USING REAL-TIME BIOMECHANICAL FEEDBACK TO CHANGE ERGOMETER ROWING TECHNIQUE

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Study focuses on improving ergometer rowing technique using biomechanical feedback. Kinetic and kinematic data are acquired during rowing, processed, and compared with reference models based on skilled rowers. Feedback information provides knowledge of performance using concurrent feedback, video feedback, video modelling, and error correction strategies. Based on the real-time feedback, the rower modifies movement towards a proper technique. 36 participants in three groups took part in an evaluation study. One group trained without supervision, one with a trainer, and one with the real-time biomechanical feedback. The results show that participants were able to utilize the provided feedback. The results of training with the biomechanical feedback were much better than training without supervision and comparable to training with a trainer.

KEY WORDS: human kinematics, motor learning, modelling, virtual environment

INTRODUCTION: Ergometer rowing has become established as a sport in its own. Ergometer rowing is a complex motor skill. A rower must have a good command of technique, timing, and power. Biomechanical feedback can be used for successful alteration of an athlete's technique (Buttifield, Ball, MacMahon, & Farrow, 2009). Video feedback involves showing an athlete a video clip of his or her own performance of a particular skill, and video modelling involves presenting the athlete with a video clip of an expert performing the skill. The combined use of video modelling and video feedback holds promise for improving the execution of complex athletic skills (Boyer, Miltenberger, Batsche, & Fogel, 2009; Eaves, Breslin, Van Schaik, Robinson, & Spears, 2011). Video feedback in conjunction with verbal cues and error correction advice has been shown to benefit skill acquisition (Rucci, & Tomporowski, 2010).
The goal of this study was to propose an alternative method for supervision and learning of proper ergometer rowing technique. The method uses biomechanical feedback to complement the method of training with a trainer. To demonstrate the method, an ergometer training platform with real-time feedback information has been developed and evaluated.

METHODS: For the evaluation of the ergometer training platform, 36 males with no prior experience of rowing participated in the study. Participants were randomly distributed into three groups of 12 participants: group A (30.7 [range 25-38] years; 180.8 [172-189] cm; 78.6 [58-97] kg), group T (30.5 [22-45] years; 180.3 [170-193] cm; 78.0 [69-96] kg), and group S (26.4 [17-31] years; 181.7 [170-193] cm; 78.8 [55-98] kg). After warming up with running or bike spinning and dynamic stretching exercises, each participant performed an initial test, Test 1 (1T). After Test 1, training was performed based on the group type: group A trained alone without supervision, group T trained under the supervision of a trainer, and group S used the developed training platform. The training consisted of 3 5-minute intervals for all groups. After the training, participants performed Test 2 (2T). Each subject's test consisted of two parts; 2 minutes of rowing with a target stroke rate of 20 strokes/minute and rowing over a 500-meter distance at top speed. Subjects were given 2 minutes of rest time between the parts of the test. During the tests, data was acquired for analysis.
The ergometer training platform is controlled using the xPC Target real-time environment (The MathWorks, Natict, MA) and consists of a measurement module, a data processing module, a reference module and a module for feedback information. The measurement module includes a load cell that measures the arm pull force, a 6-DOF force sensor that measures the leg drive force, an optical encoder that measures the length of a chain pull, and a wire optical encoder that measures the position of the seat (Černe, Kamnik, & Munih,

2011). The optical system Optotrak Certus with 3 measuring markers was used to measure the upper body orientation. The data is processed in the data processing module that calculates biomechanical parameters. Based on experimental data from skilled rowers (Černe, Kamnik, Vesnicer, Žganec Gros, & Munih, 2013), the reference module describes proper ergometer rowing technique. Fuzzy logic was used to model trunk inclination and seat position, nonlinear dynamical systems were used to to model periodic handle movement, mathematical modelling was used to describe joint angles and rowing phase duration, a reference interval was used to define stroke length, maximum forces and maximal trunk inclination, and a conditional distribution was used to model force curves. The reference module compares the biomechanical data of the trainee with the reference data. Based on the results of the comparison, the feedback information module determines the needed instructions and outputs graphical and audio information to the trainee rower. The developed feedback is based on knowledge of performance, concurrent feedback, video feedback, video modelling, and error correction strategies. The feedback to the user is provided in a three-tiered learning system. The first level deals with body posture and includes information on stroke length, seat position, trunk inclination and sequence of body segment movements. The second level deals with the kinematics of movement and is represented by the duration of stroke phases. The third level represents the kinetics of movement, which is shown by the time course of the forces. When the rower acquires the skills of each level, the system proceeds to higher levels. The main visual element at all levels of feedback is a virtual mirror (Koritnik, Bajd, & Munih, 2008): an animation with two figures where the figure closer on the screen represents the current body posture of the trainee. The figure behind it is shaded and represents the reference body posture. Graphs, bars and written instructions are used to provide additional information. Feedback information to the trainee is provided on a screen in real-time using Musculo-Skeletal Modelling Software - MSMS (Medical Device Development Facility, University of Southern California, Los Angeles, CA). According to the feedback information, the rower modifies movement towards proper ergometer rowing technique.

