Rowing stroke on a single scull versus rowing stroke on an ergometer Concept 2 - Preliminary case study

Martina Zbořilová[1], **Jan Sedlák**[2], **Bronislav Kračmar**[1]
[1]*Charles University in Prague, Faculty of Physical Education and Sport*
[2]*Czech Technical University in Prag, Faculty of Electrical Engineering*

Abstract

The results of common studies have shown that rowing ergometers currently used for training and for competing have a fixed support base contrary to a real rowing boat, what cause differences in muscular coordination. In the Czech Republic, there is a lack of evidence of this issue despite the fact of success achieved by Czech rowers on the world rowing competitions. Objective: The purpose of the present preliminary case study was to determine a specific structure in timing of 16 selected muscles of specifically chosen experienced elite rower, during two movement patterns: rowing on a single scull versus rowing on an ergometer Concept 2. Methods: By surface electromyography (EMG) we recorded muscular activity, synergies and involvement throughout mean cycle of the rowing stroke. Participant of this study, trained athlete, performed three 2 min. trials on an ergometer Concept 2 separated by 3 min. break. After 10 min athlete repeated three times 2min of rowing separated by 3 min break. Results: The mutual correlations of mean EMG curves of all measured muscles showed, that there were not found any differences in inter-locomotive synchronization of measured muscles. Established values of correlation (r) showed higher level of dynamic balance (performance similarity) between both measured activities. But determination of the muscular activity timing, considering onsets and cessations, was in the percentual results explication of the movement cycle inter-locomotive different. Conclusion: Results showed a great similarity in synergies organizing the muscular coordination in between both measured physical activities. But specific structure timing of the movement in measured muscles was inter-locomotive different in the moments of muscular activity onsets during rowing and during ergometer rowing. This is attributed to the specificity of on-water locomotion.

Key words:

Rowing, Concept 2, Electromyography, Biomechanics

Souhrn

Výsledky zahraničních studií ukázaly, že veslařské trenažery, aktuálně používané pro trénink a závodění, mají pevný bod opory, na rozdíl od veslařské lodě, což způsobuje rozdíly ve svalové koordinace. V České republice je nedostatek literatury na toto téma, přestože čeští veslaři dosahují mnoha výsledků. Cílem této studie pilotní případové studie je determinovat a specifikovat strukturu timingu šestnácti vybraných svalů u zkušeného veslaře ve dvou výzkumných situacích – při veslování na skifu a při jízdě na trenažeru Concept 2. Byla použita metoda povrchové polyelektromyografie, která zaznamenává svalovou aktivitu a zapojení během průměrného cyklu veslařského tempa. Účastník této studie absolvoval tři dvouminutové úseky na veslařském trenažeru Concept 2, oddělené pauzou tři minuty. Pak po deseti minutách absolvoval znovu 3x 2min/3min pauza. Vzájemné korelace průměrných EMG obálek všech měřených svalů ukázaly, že nebyly nalezeny žádné rozdíly v interlokomoční synchronizaci změřených svalů. Dosažené hodnoty korelace (r) ukázaly interlokomočně velkou podobnost v synergii vzájemné svalové koordinace u obou měřených výzkumných situací. Avšak determinace svalového timingu, zahrnující počátky a konce svalové aktivity byla *v procentuálním vyjádření u všech měřených svalů v obou výzkumných situací rozdílná. Toto může být způsobeno specifickou lokomocí na vodním povrchu.*

