A KINEMATIC ANALYSIS OF ROWING PERFORMANCE DURING A 2000M ERGOMETER TEST

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Abstract: The aim of this study was to investigate how force, velocity and power evaluate during a 2000m rowing test, and to examine the relation between several kinematic variables with the final result of the test. On a Concept2 Rowing ergometer ten male rowers performed a 2000m test, which was analysed in five periods, considering also the mean final results. Two-way ANOVA for repeated measures showed that force, velocity and power changes significantly during the 2000m test. The kinematic variables evidenced that only the knee, with regard to the angular displacement and angular position at the catch, changed significantly during the 2000m test. A stepwise multiple regression analysis evidenced that the knee angular position at the catch has a strong relation with the final results and can be considered as a single predictor of performance.

KEY WORDS: Rowing performance, rowing kinematics.

INTRODUCTION

Rowing simulators are often used on-land training programs (Holt et al. 2003; Ingham et al. 2002; Lamb 1989; Soper & Hume 2004; Torres-Moreno et al. 2000), and the Concept2 rowing ergometer is a reliable tool for monitoring rowing performance and for investigating factors that affect performance (MacFarlane et al. 1997; Schabort et al. 1999)

During a 2000m rowing race, rowing is a sport that demands a high technical skill level as well as strength and other physiological requirements (Lamb 1989). For this reason, in the daily routine of rowing diagnostics, force, velocity and power, as well as other variables, are quantified (Hartmann et al. 1993, Ingham et al. 2002).

Moreover, rowing biomechanics research has studied the relationship between rowing performance and selected kinematics variables (Caldwell et al. 2003; Holt et al. 2003; Kyrolainen & Smith 1999; McGregor et al. 2004; McGregor et al. 2005; Rockenbauer et al. 1992). However, biomechanical predictors of 2000m rowing performance are indistinct in the literature (Soper & Hume 2004), although body segment velocities affect performance (Soper & Hume 2004).

The general aim of this study was to determine in greater detail how force, velocity and power evaluate while the subjects perform a self-paced 2000m rowing test, and to examine the relationship between selected kinematic variables, with mean power and mean velocity in the end the 2000m rowing test.

METHODS

Ten male rowers (body mass 79.8 ± 1.7 kg; 183.8 ± 1.8 cm height; age 19.9 ± 1.0 years) volunteered to participate in this study. All subjects were well familiarised with both the ergometer (Concept2, model C) and the exercise test used in the study.

The ergometer was set with damping factor adjusted at level 3 and calibrated with the drag factor 129. The software e-Row (version 4.0) was connected to PM2+ performance monitor and used to obtain the pace, velocity and mean power of each stroke. Force was measured by a strain gauge (HBM type u9b 2Kn 1mV/V) that was attached to the chain–handle connection. Heart rate was obtained by telemetry (Polar Accurex Plus, Tempele, Finland).

The rowing kinematics data was collected in the sagittal plane, being assumed that the motion of the body segments is two-dimensional, and analysed with Ariel Performance Analysis System. Reflective markers were fixed on the left side of the wrist, elbow, shoulder, hip, knee, ankle and on the chain-handle connection. Linear velocity from the chain-handle

connection was used to separate the drive from recovery and only the drive was analysed (from the catch to the finish). Kinematics data were normalised to 100%.
The 2000m test was analysed in five periods, representing each period the mean of three consecutive strokes. Differences between periods were analysed by two-way ANOVA for repeated measures. Repeated contrasts were used to compare the five periods of 2000m test. Significance was accepted at $P<0.05$. Values presented are mean ? SED. A stepwise multiple regression analysis was used to identify the kinematic variable that can be considered as the single predictor for the 2000m performance (as response variable).
After a 10-min warm-up, subjects were asked to perform the 2000m test.

