DIFFERENCES BETWEEN ELITE AND NOVICE ROWERS ON ERGOMETER

Tomaž Černe[1], Roman Kamnik[2], Jerneja Žganec Gros[1], Marko Munih[2]

Alpineon, Ljubljana, Slovenia[1]
University of Ljubljana, Faculty of Electrical Engineering, Ljubljana, Slovenia[2]

The study focuses on how technique of differently skilled rowers is dependent on stroke rate. Five elite and five novice rowers participated, and the selected kinematic and kinetic parameters of rowing on an ergometer were analyzed at stroke rates of 20 strokes/min, 26 strokes/min and 34 strokes/min. The results show that elite rowers use consistent rowing technique at all stroke rates while the technique of novice rowers significantly differs from the elites' and varies between subjects and with stroke rate. Variation in technique among five elite rowers is small. Although a lack of technique is evident, novice rowers demonstrated a consistent pattern at the same stroke rate. On the basis of the results, the crucial parameters that differentiate elite and novice rowers are indicated.

KEY WORDS: rowing, biomechanics, level of expertise.

INTRODUCTION: Ergometer rowing is a complex motor skill. Rowing ergometers can be found in most gyms and fitness centres, but many people who use them have little or no instruction in rowing technique. Feedback of information is considered important for learning motor skills (Newell & Walter, 1981). A novel approach for training both novice and elite rowers incorporates real-time feedback providing quantitative information about rowing kinematic and kinetic parameters (MacFarlane, Edmond & Walmsley, 1997). Smith & Loschner (2002) described rowing parameters that influence performance and stated that these should form the basis of feedback.
Černe and colleagues (2011) have developed an instrumented rowing ergometer system that acquire data in real-time. We propose a training platform for learning rowing technique on an ergometer which provides not only biomechanics-related feedback about performance but also instructions for technique improvement.
The goal of this study was to investigate the variation of rowing technique with a main focus being on the differences between elite and novice rowers in order to identify parameters that have the potential to be incorporated in the training platform for learning rowing technique, their range of values and consistency. With this objective, we analyzed technique of ergometer rowing in five elite and five novice male rowers.

METHODS: Ten males participated in this study and this cohort included five elite rowers (30.4 y: range 20-38 y; 191.6 cm: range 186-197 cm; 89.0 kg: range 84-100 kg), who are members of the National Rowing Team and five novices rowers (28.0 y: range 25-32 y; 182.8 cm; range 171- 188 cm; 84.6 kg: range 76-100 kg), who were introduced to a rowing ergometer for the first time.
We used a measurement system for rowing assessment on an ergometer developed by Černe et al. (2011). The measurement system consisted of a Concept II rowing ergometer instrumented by a load cell for measuring the force of arm pull, a 6-DOF force sensor for measuring the force of leg drive, an optical encoder for measuring the length of a chain pull and a wire optical encoder for measuring the position of the seat. Optotrak Certus and 14 measuring markers were used for measuring the kinematics of the rower's movement. Joint loading was calculated according to the recursive Newton-Euler inverse dynamics approach for ankle, knee, hip, lumbo-sacral (LS), and shoulder joints (Kane & Levinson, 1985).
Each subject's measurement test consisted of three types of activity; each had a defined stroke rate according to typical training procedure: an aerobic type activity at a rate of 20 strokes/min, an aerobic threshold activity at 26 strokes/min and an anaerobic activity at 34 strokes/min.
Data from ten consecutive strokes at each stroke rate from each participant were acquired for analysis. The Matlab software package (The MathWorks, Natict, MA) was used for data

processing and SPSS (IBM, Armonk, NY) for statistical analysis. Evaluation of motion performance was assessed by calculating the trajectory tracking repeatability (RT_p) following the ISO 9283 standard (1998). We performed a one-way repeated-measures ANOVA with three levels of stroke rate for each variable (stroke rate influence to variables) and a two-way mixed-design ANOVA with one within-subject factor (stroke rate) and one between-subjects factor (rower type). In all cases, the threshold for significance was set at p=0.05.The variance-to-mean ratio (VMR) was used to evaluate the consistency of variables. A VMR below 0.05 was considered insignificant.

