can not achieve such a long stroke distance, so they have to use higher stroke rate to compete with others.

Training methodology is another factor, which affects ratio of ***SR*** to ***SD***. Emphasis on the aerobic and strength training and improvement of technique would produce longer distance per stroke (Wakayoshi et al., 1993). Speed and speed-endurance training methods can help athletes to sustain higher stroke rate, but the distance per stroke would be shorter (Ebben et al., 2004).

If we want to achieve the top performance, we can ignore neither stroke rate nor distance per stroke. Therefore, assessment of these variables for each athlete, crew in training and competitions plays very important role. Speed of locomotion ***V*** is a product of the stroke rate ***SR*** and distance per stroke ***SD*** and can defined through the time of stroke cycle ***T***:

$$V = SD / T = SD\ SR / 60 \qquad (1)$$

Equation **(1**)can be rewritten for the distance per stroke ***SD***:

$$SD = V * T = 60\ V / SR \qquad (2)$$

This means that the stroke rate and distance per stroke are reversely proportional at the constant speed. When athletes increase stroke rate, distance per stroke is always goes down, because time of the cycle ***T*** became shorter. Quite often coaches ask athletes to maintain constant ***SD*** at higher ***SR*** that means the speed must be increased proportionally to the stroke rate, which never happens in practice.

Some authors (Keskinen et al., 1989, Pyne et al. 2001) used an index **I** equal to product of the speed ***V*** and ***SD*** as a measure of stroke efficiency.

$$I = V\ SD = 60\ V^2 / SR = SD^2\ SR / 60 \qquad (3)$$

This index is dimensioned in m^2/s units, which has no any physical meaning. It has little practical application, because it always goes down with increase of the stroke rate.

Therefore, we could not find in the literature any adequate methods of evaluation of relationship between ***SR*** and ***SD*** in aquatic locomotions and attempted to cover this gap in this study.

Methods

For validation of the developed method we used data of biomechanical measurements in rowing, where mechanical power can be measured much easier than in swimming or canoeing. Two data sets were used in the study:

The first large data set was collected during routine biomechanical testing of athletes in Australian Institute of Sport during 1998-2005. Total number 294 crews in all boat types were tested and 1444 data samples collected.

The second data set was extracted from the first one and used for illustration of the method in more details. Two subjects were experienced rowers in the single scull (height 1.90 and 1.99m, weight 86 and 100kg). Subjects were instructed to row at rates of 22, 26, 30 and 34 strokes per minute. This range represents the range of stroke rates typical for training and competition.

Forces on the oar handle were measured using custom made strain-gauge transducer mounted on the oar shaft. Each transducer was calibrated by means of applying known force through a precise load cell. Oar angles in the horizontal plane were measured using conductive-plastic potentiometers, which were mounted to both oars using a carbon-fibre rod with bracket. Boat velocity was measured using a trailing turbine (Nielsen Kellermann) with embedded magnets, mounted underneath the hull of the boat. All data were sampled at 50 Hz. Raw data were transmitted to the shore in real-time using a wireless transmitter, acquired into notebook PC using custom made software and stored on the hard drive. For all variables of interest, the average over an entire rowing cycle was calculated for each data sample.

Mechanical power and work per stroke were derived from measurement of the forces applied to the oars and oar angles (Kleshnev, 2000). Rowing propulsive efficiency was defined as it was described by Kleshnev, 1999.

Results

Definition of the analysis method

If ***SD*** can not be constant at increasing ***SR***, then the question rises: What variable can be used as a measure of consistency of athlete's technique at different stroke rates? We defined that the main objective is to sustain force application ***F***, stroke length (amplitude) ***L***, and of mechanical efficiency ***E***. The effective work per stroke ***eWPS*** is a product of all these variables and we used it as the criterion of the method:

$$eWPS \sim F * L * E \qquad (4)$$

The relationship between hydrodynamic drag resistance force ***Fd***, speed ***V***, and power, generated by the athlete ***P*** in such aquatic sports as swimming (Huub et al., 2004) and rowing (Baudouin and Hawkins, 2002) can be defined:

$$Fd = k\,V^2 \qquad (5)$$

$$P = V\,Fd = k\,V^3 \qquad (6)$$

where ***k*** is some dimensionless drag resistance factor, which depends on the type of locomotion, characteristics of athlete, equipment and weather conditions. ***eWPS*** can be expressed in terms of power ***P***, time of stroke cycle ***T***, speed ***V***, and stroke rate ***SR***:

$$eWPS = P\,T = k\,V^3\,(60 / SR) = 60k\,(V^3 / SR) \qquad (7)$$

If the following two conditions maintained during the two sections of locomotion in water with different stroke rates (R_0 and R_1):