Klíčová slova:
Veslování, Concept 2, electromyografie, biomechanika

Introduction

Rowing is a complex of motor skills. A considerable amount of research has been done on the mechanics and biomechanics of rowing. Because of the demand for all-year training and control tool, manufacturers developed ergometers for indoor training. Kleshnev (2016) observed rowing ergometer as an efficient device to simulate biomechanical and physiological demands of rowing. Including the use of rowing ergometers as a means for indoor training, rowing became a year-round sport. Consequently, modelled rowing on an ergometer Concept 2 (Concept2, Inc., Morrisville, VT, USA) became a matter to compare with the real on-water rowing. For instance, Marcolin, Lentola, Paoli, & Petrone (2015) compared electromyographic results of elite rowers on-water and ergometer tests. Results showed higher muscles activity on the ergometer, but different coordinative patterns comparing these experimental conditions. Anyway, they concluded ergometer as a valid training device. However specific mechanical variances of these two types of physical activity may affect the pattern of muscle recruitment, coordination and adaptation. Rowing as a power-endurance sport recruits approximately 70% of total body mass and muscle coordination is particularly important due to affect rowing performance (Rodriguez, 1990). Rowing on a Concept 2 ergometer constrains motor control patterns and abilities in coordination and adaptation, which are the consequences of mechanical and external factors during rowing (Nevill, Allen, & Ingham, 2011). Different structure of momentum during rowing stroke on an ergometer causes different timing of peak point (Christov, Ivanov, & Christov 1989; Nolte, 2011) and its fixation in rotary and vertical axes reduces efficiency in activation of flexors and extensors and power output between upper body and lower body (Jones, 2011). Mentioned authors concluded that ergometers should be considered as a cross-training tool for rowers and cannot replace on-water rowing.

On basis of these previous investigations, this present preliminary case study aimed to report differences in synergies organizing the muscular coordination and structure of timing between rowing on a single scull (SS) versus modelled rowing on an ergometer Concept 2 (C2). We considered surface electromyography (sEMG) to identify timing and muscle synergies, for a wider understanding of involved motor control patterns.

Methods

Subject

Selected highly trained elite class female athlete volunteered on this study. Participant had seven years of experiences of continual competitive practise in rowing on a single scull as well as on an ergometer Concept 2. Athlete had technically fixed locomotive routine and no objective difficulties. Prior to study, athlete was fully informed about the kinesiology study and signed an informed consent form about the research approved by the Ethics Committee of the Faculty of Physical Education and Sport of Charles University in Prague. The study was performed in accordance with the guidelines of Declaration of Helsinki 2006. Testing was done in February 2015 by a team trained in sEMG research and took place in the Bohemians Rowing club in Prague.

Measurements

After individual warm up subject completed three of two min. experimental sessions at pace 22 strokes per minute, included three min. rest among them on an ergometer Concept 2 model D PM3. After ten min. rest subject repeated three of two min. on three min. rest testing at the same pace on a single scull. Rowing pace was calculated by determining power output for subject on her average 500 m split during a 2.000 m trial. Subject was instructed to achieve 80% of maximal heart rate and repeat similar strokes in sessions. Heart rate was tracked with a Polar 1 heart rate monitor (Polar Electro Oy, Kempele, Finland).

16 muscles were evaluated on the left side of the body: m. biceps brachii – long head (BB), m. trapezius med. (TrM), m. deltoideus med. (DeM), m. triceps brachii (TB), m. pectoralis major (PM), m. serratus anterior (SA), m. latissimus dorsi (LD), m. erector spinae (ES), m. external abd. oblique (EAO), m. rectus abdominis (RA), m. gluteus maximus (Gmax), m. gluteus medius (Gmed), m. rectus femoris (RF), m. biceps femoris (BF), m.

semitendinosus (Sem), m. vastus lateralis (VL). Measured muscles were chosen on behalf of the preliminary case study. Selected muscles embody the most telling variance. Laterality was not examined, because results of the preliminary were not conclusive. As the rowing is not a natural locomotion, we have not mentioned muscular chains.

Muscular activity was recorded using portable measuring device working on basis of EMG potentials. Biomonitor ME 6.000 (Mega Electronics Ltd., Kuopio, Finland) providing 16 channels, used sampling frequency was set up to 1.000Hz. The device was carried on the athlete's body. Ag/AgCl electrodes Kendall (Bio-Medical Instruments Inc., Clinton Township, MI, USA) were used. Followed the recommendations of SENIAM (2015) testing facilities met the prescribed criteria according recommended standards to minimize measurement errors. Acquired data were transferred to PC and processed in MegaWin software (Mega Electronics Ltd., Kuopio, Finland) and analysed in Matlab 2013a software (MathWorks, Inc., Natick, MA, USA).

