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

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The aim of this study was to investigate how force, velocity and power change during a maximum 2000m-rowing test, and to examine the relationship between 2-D joint kinematics and performance. Ten male rowers performed a 2000m test, which was analysed in five periods, considering also the mean final results. One-way ANOVA for repeated measures showed that force, velocity and power changed significantly along the 2000m test. Hip, and elbow joint kinematic parameters remained unchanged throughout the test but knee's 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 is in relationship with time to finish the 2000m rowing and remained the single predictor of performance.

**KEY WORDS:** rowing, performance, kinematics.

**INTRODUCTION:** Rowing performance demands high level of technical skill and the ability to generate and sustain high amounts of force and power (Lamb 1989, Hartmann et al. 1993, Ingham et al. 2002). The biomechanics of rowing has been studied extensively, mainly with the help of rowing ergometers and in a few studies a relationship between selected kinematic variables and performance during rowing could be found (Caldwell et al. 2003; Holt et al. 2003; Kyrolainen & Smith 1999; McGregor et al. 2004; McGregor et al. 2005; Rockenbauer et al. 1992), but insofar it has not been possible to find any biomechanical factors that clearly predict performance during 2000m rowing distances (Soper & Hume 2004).
The aim of this study was to assess changes in force, linear velocity and power during the course of a self-paced 2000m maximal rowing test, and to examine the relationship between 2-D knee, hip and elbow kinematic variables and values of power and velocity obtained along the 2000m test.

**METHODS:** Ten male rowers (body mass 79.8 ± 1.7 kg; height 183.8 ± 1.8 cm; 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. They were fully informed about the procedures and their informed consent obtained.
The ergometer's damping factor was set at level 3 and calibrated with the drag factor 129. The PM2+ performance monitor was interfaced with the e-Row software (version 4.0) to obtain values of pace, velocity and mean power of each stroke. Force was measured by a strain gauge (HBM type u9b 2Kn 1mV/V), attached to the chain–handle connection. Heart rate was obtained by telemetry (Polar Accurex Plus, Tempele, Finland).
digital images were recorded in the sagital plane at 100Hz (JVC, GRDV9800). Reflective markers were fixed on the left side of the wrist, elbow, shoulder, hip, knee, ankle and on the chain-handle link. Digitization was performed semi-automatically. Linear velocity from the chain-handle connection was used to separate the drive phase from the recovery phase. Only the drive phase was considered for further analysis (from the catch to the finish). The duration of the drive was normalised (method for normalisation) to 100%.
The 2000m test was separated in five time intervals: start, 25%, 50%, 75% and 100% of the duration of the test and values in each moment represent averages of three consecutive strokes. Differences between periods were analysed by one-way ANOVA for repeated measures. Repeated contrasts were used to compare the five periods of 2000m test (SPSS, version 13.0). Significance was accepted at $P<0.05$. Values are presented as mean ± SEM. The stepwise multiple regression analysis was used to assess the relationship between kinematic variable performance parameters.

**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 applied to the handle bar decreased from 1274,9 ± 47,4 N, at the start, to 1042,8 ± 34,8 N at the end of the 2000m test, representing a decline in force production of 18,2% (Fig. 1).
Velocity and power changed similarly 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. Both velocity and power increased to 5,1 ± 0,1 m.s-1 and 372,0 ± 12,7 watts near de end of the 2000m 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).

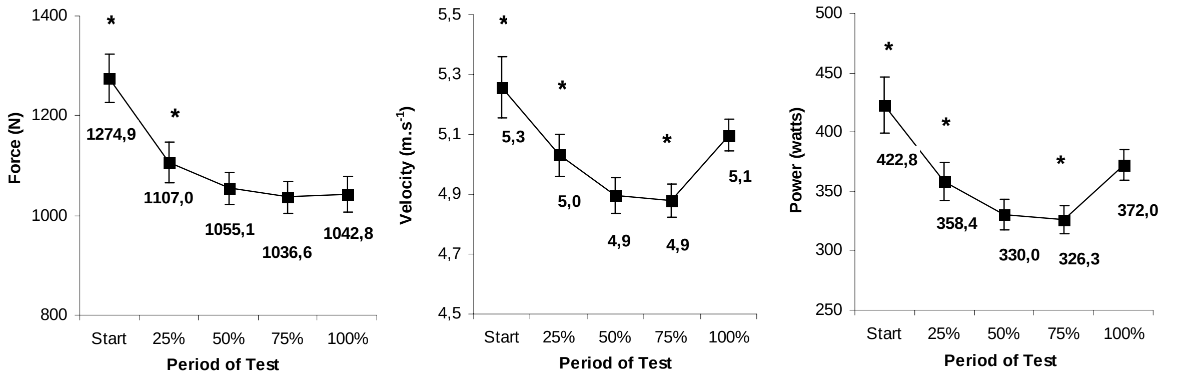


Figure 1 – Force, velocity and power in five time intervals of 2000m ergometer test (Start, 25%, 50%, 75% and 100%). * represents significant differences to the following period (P<0.05) (N=10).

Knee angular velocity during the 2000m test reveals a trend to increase but differences between the five periods are not significantly different. The hip and elbow angular velocity also remained unchanged along the performance of the rowing test (Table 1).
Knee angular displacement increased significantly from 94,6º ± 6,0º at the start of the 2000m test to 123,2º ± 2,1º at 25% of its duration. Afterwards, knee joint excursion remained stable. The amplitudes of movement of both hip and elbow joints did not vary throughout the 2000m test (Table 1).
Knee position at the catch point decreased significantly from the start to 25% of the 2000m test, from 70,7º ± 7,0º to 42,5º ± 3,6º (180º full extension), without further changes afterwards. Hip and elbow joint position at the catch point (in flexed and extended position, respectively), remain unaltered during the entire 2000m test (Table 1).
Considering knee, hip and elbow angular displacement data, stepwise multiple regression reveals that the amplitude of elbow joint movement is the only variable that significantly explains the variance of parameters related to 2000m performance (Table 2).
When data from the knee, hip and elbow angular position at the catch are considered, 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).
Values of angular velocity of each of the three joints analysed were not related to changes in mean power and mean velocity of the 2000m tests.

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 $_{Angular\ Displacement}$ (degrees) | 0,467 | y=3,7028x-39,066 |
| | Knee $_{Angular\ Position}$ (degrees) | 0,681 | y=-2,598x+479,53 |
| Velocity $_{2000m}$ ($m.s^{-1}$) | Elbow $_{Angular\ Displacement}$ (degrees) | 0,457 | y=0,0173x+3,168 |
| | Knee $_{Angular\ Position}$ (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 mainly 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 the study of Kyrolainen & Smith (1999). The knee angular displacement increases significantly right after the start of the test, caused by a more flexed knee position at the catch, and differences in movement amplitude of this joint affects the time taken to complete the 2000m rowing task.

Changes in elbow joint movement amplitude also emerged as in relationship with the results of the 2000m rowing time trial. The decrease in the movement amplitude of this joint may indicate muscle fatigue of the upper limb musculature, and suggests that upper limb muscles fatigue is the limiting factor of the capacity to sustain high levels of force and power production during rowing.

The hip and elbow angular velocity, angular displacement and angular position at the catch do not change throughout the 2000m test, indicating that these are stable features of the rowing technique even at high levels of physical exertion.

**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 are able to sustain a long rowing stroke with the lower limbs and those who extend more the upper limbs in the beginning of each stroke (as we measured it in the catch), can expect better results.

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, which allow us to consider future investigations analysing other factors and variables, such 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 were not fully explained by only analysing the drive phase thus future analyses should consider the whole rowing cycle.

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