RESULTS: Results for the stroke length L (difference between the max and min length of the chain pull), normalized stroke length L_n (L divided by the height of the rower), the ratio of the stroke phases R (ratio between the duration of the drive and the recovery phase of the stroke), the maximum pull force F_p (max absolute value of the handle pull force), the max feet reaction force F_r (max absolute value of the measured force vector on the foot stretcher), trunk inclination (angle between trunk and coronal plane) φ_s (start of drive phase) and φ_f (finish of drive phase) and RT_p are presented in Table 1.

Table 1: Results of averaged rowing biomechanical parameters with standard deviation.

	Elite rowers			Novice rowers		
Str. rate	20	26	34	20	26	34
L (m)	1.59 (0.05)	1.61 (0.07)	1.57 (0.07)	0.98 (0.16)	1.09 (0.12)	1.16 (0.19)
L_n	0.83 (0.02)	0.84 (0.03)	0.83 (0.04)	0.54 (0.10)	0.60 (0.09)	0.54 (0.12)
R	1:2.04 (0.15)	1:1.66 (0.06)	1:1.31 (0.09)	1:1.01 (0.18)	1:1.00 (0.12)	1:1.04 (0.06)
F_p (N)	1,022 (74)	1,088 (67)	1,162 (93)	145 (159)	238 (160)	448 (190)
F_r (N)	1,232 (105)	1,250 (84)	1,294 (92)	440 (97)	612 (97)	816 (89)
φ_s (°)	-33.2 (3.2)	-33.4 (3.3)	-36.1 (4.3)	-21.6 (7.6)	-17.9 (8.4)	-18.8 (8.1)
φ_f (°)	37.0 (3.9)	39.8 (3.9)	39.9 (4.3)	17.8 (19.4)	19.2 (17.9)	19.7 (19.1)
RT_p (cm)	4.5 (1.5)	4.0 (1.4)	4.4 (2.0)	7.0 (2.2)	7.5 (2.6)	7.0 (1.3)

Figure 1 shows the handle motion trajectories from six typical rowers presented in the sagittal plane (x represents the horizontal direction, y represents the vertical).

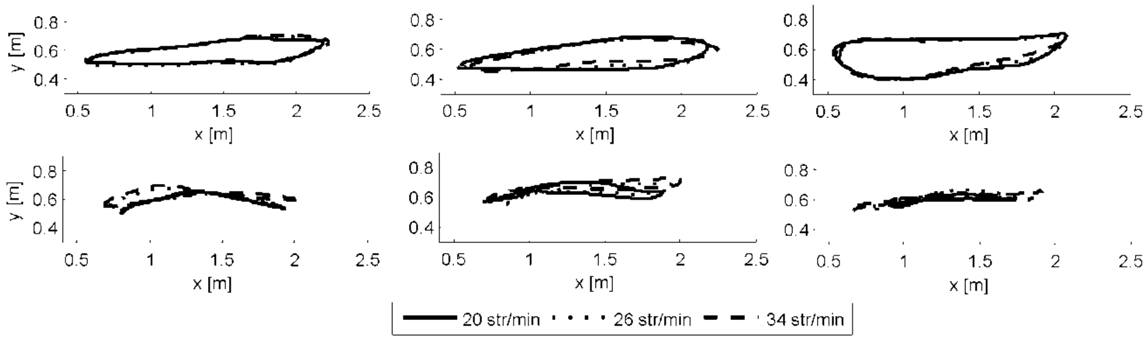

Figure 1: Handle motion trajectories during a single stroke at different stroke rates: elite rowers at top (E1 left, E2 middle, E5 right), novice rowers at bottom (N2 left, N3 middle, N4 right).