Data analysis

Acquired data were processed in MegaWin software. Than algorithmically analysed in Matlab 2013a, conducted and evaluated using custom code. Presented results are based on data's linear signal envelope. The raw EMG signal was high-pass filtered (Butterworth 6th filter, cut-off frequency 20Hz) due to the artefacts elimination. Then fully rectified and low-pass filtered (Butterworth 6th filter, cut-off frequency 20Hz) EMG signal was used to create linear envelopes. The value of cut-off frequency 20Hz was chosen to preserve details in signal envelope and hence the time precision in muscle activity detection task. The signal processing met prescribed criteria in accordance the recommendations of SENIAM (2015) and ISEK (2015) standards.

The rowing cycles were defined due to positions of consecutive local maxima in timing of linear signal envelope. The boundaries of movement cycles are calculated by using standard Matlab function "findpeak" with a parameter of "minipeakdistance". The parameter value is equal to 70% of average movement period estimation. The average period estimation is based on the autocorrelation function applied to the signal envelope. The evaluation of muscle activity is supported by interpretation of mean EMG signal envelope of all channels. EMG signal envelopes are segmented due to individual movement cycles and segments are linearly time-interpolated over a 1000-point time base. The segments with interpolated envelopes are arranged in a matrix A that has 1000 columns and number of rows corresponds to count of identified movement cycles. Mean of the signal envelopes is calculated like the arithmetic mean applied on every column from the matrix A. In the last step is the mean signal envelope smoothed by 100-point moving average filter. The normalized time base 1000 point is chosen like optimal value for parametrization of mean muscle activity. The normalized time base corresponds to one second interval due to the sample frequency 1000Hz and is transformed into the range 0 – 100% mean movement cycle for presentation in Figure 1 (Špulák, 2016).

The muscle activity timing was detected using adaptive threshold detector separate in every channel. First step of detection requires identification and analysis of significant local extrema in mean signal envelope. Local extrema are sorted according the amplitude ratios of extrema. Significant extrema positions in mean movement cycle are transformed consequently into individual movement cycles. Every potential activation is represented by a pair of time positions of local minimum in signal envelope. Position of minimum value is redefined in range 5% of movement cycle length. Maximum value of signal envelope used for adaptive thresholding is defied in range limited by a pair of time positions of local minimum. Threshold is defined as 20% of difference between maximum and minimum of signal envelope. Onset threshold is calculated by first minimum extrema amplitude and offset by second minimum extrema amplitude. The muscle activity is detected if the signal envelope range onset threshold. The offset is detected analogically by using offset threshold. Muscular contraction timing was detected using threshold detector described in (Špulák et al. 2014).

The muscle activity detected in all movement cycles is subsequently transformed to normalized time base in range 0-100%. Processing is applied separately in every channel and activation identified in mean movement cycle. Mean muscle activation is represented by distributions of onsets and offsets timing in mean movement cycle. The first, second and third quartile is determined is distributions of onsets and offsets timing. Activation in normalized base represented by rectangle which shape of left and right side marks quartiles of activity timing Figure 1 shows average muscle activity identified in all cycles. Number of included movement cycles used for evaluation is denoted in column on the right side of graph. The amplitude of mean envelopes is normalized to global maximum value in envelope due to improve resolution in amplitude. Descriptive statistics included mean ± standard deviation (SD) of muscle activity are summarized in table. 1. The local extremes of mean envelopes were analysed and detections in signal envelopes were done. Observation was completed by kinematic analysis of movement due to the artefacts elimination by digital camera SONY HDR-SR12 (Sony Co., Tokio, Japan) connected by triggers to the measuring device.