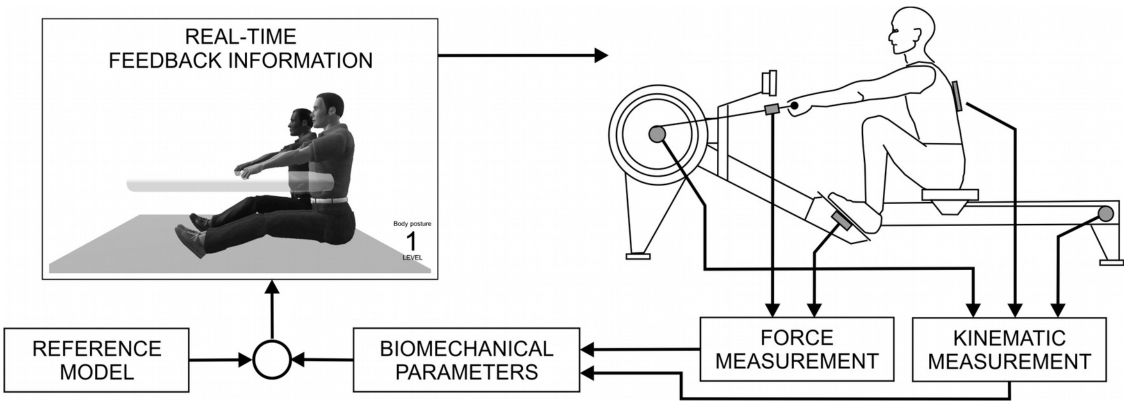

Figure 1: The concept of the ergometer training platform that uses real-time biomechanical feedback to change ergometer rowing technique.

Matlab (The MathWorks, Natict, MA) was used for data processing while SPSS (IBM, Armonk, NY) was used for statistical analysis. A one-way repeated-measures analysis of variance (ANOVA) was performed with different variables. The threshold for significance was set at p=0.05. The coefficient of variation (*CV*) was used to evaluate the consistency of variables. A *CV* below 0.05 was considered insignificant.

RESULTS: Results for the stroke rate R, normalized stroke length L_n (difference between the maximal and minimal length of the chain pull divided by the seat displacement at the finish of the drive phase, when the legs are fully extended), duration of the drive phase t_d, trunk inclination (angle between trunk and coronal plane) φ_s (start of drive phase) and φ_f (finish of drive phase), the maximum pull force $F_{p,max}$ (max absolute value of the handle pull force), the max feet reaction force $F_{r.max}$ (max absolute value of the measured force vector on the foot stretcher), and stroke work are presented in Table 1 for the 2-minute test and in Table 2 for the 500-meter test. An asterisk represents $CV<0.05$. Results for one-way repeated-measures ANOVA between tests before and after the training are presented in Table 3. An asterisk represents $p<0.05$, meaning that there is at least a 95% confidence that the differences in variables are a consequence of the training. Partial eta-squared was used to estimate the training effect, the higher number represents higher effect.

Table 1: Results of averaged rowing parameters with standard deviation for the 2-minute test.

	Group A		Group T		Group S	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
R **(str/min)**	22 (1)	21 (0)*	22 (1)	21 (1)*	22 (1)	21 (1)*
L_n	1.48 (0.33)	1.64 (0.29)*	1.32 (0.14)	1.72 (0.12)*	1.29 (0.25)	1.79 (0.13)*
φ_s (°)	26 (16)	32 (16)	23 (17)	38 (10)	24 (14)	40 (8)
φ_f (°)	-20 (19)	-24 (24)	-9 (13)*	-22 (9)*	-6 (8)	-29 (8)*
t_d (s)	1.26 (0.17)	1.26 (0.21)	1.32 (0.16)	1.07 (0.11)	1.37 (0.17)	1.09 (0.08)
$F_{p,max}$ (N)	471 (319)	582 (341)	294 (158)	818 (112)	292 (187)	826 (182)
$F_{r,max}$ (N)	306 (152)	324 (154)	232 (72)	411 (64)	220 (59)	427 (86)
A **(J)**	338 (245)	437 (281)	187 (92)	596 (98)	180 (115)	632 (142)

Table 2: Results of averaged rowing parameters with standard deviation for the 500-meter test.