- drag resistance factors are equal ($k_1 = k_2$), which should the case in the same athlete/crew and in the same conditions,
- values of ***eWPS*** are equal ($WPSe_0 = WPSe_1$),

then using equation **(7**) we can make the following equation:

$$60k\,(V_1^3 / SR_1) = 60k\,(V_2^3 / SR_2) \qquad (8)$$

After simplifications we can derive the ratio of the boat speeds V_0 and V_1 for these sections as follows:

$$V_1 / V_0 = (SR_1 / SR_0)^{1/3} \qquad (9)$$

Correspondingly, the ratio of ***SD*** values is:

$$SD_1 / SD_0 = (SR_0 / SR_1)^{2/3} \quad (10)$$

To use equations **(9**) and **(10**) we don't need to know factor ***k***, because we assume that it is the same for the two sections. However, this is applicable only for the same athlete/crew/equipment and the same weather conditions, which is a limitation of the method.

The most practically convenient implication of the method is the definition of "model" values of speed V_m and distance per stroke SD_m for each particular SR_m, which can be achieved at the constant effective work per stroke ***eWPS***:

$$V_m = V_0 (SR_m / SR_0)^{1/3} \quad (11)$$

$$SD_m = SD_0 (SR_m / SR_1)^{2/3} \quad (12)$$

where V_0 and SD_0 are base values, which can be one of the following:

1. Average values of all samples taken from particular subject;
2. Minimal or maximal values of **V** and **SD**;
3. Values obtained at the lowest or highest stroke rate.

The first option should be used for race analysis, because it represents the average speed and rate over the whole race. In a step test, we can use option 1 as well, but option 3 also makes sense. Figure 1 (a) illustrates trends of the "model" ***V*** and ***SD*** at different ***SR***.

Finally, ratios of the real values ***Vi*** and ***SDi**,* for each race section, to the "model" values were used for evaluation of the effective work per stroke:

$$eVi\ (\%) = Vi / Vm \quad (13)$$

$$eSDi\ (\%) = SDi / SDm \quad (14)$$

Validation and illustration of the method

For validation of the method we need to check if the

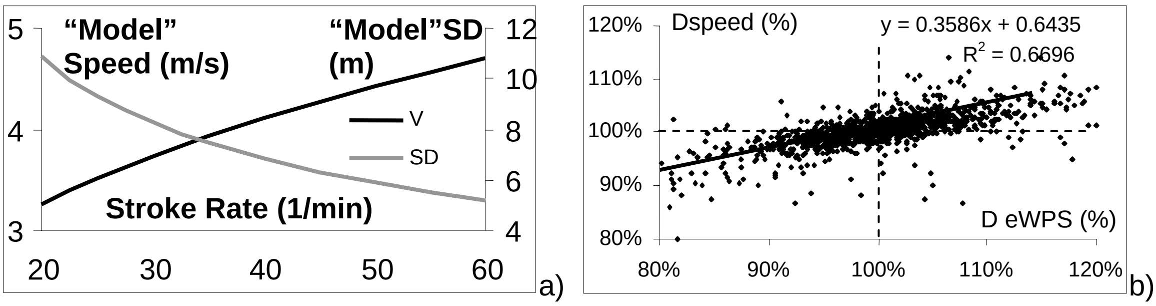
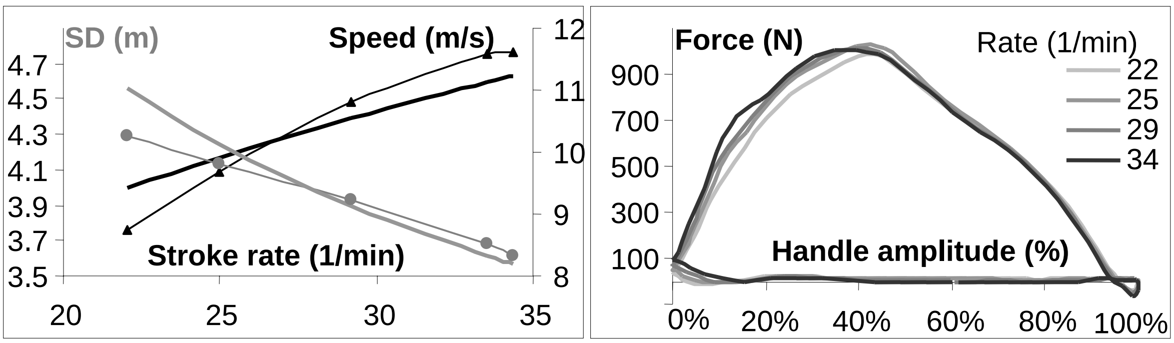