Statistical analysis

The comparison of C2 and SS muscle activity was evaluated by visual inspection of mean envelopes and mean muscle activity but also by using Pearson correlation coefficients (r). Correlation coefficients are determined for a pair of mean envelopes in every channel. The muscle activity was assessed using tree criteria: correlation r, rmax and the lag time. The correlation coefficients were calculated by using standard Matlab function xcorr with option ‚coef'. The coefficient r is defined like cross-correlation between average signal envelopes, rmax is defined like maximum value of cross-correlation function between average signal envelopes in identical muscle for C2 and SS activity. Lag time corresponds with time shift in maximum value of correlation rmax. Table 3 shows coefficients and confidence intervals of rmax with level of significance alpha 0,05. The statistical test was applied in order, to verify the hypothesis of no correlation. The test ensures elimination of random chance to accept large correlation value when the true correlation is zero. Table 3 contains the values of probability and values less than 0,05 confirms the significant result. The process was referred in analogical application in (Turpin, Guével, Durand, & Hug, 2011b).

The inter-group comparison of mean EMG envelopes was computed by application of Spearman's rank correlation coefficient (r) between each pair of measured muscles. The onsets and cessations of EMG activity were time-normalized and merged for all movement cycles. Descriptive statistics included mean ± standard deviation (SD) was calculated for timing of each muscle activity.

Results

EMG envelopes were compared to the ensemble of averaged EMG linear envelopes for overall measured muscles during both movement patterns. The graphic records of mean EMG curves and onsets and cessations of the muscles activity during rowing stroke are depicted into the Figure 1 and Figure 2. We suppose that the positive high value of Pearson correlation coefficient proves similarity of muscle activity profiles and synergies organizing the muscular coordination.

Figure 1. The graphic records of mean EMG curves, onsets and cessations of the muscles activity during rowing stroke on SS (A) and C2 (B).

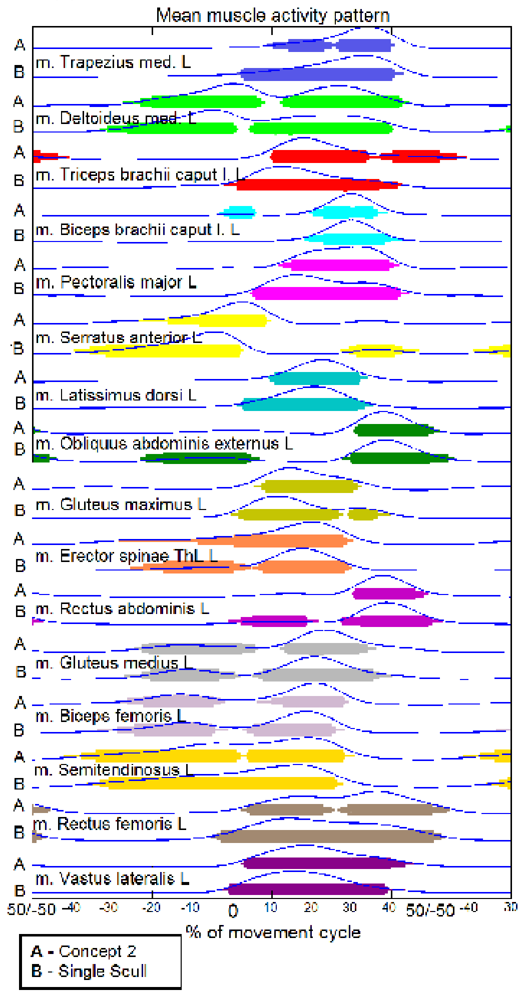

Figure 2. The graphic records of mean EMG curves, onsets and cessations of the muscles activity during rowing stroke on SS (green curve) and C2 (red curve).

