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Stroke power consistency and 2000 m rowing performance in varsity rowers

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We studied the relationship between stroke power consistency and 2000 m rowing time besides determining maximal oxygen uptake (VO_{2max}) and leg extension power. The subjects ($n = 16$, male varsity rowers) carried out an incremental test to volitional exhaustion on a rowing ergometer, and the VO_2 at each stage was determined. The stroke power consistency was assessed by the coefficient of variation of power (CVP_{high}) at the highest workload at which each subject could maintain power. Besides the incremental test, 2000 m all-out rowing was performed on the ergometer and leg extension power was measured. Stepwise multiple regression analysis indicated that the 2000 m rowing time could be predicted by VO_{2max}, leg extension power and CVP_{high} in order of strength of standardized partial correlation coefficients as explanatory variables. The CVP_{high} correlated with the residual of the regression between 2000 m rowing time and VO_{2max}. The findings suggest that the stroke power consistency contributes to maintenance of the power during ergometer rowing.

Rowing involves repetitive cyclic motions with different directions repeated approximately 220–240 times during the 2000 m race. The time course of mean power and variations in motion and power during the stoke cycle have been documented (Hagerman et al., 1978; Mahler et al., 1984; Hartmann et al., 1993; Schabort et al., 1999). Henry et al. (1995) investigated strokes in tank rowing and found that power–oar angle curves for consecutive strokes and time course variations of the power and the oar angle represent skill parameters. Smith and Spinks (1995) determined in ergometer rowing work consistency and stroke-to-stroke consistency, in which similarities of force values were quantified after normalizing force data for each stroke with respect to time. The consistency evaluated by the coefficient of variation discriminated the ability level of the rowers. These findings indicate that the consistency in force, work and power of the stroke are determinants of performance. Also, the stroke power consistency correlates with the velocity of a rowing shell (Shimoda & Kawakami, 2004).

Physiological determinants including maximal oxygen uptake (VO_{2max}) and lactate and ventilatory thresholds of rowers have yielded large values (Secher, 1993; Shephard, 1998). Especially, an intimate relationship between rowing performance and VO_{2max} has been reported (Secher, 1993; Shephard, 1998; Cosgrove et al., 1999). Also, isokinetic and isometric knee extension strength measured in a simulated rowing position and leg extension power are correlated to ergometric rowing performance (Secher, 1975; Pyke et al., 1979; Yoshiga et al., 2000). These findings prompted us to suppose dependence of stroke power consistency, aerobic capacity, leg extension power and rowing performance.

Methods

Sixteen male university rowers volunteered to participate in this study [age 20.7 ± 0.9 years, height 176.2 ± 7.3 cm, body mass 72.5 ± 6.4 kg (mean ± SD)]. The subjects all had experience of 2000 m rowing competition from 1 to 3 years and trained regularly on a rowing ergometer (Concept II, Model C, Morrisville, Vermont, USA) and were at an average performance level of Japanese collegiate rowers. All procedures were undertaken with the informed consent of the subjects and the study was approved by the Ethics Committee of the Faculty of Sport Sciences, Waseda University, in the spirit of the Helsinki Declaration.

Experimental protocol

The subjects performed a continuous incremental test to volitional exhaustion on a rowing ergometer. After 1 min of rest sitting on the rowing ergometer, the subjects rowed at 150 W. The workload was increased by 50 W every second minute until exhaustion (Steinacker et al., 1986), while the subjects were encouraged. The subjects rowed at their preferable stroke rate and were instructed to keep exerting as constant as possible a power at each workload. The subjects monitored the power on the display of the ergometer. Expired air was sampled breath by breath and VO_2 was measured using an electronic spirometer (Aeromonitor AE-300S, Minato Medical Science Co., Ltd., Osaka, Japan). A 3-lead electrocardiogram (Cardiosuper 2E32, NEC Medical Systems, Tokyo, Japan) was monitored to measure the heart rate (HR). The VO_2, carbon dioxide expiration (VCO_2), ventilation (VE) and HR were averaged every 10th second and the power was also displayed.

A maximal bilateral leg extension power was determined by an isotonic dynamometer (Anaeropress 3500, Combi Co., Tokyo, Japan). The subjects sat and pressed their feet on the foot plate as intensively as possible in a horizontal direction until the legs were fully extended. The maximal leg extension power was the highest value obtained in five trials.

Before the incremental test on the rowing ergometer and the maximal leg extension power test, a 2000 m simulated rowing on the rowing ergometer was carried out to simulate the on-water race, starting with an initial spurt, followed by a constant pace at the preferable stroke rate and to perform their best. The total and split times were recorded.