RESULTS

The 2000m rowing test was completed in 400,5 ± 5,1 seconds, with a mean power of 353,3 ± 13,7 (watts) and a mean velocity of 5,0 ± 0,1 ($m.s^{-1}$).
Force decreased from 1274,9 ± 47,4 N during the star period to 1042,8 ± 34,8 N at the end (100% of the 2000m test), or by approximately 18,2%, and the differences were significant until 50% of the test.
Velocity and power developed the same way along the 2000m test, decreasing from 5,3 ± 0,1 $m.s^{-1}$ and 422,8 ± 23,8 watts, during the start, to 4.9 ± 0.1 $m.s^{-1}$ and 326,3 ± 11,8 watts, at 75% of the test, followed by an increase to 5,1 ± 0,1 $m.s^{-1}$ and 372,0 ± 12,7 watts at 100% of the test. For velocity and power, significant differences were found from the start until 50% of the test and from 75% to the end (100% of the 2000m test) (Figure 1).

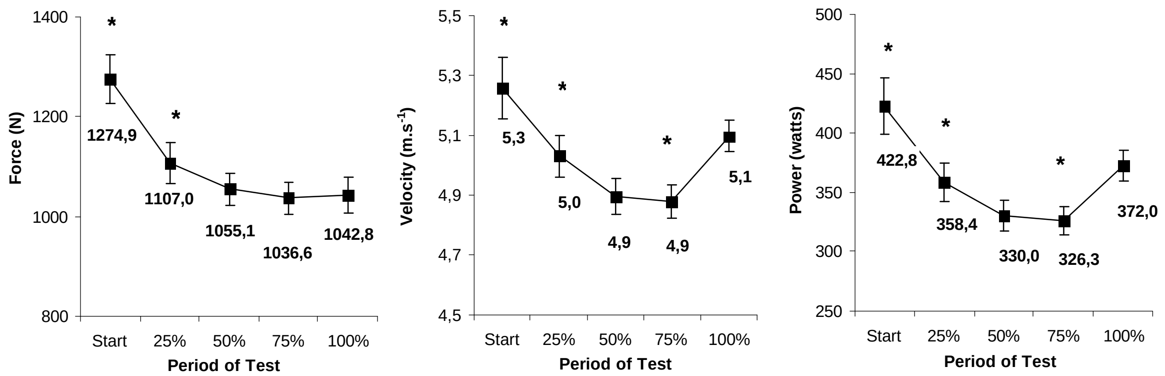

Figure 1 – Force, velocity and power in five periods of 2000m ergometer test (Start, 25%, 50%, 75% and 100%). * represents significant differences to the following period ($P<0.05$) (N=10).

The knee angular velocity during the 2000m test shows an increasing trend but differences between the five periods are not significantly different. The hip and elbow angular velocity also didn't have significant differences along the test (Table 1).
The knee angular displacement increased significantly from the start period to 25% of the 2000m test, from 94,6º ± 6,0º to 123,2º ± 2,1º, and afterwards was relatively constant. The hip and elbow angular displacement had no significant differences along the five periods of 2000m test (Table 1).
The knee angular position at the catch decreased significantly from the start to 25% of 2000m test, from 70,7º ± 7,0º to 42,5º ± 3,6º, and afterwards was relatively stable. The hip and elbow angular position (flexion and extension, respectively) at the catch, had no significant differences along the five periods of 2000m test (Table 1).
When data from the knee, hip and elbow angular displacement are entered in a stepwise multiple regression model, the only single predictor for 2000m performance (the response variable), is the elbow angular displacement, explaining changes in mean power in 47% and mean velocity in 46% (Table 2).
When data from the knee, hip and elbow angular position at the catch are entered in a stepwise multiple regression model, the only single predictor for 2000m performance (the

response variable), is the knee angular position, explaining changes in mean power in 68% and mean velocity in 67% (Table 2).
The stepwise multiple regression model, constructed with knee, hip and elbow angular velocity, did not produced statistical results to identify witch variable can explain by itself the mean power and velocity in the end of 2000m test.

Table 1 – Mean (±SEM), for maximal angular velocity (A.Vel.), angular displacement from the catch to the finish (A.Disp.), and angular position at the catch, for the knee, hip and elbow in five periods of 2000m ergometer test (N=10).