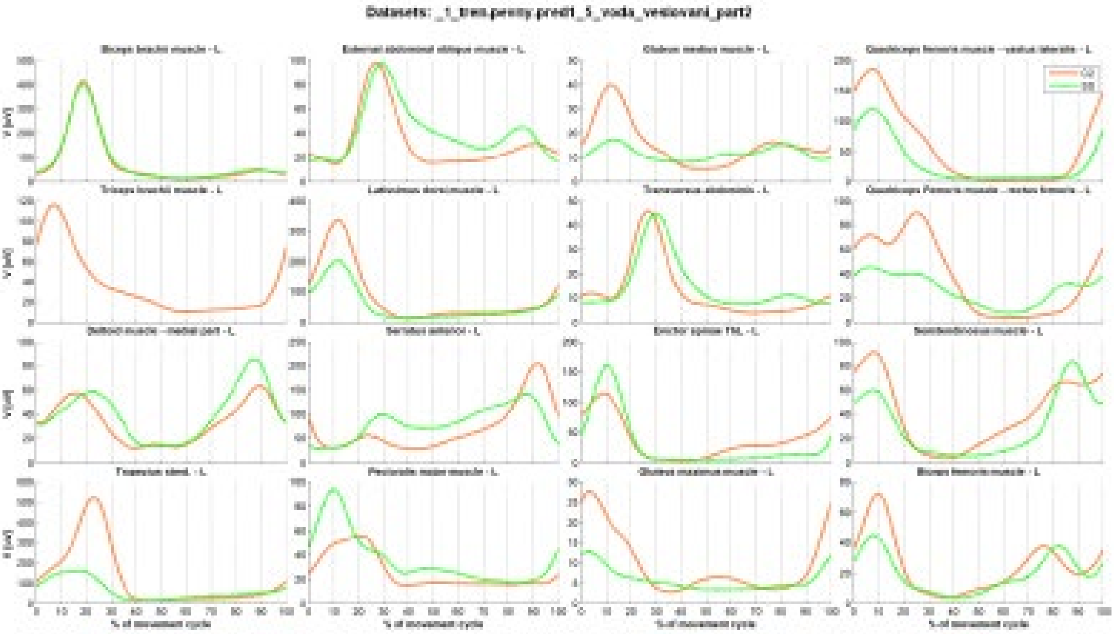

Table 1 and Table 2 illustrate numeric results of the inter-individual similarity indices of onsets and cessations for each channel. In ranging interval -50% – 50%, cycle initiation pertains 0%. The correlation coefficients for all observed muscles are depicted into Table 3. Results of muscular activity timing was inter-locomotive different, concretely lag of onsets on the C2 behind the onsets of the SS.

Table 1 Mean delay of onsets of muscle activity ranging interval -50% – 50%. Detected by threshold detector.

	C2 Act %	**SS Act %**
Measured muscles	Mean ± SD	Mean ± SD
m. trapezius med.	-0.94 ± 7.20	-20.09 ± 6.08
m. deltoideus med.	-31.37 ± 5.66	-49.31 ± 4.95
m. triceps brachii caput l.	-10.09 ± 3.95	-22.63 ± 9.35
m. biceps brachii caput l.	7.69 ± 3.62	2.49 ± 5.56
m. pectoralis major	-10.39 ± 2.91	-19.50 ± 6.49
m. serratus anterior	-38.57 ± 6.28	19.04 ± 2.79
m. latissimus dorsi	-13.23 ± 3.30	-15.42 ± 3.44
m. obliquus abdominis ext.	9.61 ± 3.01	0.46 ± 2.48
m. gluteus maximus	-12.10 ± 2.93	-13.53 ± 6.32

Table 2. Mean delay of cessations of muscle activity ranging interval -50% – 50%. Detected by threshold detector.

	C2 Act %	**SS Act %**
Measured muscles	Mean ± SD	Mean ± SD
m. trapezius med.	22.94 ± 8.18	4.74 ± 1.20
m. deltoideus med.	24.64 ± 2.97	27.59 ± 8.81
m. triceps brachii caput l.	20.10 ± 5.63	24.65 ± 12.32
m. biceps brachii caput l.	19.99 ± 3.41	19.73 ± 7.40
m. pectoralis major	3.19 ± 4.95	9.39 ± 6.56
m. serratus anterior	-14.03 ± 4.62	-25.72 ± 2.12
m. latissimus dorsi	10.03 ± 3.11	13.87 ± 5.28
m. obliquus abdominis ext.	30.42 ± 2.79	25.86 ± 7.08
m. gluteus maximus	4.03 ± 2.24	5.00 ± 1.55
m. erector spinae ThL	11.56 ± 4.96	11.47 ± 4.69
m. rectus abdominis	29.43 ± 2.82	39.64 ± 3.99
m. gluteus medius	21.05 ± 6.03	13.34 ± 10.06
m. biceps femoris	6.97 ± 3.36	6.17 ± 6.17
m. semitendinosus	7.64 ± 3.11	0.82 ± 4.49
m. rectus femoris	33.74 ± 3.21	40.90 ± 2.49
m. vastus lateralis	19.89 ± 7.85	22.26 ± 8.66

Table 3. Spearman's rank correlation coefficients (r) comparing mean EMG waveforms of SS and C2: r (max) indicates the best time delivery between EMG waveforms, r (no shift) indicates the correlation value expect of time delivery between EMG waveforms. Alpha 0.05.