	Group A		Group T		Group S	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
R **(str./min.)**	34 (5)*	34 (6)	34 (2)	34 (2)*	38 (8)	33 (3)*
L_n	1.61 (0.18)*	1.64 (0.21)*	1.63 (0.18)*	1.73 (0.12)*	1.51 (0.22)*	1.78 (0.10)*
φ_s (°)	36 (11)	34 (17)	33 (19)	45 (6)	31(10)	40 (7)
φ_f (°)	-19 (19)	-19 (19)*	-14 (9)	-17 (6)*	-7 (14)*	-29 (8)*
t_d (s)	0.87 (0.10)	0.86 (0.09)	0.86 (0.09)	0.86 (0.05)	0.83 (0.14)	0.90 (0.06)
$F_{p,max}$ (N)	790 (176)	837 (149)	773 (142)	891 (125)	725 (178)	898 (166)
$F_{r,max}$ (N)	409 (63)	446 (71)	429 (70)	475 (60)	424 (83)	463 (68)
A **(J)**	527 (109)	572 (131)	538 (113)	625 (102)	467 (142)	655 (84)

Table 3: Partial eta-squared obtained using analysis of variance for different parameters.

Test	Group	L_n	φ_s	φ_f	t_d	$F_{p,max}$	$F_{r,max}$	A
	A	0.29	0.09	0.11	0.00	0.24	0.03	0.20
2 min.	T	0.94*	0.56*	0.56*	0.64*	0.91*	0.83*	0.93*
	S	0.80*	0.66*	0.91*	0.74*	0.86*	0.87*	0.86*
	A	0.02	0.04	0.03	0.02	0.19	0.49*	0.18
500 m	T	0.30*	0.30*	0.09	0.01	0.64*	0.51*	0.49*
	S	0.69*	0.51*	0.68*	0.23	0.59*	0.34*	0.73*

DISCUSSION: The results in Table 1 show that the coefficient of variation of the stroke rate and stroke length were below 0.05 for all groups in Test 2 . This indicates that participants learned how to continuously control these two parameters.
The stroke length at 1T-500m was larger than at 1T-2min, but shorter than values defined by the reference module. In both parts of the test the stroke length was enlarged during training. However, only half of group A participants achieved the reference value while all participants in group T and S did so.
There was no statistical difference in trunk inclination between the 2-minute and 500-meter tests. In general, φ_s values at Test 1 corresponded to the reference model values. Large standard deviations of φ_f indicate that subjects use different rowing patterns. Group A participants did not change trunk inclination during the training, while the groups T and S

achieved values similar to reference values. However, the results show that the trainer's criteria for φ_f are different from those of the reference model.
Elite rowers perform a fast drive and a slow recovery during a single stroke. No participants used this concept 1T-2min. Group A also did not learn it during training, resulting in an unchanged t_d at 2T-2min. Groups T and S were able to learn the fast drive concept and lowered their t_d during the 2T-2min test. There was no change in t_d during the 500 m test.
The force values were always higher in test 2 then in test 1. Groups T and S increased their force values in the 2-minute test more than 7 times higher than group A did. At 500 m, handle pull force values are more than 3 times higher in groups T and S compared to group A, with similar foot reaction forces. There are noticeable differences in parameter values between the 2-minute and 500-meter tests within test 1 in all groups. This indicates that, in the 2-minute test, participants did not produce the kind of forces that they produced during the 500-meter test. The differences remained almost unchanged during test 2 in group A (for example: $F_{p,max}$ was 319 N at test 1 and 255 N at test 2), but decreased considerably in groups T and S (for example: $F_{p,max}$ decreased from 479 N to 73 N in group T and from 433 N to 72 N in group S).
During test 2, all groups produced more stroke work. However, during the 2-minute test, the increases in groups T and S were significantly higher than in group A. There was also a large standard deviation among participants, representing the use of different rowing techniques.
The results of ANOVA in Table 3 confirm the findings of the parameter analysis. During the 2-minute test, training had an influence on all parameters in groups T and S, but not in group A. There is also no significant difference between groups T and S. During the 500-meter test, the training had no influence on t_d. There is no significant change in φ_f in group T, representing that the trainer did not force proper trunk inclination. In group A, the training period only influenced $F_{r,max}$.

CONCLUSION: An ergometer training platform with real-time biomechanical feedback for monitoring and improving rowing technique has been developed and evaluated. Feedback information was divided into three levels: body posture, timing and forces. The evaluation study showed that participants were able to understand the provided feedback and utilize it to learn proper movement strategies. The results of training with the developed platform were much better than results of training without supervision and comparable with results of training with trainer supervision. The study showed that biomechanical feedback can improve ergometer rowing technique.

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