VO_{2max}

VO_{2max} was defined when oxygen consumption reached a plateau and the respiratory exchange ratio (VCO_2/VO_2) was 1.1 or greater (Shephard, 1992). Maximal values of VCO_2, VE and HR were also determined. Calibration of the air flow of the expired air was carried out before each test using a calibration syringe. The spirometer was calibrated before and after each test with a certified gas mixture. Experiments were performed at a room temperature of 24 °C and at a humidity of 46%.

Stroke power consistency

The stroke power consistency at each workload was assessed by the coefficient of variance of power (CVP) (Smith & Spinks, 1995). The stroke power consistency for each subject was expressed as CVP at the highest workload at which the subject maintained power (CVP_{high}).

Statistics

Values are presented means ± SD, unless otherwise stated. Pearson's correlation coefficient (*r*) was used to examine the interrelationships between the variables. One-way analysis of variance (ANOVA) analyzed VO_{2max} and CVP at each workload during the test. To adjust for multiple comparisons when ANOVA showed a significant difference between groups, a Tukey *post hoc* test was used to identify which group differences accounted for the significant *P* value. Stepwise multiple regression analysis was conducted to select explanatory variables that could predict the 2000 m rowing time. The explanatory variables included the VO_{2max}, VO_{2max} per body mass and CVP_{high}. Single and multiple linear regression analyses were performed to predict 2000 m rowing time. The criterion of addition and elimination of variables was a *P* value <0.05 and more than 0.1, respectively. In each statistical analysis, the significance was accepted at the 0.05 level.

Results

The VO_{2max}, leg extension power and 2000 m rowing time were $4.1 \pm 0.4\,\mathrm{min}^{-1}$, 2241 ± 286 W and 409.3 ± 12.2 s, respectively. All subjects maintained 300 W for 2 min and VO_{2max} was observed at the subsequent workload. Three subjects completed 350 W, and only one subject completed 2 min at 400 W. The CVP decreased from 3.0 ± 0.9 to 1.7 ± 0.5% (Fig. 1).

The 2000 m rowing time correlated with VO_{2max} ($r = -0.61$, $P = 0.012$), leg extension power ($r = -0.68$, $P = 0.004$) and with CVP_{high} ($r = 0.69$, $P = 0.003$). Stepwise multiple regression analysis indicated that the 2000 m rowing time could be predicted by the VO_{2max}, leg extension power and CVP_{high} (adjusted coefficient determination $r^2 = 0.79$) in this order of strength of standardized partial correlation coefficients (Table 1). The CVP_{high} correlated with the residual of the single regression between 2000 m rowing time and VO_{2max} ($r = 0.64$, $P = 0.007$) but did not correlate with those between 2000 m rowing time and leg extension power (Fig. 2).

Discussion

The major finding of study is that the 2000 m rowing time correlated with VO_{2max}, leg extension power and CVP_{high}. The CVP_{high} correlated with the residual of the single regression model of the 2000 m rowing time and VO_{2max}. Although the correlation between rowing performance and VO_{2max} of rowers is widely recognized (Secher, 1983; Kramer et al., 1994; Cosgrove et al., 1999), rowers with similar

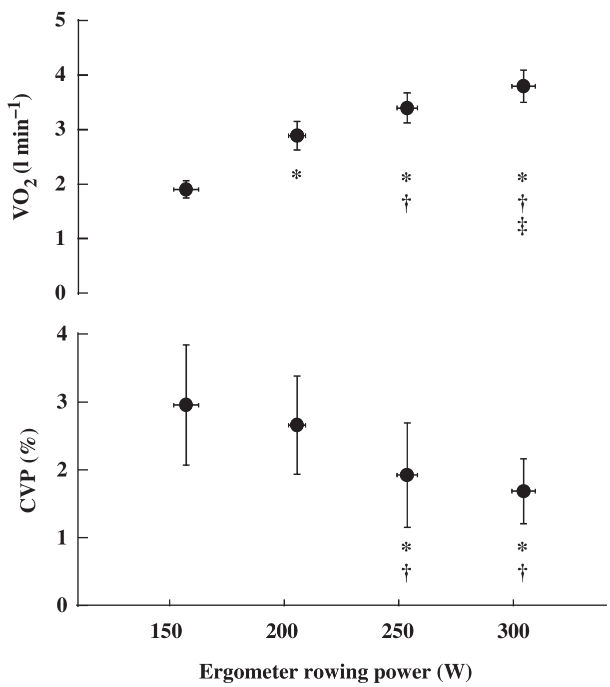

Fig. 1. Power and physiological parameters at different ergometer rowing workloads. *Different from 150 W; †different from 200 W; ‡different from 250 W. VO_{2max}, maximal oxygen uptake; CVP, coefficient of variance of power. Values are means ± SD.