Measured muscles	r (max)	r (no shift)
m. trapezius med.	.9629	.7826
m. deltoideus med.	.8849	.8823
m. triceps brachii caput l.	.9214	.9149
m. biceps brachii caput l.	.9988	.9988
m. pectoralis major	.9230	.9136
m. serratus anterior	.8190	.7374
m. latissimus dorsi	.9952	.9931
m. obliquus abdominis ext.	.9260	.9217
m. gluteus maximus	.9471	.9471
m. erector spinae ThL	.9571	.9571
m. rectus abdominis	.9724	.8939
m. gluteus medius	.9626	.9626
m. biceps femoris	.8954	.8954
m. semitendinosus	.9671	.9671
m. rectus femoris	.9597	.9597
m. vastus lateralis	.9665	.9665

Discussion

In our analysis, both rowing conditions was accompanied by muscle patterns. These indicated neuromuscular control to adapt to various mechanical constraints. We observed that the inventory of rowing tasks was achieved through modification of muscle loadings but not muscle synergy structure in agreement to the synergy studies on rowing (Marcolin et al., 2015; Shaharudin, Zanotto, & Agrawal, 2015; Turpin, Guével, Durand, & Hug, 2011a).

The aim was to consider similar kinesiological movement contents, that are the coordination and timing of 16 selected muscles of the body, during rowing on a single scull and rowing on an ergometer Concept 2 D PM3, even though there are considerable differences on the outer shape of the movement. In rowing, symmetrical involvement and effective coordination of the muscles is needful to reach maximal effort, since a non-optimal strategy could limit the power output and the limb motion (Wilson, Gordon E Robertson, & Stothart, 1988). Rowing on an ergometer Concept 2 showed the same number of muscle synergies in agreement to Marcolin et al. (2015), which indicated inter-locomotive similarity, but cross-plots showed different coordinative patterns. Thigh multi-joint muscles play role in transferring force generated from the foot stretcher to the trunk (Guével, Durand, & Hug 2011; Hofmijster, Van Soest, & De Koning, 2008). At the transition point, eccentric contraction was immediately followed by a concentric contraction, which was characterized by increased Sem neuromuscular activity on a C2 that likely served to accelerate the mass of the rower. This type of forceful Sem activity could not be performed on a SS because of the lower inertial mass of the boat relative to the body mass of rower. Observed trend may be explained by the fact, that in the stationary conditions, rowers need to accelerate their body mass to generate force at the handle. The patterns of neuromuscular activity met in agreement with the report from Rodriguez (1990). The graphic records of EMG curves showed high co-contraction of all measured muscles and approved its equality during both observed physical activities. Comparing rowing on C2 to SS, muscles showed different timing and strategy of muscle recruitment especially during the propulsive phase. Figure 1 suggests that muscles activity was not orthogonal. The most variable pattern was observed in the SA. Coactive SA and EAO create on SS linked chain.

Similar values indicate moderate variability of mean waveforms. The results in Table 3 support the hypothesis about similarity of the patterns of measured physical activities. All muscles showed high value of Spearman's rho, which indicates similar muscle activation during both movement patterns. Significant correlations approximated 0.9.

Limitation of this preliminary case study was low number of tested persons (one), therefore the results of this case study cannot be generalized to the entire Czech rowing population. Due to extend of the study, it would be appropriate to do further research.

Conclusion

Rowing on C2 and SS showed the same number of muscle synergies, but the muscle loading was different. Rowing on SS emphasized on earlier onsets and cessations of muscle loading. Video analysis has shown that the earlier beginning of the muscle activation during rowing on SS is a consequence of different fulcrum. This finding is consistent with the findings of Nolte (2011).