The torque around the transversal direction M_z was analyzed as the parameter of joint loadings that contribute to movement in the sagittal plane. For better comparison, data have been normalized to a longitudinal handle displacement M_h (the beginning of the drive was assigned to -100, the end of drive and the start of the recovery to 0 and the end of the recovery to 100). Figure 2 presents the instant of peak torque at knee joint and LS joint.
Results for one-way repeated-measures ANOVA with three levels of stroke rate (first two rows) and two-way mixed-design ANOVA with one within-subject factor (stroke rate) and one between-subjects factor (third row) are presented in Table 2. An asterisk means that there is at least a 95% confidence that the differences in variables are not random, but are consequence of the changes in stroke rate or rower type. The numbers represent the size of the effect of the stroke rate or rower type, a higher number describes greater distinction.

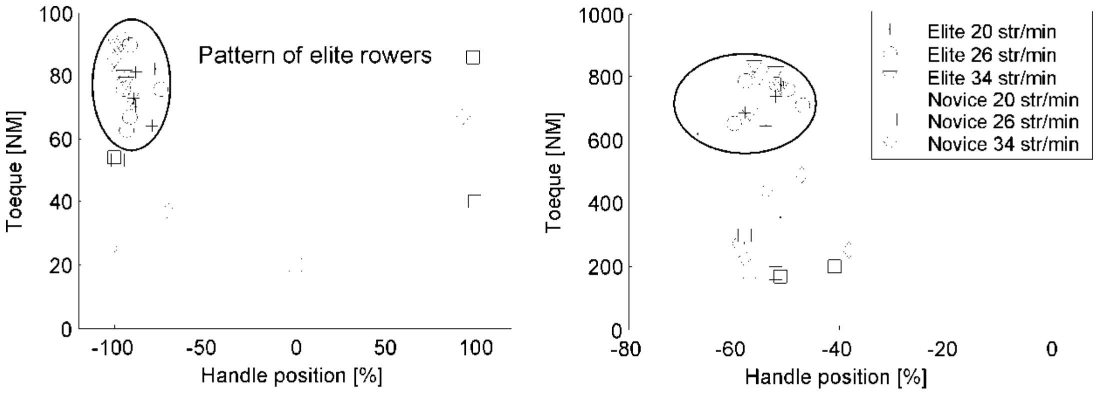

Figure 2: The instant of peak torque at knee joint (left) and LS joint (right).

Table 2: Partial eta-squared obtained using analysis of variance for different parameters.

	L_n	R	F_p	F_r	RT_p	φ_s	φ_f	$M_{z\ k}$	$M_{h\ k}$	$M_{z\ ls}$	$M_{h\ ls}$
Elite	0.33	0.99*	0.58	0.62*	0.53	0.58	0.69*	0.36	0.77*	0.57	0.04
Novice	0.60*	0.08	0.83*	0.87*	0.03	0.14	0.10	0.84*	0.03	0.75*	0.72*
Rower type	0.78*	0.92*	0.93*	0.95*	0.57*	0.70*	0.37	0.70*	0.01	0.93*	0.47*

DISCUSSION: The pattern of *L* in elite rowers was extremely consistent, with an average within-subject standard deviation (SD) less than 1 cm (*VMR*=.04). The *L* of novices varied. The L_n was smaller than that of elite rowers and increased with increasing stroke rate. The average within-subject SD of strokes from single novice rowers was less than 3 cm, meaning that novices rowed with a fairly constant *L* at a certain stroke rate. In conclusion, the *L* of elite rowers was consistent and not dependent on the stroke rate (p=0.21) while the stroke length of novices was consistent only within the same stroke rate, and lengthened with increasing stroke rate (p=0.04).

The elite rowers performed a fast drive and a slow recovery during a single stroke, so the ratio between the drive and recovery phase durations decreased with increasing stroke rate (p<0.01). This means that the recovery duration has more influence on the stroke rate than drive duration. Novices achieved a lower ratio (around 1:1), which did not change significantly (p=0.60) with increasing stroke rate.