Figure 1 Left (a): Dependence of "model" speed and SD on SR. Right (b): Correlation of the deviations of real speed form "model" and real eWPS from the crew average.

The "model" values of speed and SD were calculated for both rowers using equations **(11**) and **(12**). The average values of ***V*** and ***SD*** for each athlete in all four samples were taken as the base values V_0 and SD_0. Then, these "model" values were plotted together with the real data relative the stroke rate (Figure 2, left column). For visualisation of consistency of the force application and amplitude of the oar handle movement, we plotted the first variable relative to the second one for average data in each sample (Figure 2, left column).



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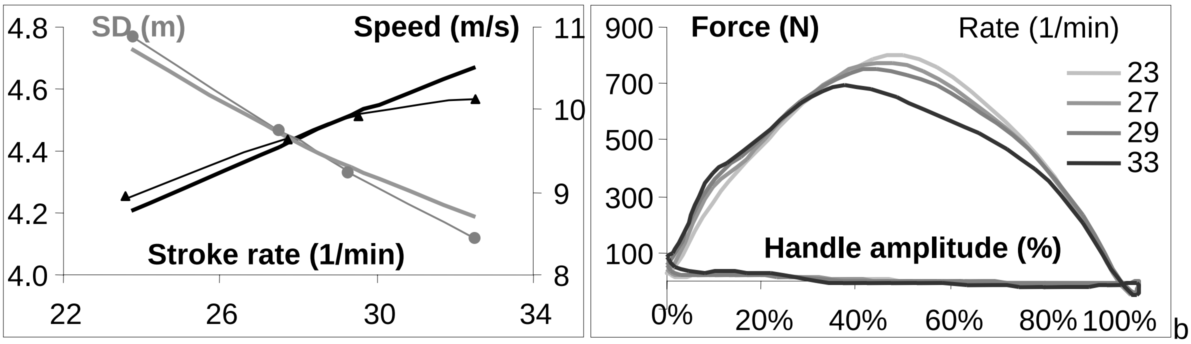

Figure 2 Left column: real (thin line) and "model" (thick line) dependencies of the speed and SD on SR. Right column: Force/Amplitude curves at different stroke rate. Each row represents one crew.

Table 1.

1st crew				2nd crew			
Stroke Rate (1/min)	Rowing Power (W)	Work per Stroke (J)	WPS/ Average (%)	Stroke Rate (1/min)	Rowing Power (W)	Work per Stroke (J)	WPS/ Average (%)
22.0	380	1037	98.8%	23.8	290	733	105.7%
25.0	435	1045	99.6%	27.5	327	714	103.1%
29.2	514	1056	100.6%	29.4	341	696	100.5%
33.5	592	1060	101.0%	32.5	341	629	90.7%

The first athlete increases force and maintain length at higher stroke rates, which produces higher effective work per stroke. The measured boat speed and SD overtake "model" lines at higher rates in this athlete.

The second crew decreases both force and length at higher stroke rates, which produces lower effective work per stroke. The boat speed and SD go below "model" lines at higher rates in this athlete.

Discussion

The developed method can be successfully used for race analysis in cyclic water sports (rowing, swimming and canoeing). It can be employed for evaluation of the strength- and speed-endurance using step-test in cyclic water sports. It does not require sophisticated equipment (except for a stop watch or stroke counting devices, such as StrokeCoach ®) and can be used in every day training.

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