Results of this preliminary case study could improve our current understanding, regarding the strategy of the CNS to remain efficient in different mechanical constraints. Considering the use of C2 as training and testing device for rowers, we give a basis to the future research. Our recommendation, to eliminate consequences of artificial strengthening on a rowing machine, is to work in 15 minutes of rowing after the session to simulate right locomotive routine.

References

1. Guével, A., Boyas, V., Guilhard, V., Cornu, C., Hug, F., & Nordez, A. (2011). Thigh muscles activities in elite rowers during on-water rowing. *International Journal of Sports Medicine, 32* (2), 109-116.
2. Hofmijster, M. J., Van Soest, A. J., & De Koning, J. (2008). Rowing skill affects power loss on a modified rowing ergometer. *Med. and Sci. in Sport Exercise, 40* (6), 1101-1110.
3. Christov, R., Ivanov, S., & Christov, R. (1989). Problems of the biomechanical analysis of the rowing technique in real and test conditions. In: Tsarouchas, L. (ed.) et al. *Biomechanics in Sports V: proceedings of the Fifth International Symposium of Biomechanics in Sports*. Hellenic Sports Research Institute, Olympic Sports Center of Athens, 269-275.
4. ISEK International society of electrophysiology and kinesiology. (2015). *Standards for reporting EMG data.* Retrieved from http://www.isek-online.org/standards_emg.html
5. Jones, D. I. (2011). *Upper versus lower body contribution to the rowing stroke.* (Dissertation, NK Electronic Theses and Dissertations Centre & Cleveland State University. Cleveland, Ohio, USA).
6. Kleshnev, V. (2016). *The Biomechanics of Rowing.* Ramsbury, UK: The Crowood Press Ltd.
7. Marcolin, G., Lentola, A., Paoli, A., & Petrone, N. (2015). Rowing on a boat versus rowing on an ergo-meter: a biomechanical and electromyographical preliminary study. *Procedia Engineering, 112* (1), 461-466.
8. Nevill, A. M., Allen, S. V., & Ingham, S. A. (2011). Modelling the determinants of 2000m rowing ergometer performance: a proportional, curvilinear allometric approach. *Scandinavian Journal of Medicine & Science in Sports, 21* (1), 73-78.
9. Nolte, V. (2011). *Rowing Faster.* Champaign: Human Kinetics.

10. Rodriguez, R. J. (1990). Electromyographic analysis of rowing stroke biomechanics. *Journal of Sports Medicine and Physical Fitness, 30 (*2), 103-108.
11. SENIAM (2015). The Surface Electromyography for non-invasive assessment of muscles. Retrieved from http://www.seniam.org.
12. Shaharudin, S., Zanotto, D. & Agrawal, S. (2015). Muscle synergies of untrained subjects during 6 min maximal rowing on slides and fixed ergometer. *Journal of Sport Science and Medicine, 13*(4),793-800.
13. Špulák, D. (2015). *Zpracování povrchových elektromyografických signálů.* Dizertační práce. Praha: ČVUT FEL.
14. Špulák, D., Čmejla, R., Bačáková, R., Kračmar, B., Satrapová, L., & Novotný, P. (2014). Muscle activity detection in electromyograms recorded during periodic movements. *Comput in Biol and Med, 47* (2), 93-103.
15. Turpin N. A., Guével, A., Durand, S., & Hug, F. (2011a). Effect of power output on muscle coordination during rowing. *European Journal of Applied Physiology, 111*(12), 3017-3029.
16. Turpin, N. A., Guével, A., Durand, S. & Hug, F. (2011b). Fatigue-related adaptations in muscle coordination during a cyclic exercise in humans. *Journal of Experimental Biology, 214* (19), 3305-3313.
17. Wilson, J.-M. J., Gordon E Robertson, E., & Stothart, J. P. (1988). Analysis of lower limb muscle function in ergometer rowing. *International Journal of Sport Biomechanics, 4* (1), 315-325.

Author: Mgr. Martina Zbořilová
E-mail: zborilova.ma@gmail.com