The results showed that the average SD of F_r of elite rowers within the same stroke rate was 2.4% and could be considered insignificant, and that the average F_r at stroke rate 34 strokes/min was 4.7 % higher than that at stroke rate 20 strokes/min. It was a small increase, but could be noticed as a trend since it was present in all the elite rowers (p=0.08). The results showed that the average VMR of F_p within the same stroke rate was *VMR*=0.03. It can be seen from the results that the average F_p of elite rowers at stroke rate 34 strokes/min was 12.4 % higher than that at stroke rate 20 strokes/min. This trend of increasing F_p with increasing stroke rate was evident in all the elite rowers (p=0.02). The most obvious difference occurred at a rate of 20 strokes/min, where novice rowers hardly produced any force on the handle. The F_p and F_r increased considerably with increasing stroke rate. The F_r of subject N4 increased by 2.6 times and F_p tenfold. At the stroke rate of 34 strokes/min, novice rowers developed around 2/3 of the elite rowers' foot reaction forces, but they were obviously not able to transfer this force to the handle, where their force was only around 1/3 of the elites'. In conclusion, the peaks of the handle pull forces of elite rowers were constant, but increased slightly with increasing stroke rate. The peak forces of novices were smaller than the forces of elites, and increased significantly (p<.01) with increasing stroke rate.

The handle of elite rowers followed the upper part of motion trajectory towards the backward position (increasing x), during the recovery phase then decreased x by following the lower part of the trajectory in Figure 1 until the next stroke. As can be observed, there were no significant variations in the handle motion of the elite rowers at various stroke rates (p=0.73). The handle motion trajectories of the novices were more variable at different strokes; there was no circular motion typical of elite rowers. Figure 1 also shows the short stroke length of novices. The RT_p showed that handle motion trajectories of novices were almost double as in elites. We concluded there were no significant variations in the handle motion of the elite rowers at various stroke rates while the handle motion trajectories of novice rowers demonstrated their lack of technique.

We examined the angle of trunk inclination at the beginning and end of the drive phase. Novices lean significantly less than elites. There was no evident difference at different stroke rates ($p>0.05$), except in the angle at the end of the drive phase of elite rowers ($p=0.02$); however, we did not observe any pattern in stroke dependency. We concluded that the trunk inclination angle at the beginning and end of the drive phase of elite and novice rowers stayed constant. However, the range of trunk motion of novices was smaller than that of elites.

The analysis of the body joint loadings showed that the largest joint loadings of all elite rowers occurred during the drive phase. Joint loadings in the knees were linked with foot reaction forces. Since the elite rowers produced a larger force, their joint loadings were higher than those of novice rowers, as shown in Figure 2 (left). It was evident that all elite rowers had a similar pattern of the instant of peak value occurrence, concentrated around -89% (*SD*=7%) of handle position during a single stroke. Occurrences of peak values of novice rowers were scattered. Joint loadings in the LS joint were related to handle pull force. Since the elite rowers produced a larger force, their LS joint loadings were larger than those of novice rowers. Figure 2 (right) shows that all the elite rowers have a similar pattern regarding the instant of peak torque value occurrence, concentrated around -55% (*SD*=5%) of handle position during a single stroke. The instants of peak value of novice rowers were more scattered, but occured all in the drive phase. The results showed that torque at the knee reached its peak before torque at the LS joint, and that LS joint loadings were higher. We concluded that the value of knee and LS joint loading increased with increasing stroke rate, while the instant of peak value occurrence did not vary and had typical patterns.

CONCLUSION: The results showed noticeable distinctions between the elite and novice rowers. It was demonstrated that the elite rowers used a similar and consistent rowing technique at all stroke rates, while the technique of novice rowers varied. Our analysis revealed that the technique of elite rowers was consistent regardless of the stroke rate, while the technique of novice rowers' varied significantly. Although novice rowers showed lack of technique, and changed technique at different stroke rates, they had good consistency at the same stroke rate. With the assumption that elite rowers row efficiently, we can use their data as a reference. The differences in the parameters of novice rowers from the reference can be used as descriptors of irregularities in ergometer rowing technique that lead to poor efficiency and can be the core of instructions for technique improvement.

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