Period	Knee						Hip						Elbow					
of 2000m	A.Vel.	SEM	A.Disp.	SEM	A.Pos.	SEM	A.Vel.	SEM	A.Disp.	SEM	A.Pos.	SEM	A.Vel.	SEM	A.Disp.	SEM	A.Pos.	SEM
Start	248,4	9,7	94,6	6,0	70,7	7,0	230,3	12,5	94,5	3,6	32,7	3,8	437,9	23,2	105,3	2,0	162,3	2,1
25%	266,1	8,7	123,2	2,1	42,5	3,6	219,9	11,1	105,5	4,5	27,9	3,3	408,6	28,6	106,9	2,7	163,6	1,6
50%	266,7	10,0	122,2	2,9	42,4	4,1	205,1	10,5	101,9	4,3	23,8	2,6	394,6	29,4	105,5	3,0	163,5	1,7
75%	265,1	10,9	122,2	3,1	42,7	4,2	210,0	11,8	102,5	4,4	23,1	2,9	393,4	32,4	105,9	2,6	163,2	1,6
100%	267,7	9,7	118,3	2,8	44,7	5,0	218,0	13,5	100,9	4,0	22,2	2,7	434,0	35,5	106,1	2,9	163,4	1,7

Table 2 – Stepwise multiple regression with 2000m performance (mean power and velocity) as the response variables, for the elbow angular displacement and knee angular position (as variables entered).

Response variable	Variable entered	Results	
		R^2	Equation
Power $_{2000m}$ (watts)	Elbow $_{\text{Angular Displacement}}$ (degrees)	0,467	y=3,7028x-39,066
	Knee $_{\text{Angular Position}}$ (degrees)	0,681	y=-2,598x+479,53
Velocity $_{2000m}$ ($m.s^{-1}$)	Elbow $_{\text{Angular Displacement}}$ (degrees)	0,457	y=0,0173x+3,168
	Knee $_{\text{Angular Position}}$ (degrees)	0,667	y=-0,0121x+5,591

DISCUSSION

This study has combined kinematic data with performance data, the combination of which provides a more complete and accurate analysis of the 2000m rowing performance.
The 2000m ergometer test request considerable amount of force, velocity and power, and after the start period all this variables decrease significantly. In the end of 2000m test the increase of power is caused only by an increase of velocity, which is in agreement with previous studies (Hartmann et al. 1993).
The knee angular velocity increased slightly but nonsignificantly along the 2000m test, which is in agreement with data provided by Kyrolainen & Smith (1999) study. The knee angular displacement changes significantly from the start to the following period, caused by a change in the knee angular position at the catch, which diminishes significantly, and that has got a significant relation with 2000m performance, when determined by mean power (watts) and velocity ($m.s^{-1}$).
The hip and elbow angular velocity, angular displacement and angular position at the catch do not change when a 2000m test is performed. However, it was demonstrated that the angular displacement and angular position of the elbow has a slight positive relation with 2000m performance.

CONCLUSION

The present results are in line with those of other studies, suggesting that force and power are important to optimize rowing performance.
The kinematic data and its relation with performance allow us to say that rowers who perform a long rowing stroke with the lower limbs, with regard to its position in the beginning of each stroke (as we measured it in the catch) can expect better results. Considering also that the

angular displacement of the upper limbs have a slight influence in the final performance, we take a change to admit that extending a little more the elbow in the beginning of each stroke can also represent better results (the elbow never achieved the maximal anatomical angle in the catch, measured by its angular position).

It was apparent that angular velocity of the three joints analysed were constant throughout the 2000m test and do not influence the final performance, however there are changes in velocity and power in the end of the 2000m test that might have an explanation, witch allow us to consider future investigations analysing other factors and variables, as the angular velocity and power curves for each stroke (in agreement with the findings of Kyrolainen & Smith 1999).

The recovery phase of the rowing stroke were not included in our analysis as we deemed to be less important/trainable, however changes in force, velocity and power during the 2000m test are not fully justified. Might be important to analyse the rowing cycle as a whole.

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