METHOD OF ANALYSIS OF SPEED, STROKE RATE AND STROKE DISTANCE IN AQUATIC LOCO-MOTIONS

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A method was developed for assessment of speed (V) and stroke distance (SD) at various stroke rates (R) during aquatic locomotion. The method is based on the equation Fd = k V^2, which describes dependence of hydrodynamic drag force Fd on V in water. Equality of the effective mechanical work per stroke (EWS) at various stroke rates was taken as a criterion for assessment. Two equations were developed for calculation of "model" speed $Vm = V_0 (R_1/R_0)^{1/3}$ and $SDm = SD_0 (R_0/R_1)^{2/3}$. This method was verified using the data of biomechanical measurements in rowing, when mechanical work per stroke was measured directly. A high correlation was found (r=0.81, p<0.001) between deviations of the actual V and SD values to "models" and deviations of EWS from average. The method can be used in step-test and race analysis in swimming, rowing and canoeing.

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

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 the ratio of ***SR*** to ***SD***. Emphasis on aerobic and strength training and improvement of technique would produce longer ***SD*** (Wakayoshi et al., 1993). Speed and speed-endurance training methods can help athletes to sustain higher ***SR*** (Ebben et al., 2004).

Speed of locomotion ***V*** (m/s) is a product of ***SR*** (1/min) and ***SD*** (m). This can be defined through the time of stroke cycle ***T*** (s):

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

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

This means that ***SR*** and ***SD*** are reversely proportional at a constant speed ***V***. When athletes increase ***SR***, ***SD*** always goes down, because ***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 ***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 mechanical meaning. It has little practical application, because **I** always go down with increase of ***SR***.

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

METHODS: For validation of the developed method we used data from 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. A total quantity of 294 crews in all boat types were tested and 1444 data samples collected at stroke rates from 16 to 44 str/min.

The second data set was extracted from the initial data collection 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 stroke 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 a 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 rod with bracket. Boat speed 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 mechanical efficiency was defined as it was described by Kleshnev, 1999.

RESULTS AND DISCUSSION:

Definition of the analysis method

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

$$EWS = \sum e\, F\, \Delta L \tag{4}$$

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:

$$Fd = k\, V^2 \tag{5}$$

$$P = V\, Fd = k\, V^3 \tag{6}$$

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

$$EWS = P\, T = k\, V^3\, (60 / SR) = 60k\, (V^3 / SR) \tag{7}$$

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 ***EWS*** are equal ($WPSe_0 = WPSe_1$),

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

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

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

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

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

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

To use equations **(9**) and **(10**) we don't need to know drag 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 ***EWS***:

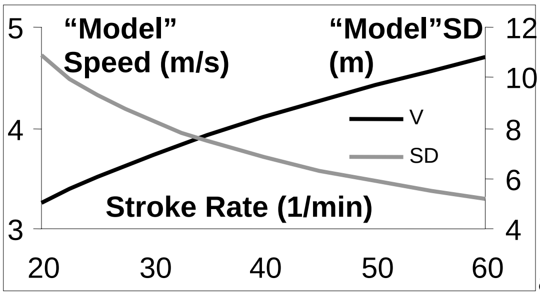
$$V_m = V_0\ (SR_m / SR_0)^{1/3} \quad (11)$$

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

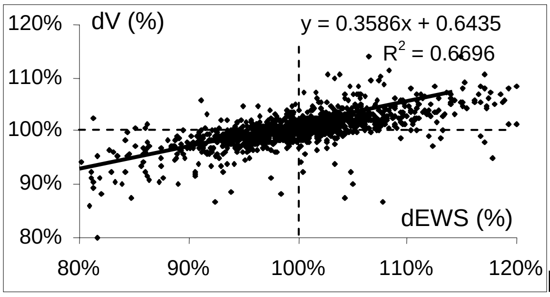
where V_0 and SD_0 are base values, which can be one of the following: 1. Average values of all samples taken from particular subject; 2. Minimal or maximal values of **V** and **SD**; 3. Values obtained at the lowest or highest stroke rate. Figure 1 (a) illustrates trends of the “model” ***V*** and ***SD*** at different ***SR***. Finally, deviations of the real values ***Vi*** and ***SDi**,* for each sample from the “model” values were used for evaluation of the effective work per stroke:

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

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



a)



b)

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

Validation and illustration of the method

For validation of the method we checked how the deviations of ***V*** and ***SD*** related to deviations of ***EWS***. We calculated average ***EWSa*** for each crew in the data set and then deviations of ***EWSi*** values from the average ***EWSa*** for each data sample:

$$dEWS\ (\%) = EWSi / EWSa \quad (15)$$

The Pearson correlation factors of ***dEWS*** with ***dV*** was 0.81 ($p<0.001$) and with ***dSD*** it was 0.79 ($p<0.001$). This means ***dEWS*** variation of explains around 67% of ***dV*** variation. The rest 33% can be explained by variation of weather conditions during the measurements.