Table 1. Multiple regression between 2000 m rowing time and the selected variables ($n = 16$)

Criterion variable	Explanatory variable	Regression coefficient	Standard error	Partial correlation coefficient	P value
2000 m rowing time (s)	VO_{2max}(L min^{-1})	– 13.0	3.57	– 0.47	0.003
	Leg extension power (W)	– 0.02	0.006	– 0.45	0.004
	CVP_{high} (%)	11.3	4.54	0.34	0.029

VO_{2max}, maximal oxygen uptake; CVP, coefficient of variance of power.

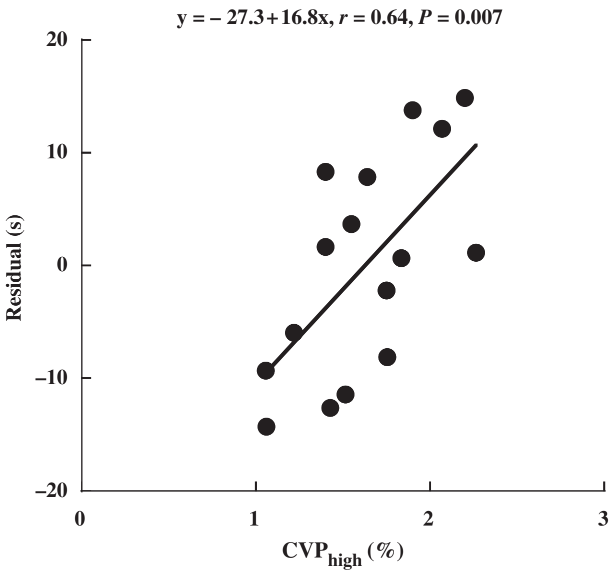

Fig. 2. Relationship between the residual of the single regression between 2000 m rowing time and maximal oxygen uptake, and coefficient of variation of power (CVP) at the highest workload.

VO_{2max} have different rowing performance (Steinacker et al., 1986; Schwanitz, 1991). The correlation between CVP_{high} and the residual of the single regression between 2000 m rowing time and VO_{2max} suggests that the stroke power consistency is related to factors influencing rowing performance that cannot be explained by VO_{2max}. Ergometer rowing performance reflects the rotational motion of flywheel affected by air resistance. When the stroke power is consistent, the flywheel continues to rotate steadily and this would be advantageous for efficient conversion of physiologic to mechanic power. Dal Monte and Komor (1989) indicate that the force during rowing is affected by oscillation of peak force during the drive portion of the stroke cycle. Although rowing power is influenced by the VO_{2max} of the rowers, the force transmitted to an ergometer is also influenced by the stroke power consistency.

There was no significant relationship between CVP_{high} and leg extension power. Competitive rowing is characterized by sustained high forces (Hartmann et al., 1993). However, there is no relationship between leg extension power and the endurance characteristics of force and power in rowing. It appears from the present result that the stroke power consistency is not strongly related to the single effort.

Rowing performance correlates with the absolute but not with the relative VO_{2max} (VO_{2max} kg^{-1} body weight) of rowers (Secher, 1993; Steinacker, 1993; Shephard, 1998; Yoshiga et al., 2000) as confirmed in this study. We further found that there was a negative correlation between the CVP_{high} and VO_{2max} per body mass ($r = -0.64$, $P = 0.008$). Higher CVPs at lower workloads (150 and 200 W) reflect the difficulty of maintaining a high power. But low-intensity CVPs were not related to rowing performance or aerobic capacity. No significant difference in CVPs between at 250 and 300 W suggests that the CVP reaches a level that is inherent to each subject, which could be an index of rowing performance other than the endurance capacity and leg extension power.

Perspectives

The present findings suggest that rowing performance can be evaluated by VO_{2max}, leg extension power and stroke power consistency. The stroke power consistency is related to the factors influencing rowing performance that cannot be explained by VO_{2max} alone. Although we studied the stroke power consistency in ergometric rowing, we would expect that the stroke power consistency plays a more important role in on-water rowing, where manipulation of oars and maintenance of boat balance under variable environmental conditions are required.

Key words: aerobic capacity, leg extension power, ergometric rowing.

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