For illustration of the method, the “model” values of speed and ***SD*** were calculated for two rowers using equations **(11**) and **(12**) and average of ***V*** and ***SD*** as the base values. Then, these “model” values were plotted together with the real data relative ***SR*** (Figure 2, row1). 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, row 2). Deviations ***dV*** and ***dSD*** from the “model” ***V*** and ***SD*** values were plotted together with deviations ***dEWS*** from average ***EWS*** (Figure 2, row 3).

The first athlete increases force at higher stroke rates, which produces higher ***EWS***. The measured boat speed ***V*** and ***SD*** overtake “model” lines at higher rates in this athlete.

The second athlete decreases both force and length at higher stroke rates, which produces lower ***EWS***. The boat speed and ***SD*** go below “model” lines at higher rates in this athlete.

In all samples higher ***dV*** or ***dSD*** correspond to higher ***dEWS***, except samples 2 and 3 in the second athlete, which can be explained by different weather conditions.

CONCLUSION: This study has shown that defined measures of speed and SD adequately reflect deviations of effective work per stroke, which is integral measure of the athlete performance. The developed method can be successfully used in two sorts of analysis in aquatic sports (rowing, swimming and canoeing): 1. For determination of athlete’s performance at different stages of the race; 2. For testing in training environment using step-test. The method is simple, does not require sophisticated equipment (except for a stop watch or stroke counting devices) and can be used by coaches in every day training.

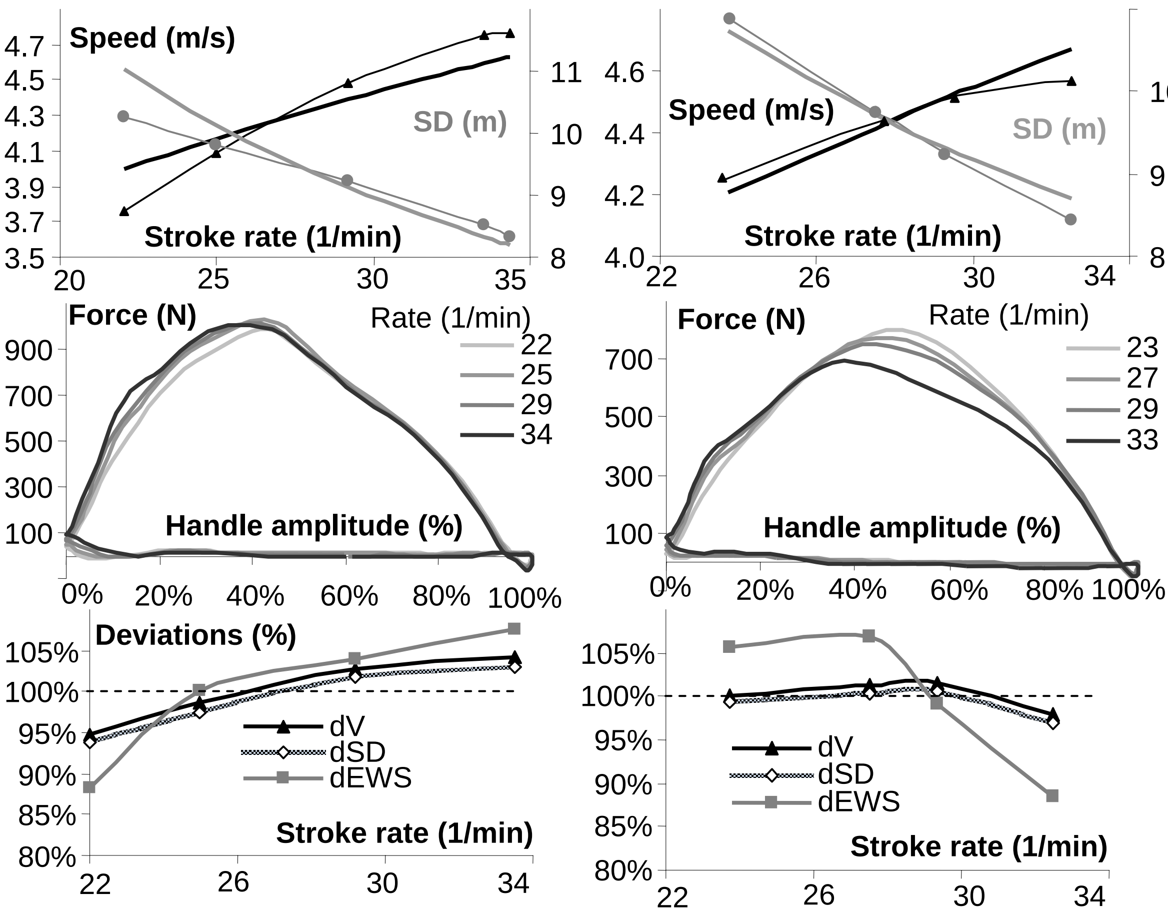


Figure 2. Row 1: Real (thin line) and "model" (thick line) dependencies of the V and SD on SR. Row 2: Force/Amplitude curves at different stroke rate. Row 3: Deviations of V, SD and EWS. Each column represents one rower.

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