Original Article

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A Comparative Analysis of the Kayak Forward Stroke

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Abstract

Introduction: This work follows previous research in the field which investigated the comparison of two types of paddling. These studies, however, focused on the similarity of kayaking and trainers, more precisely ergometers, that are used by racers during their training in the winter. However, the results of these studies indicate a significant difference in muscle involvement. *Aim of Study:* The aim of this study is to describe and to compare the muscle activation of the kayak forward stroke performed in a pool with an opposite/counter current and on flat/calm water. *Material and Methods:* The research was conducted via a selected sample of eight kayakers (subjects) who had attained a high level of performance in whitewater slalom. We observed the activity of twelve selected muscles used during the kayak forward stroke performed in a counterflow pool and on flat water by means of surface electromyography and kinematic analysis. Study results point to effects in relation to intra-individual and subsequently inter-individual muscle timing and the size of the muscle activation due to maximal voluntary contraction. We used comparative analysis and the data were measured by surface electromyography and 2D video-analysis. *Results:* The results proved equal timing of muscles in a counterflow pool and on flat water. The muscle activity in the counterflow pool was bigger than on flat water. *Conclusion:* From our results we can recommend a pool which makes use of a counter current as a replacement training tool. Compared with other training devices which might be used (such as, crank ergometers, paddling trainers, and paddling pools), this kind of training device gives the kayaker one great advantage. It is the fact that the kayaker has the same placement of the fixed point and the preservation of the feeling of grasping water.

Keywords: counterflow pool, kayak, paddling, surface electromyography

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INTRODUCTION

Kayak paddling is considered a demanding dynamic muscle activity which consists of uneven cyclic and acyclic movement sections. All necessary movement needed for managing the slalom course consists of a very complex system of neuromuscular activity. Paddling is composed of two types of movement which drive and control motion. Paddling efficacy increases based on how high the percentage of drive paddling is in contrast to the percentage of control paddling motion. When it comes to motor effects, paddling is made possible via body frame muscles and arm muscles. Lower limbs play a more passive soft motor role including high coordinating muscle activity which is necessary for successful movement in water [1,2].

Correct technique for such movement consists of high muscle coordination and movement economy, which means that only those muscles which are necessary for the motion are activated. Other muscles should be in a relaxed position. Incorrect muscle coordination, i.e., non-economic motion, consists of unnecessary muscle activation which then creates unnecessary increased muscle tone. Proper muscle metabolism inside the muscle tissue cannot be properly achieved and thus the kayaker is faced with the danger of increased fatigue. With increasing fatigue also comes decreased muscle coordination. Unnecessary muscle movement also includes facial muscle activity, e.g., grimacing, a movement which includes facial mimic muscles. This is an unnecessary waste of energy, which can also lead to the incorporation of other muscles due to muscle chain interconnections [3,4]. Correct paddling technique is based on the kayak's movement. The kayak must glide on the longest possible trajectory in order to gain enough speed. The most elementary part of paddling motion is the torso rotation, where the spinal cord is the rotation axis. The stroke itself is then performed by the back muscles (latissimus dorsi, trapezius), torso muscles (pectoralis major, serratus anterior, obliquus externus and internus) and arm muscles as well (biceps brachii, triceps brachii) [5]. The arm muscles become fatigued sooner than the large torso muscles, which is the reason that, in training, focus must also be placed on training the arm muscles. Another important aspect of kayak training is the necessity for an awareness of muscle relaxation in such muscles that are not active during movement, this being essential for short-term muscle regeneration [6].

Bílý [1] describes the direct kayak stroke movement in four stages which follow one after another and thus make the stroke motion a unified whole. Individual phases are the catch, the drive, the completion and the body over. Kračmar [7] in his monograph mentions several studies which compare these via SEMG muscle activity during different muscle motions which are similar in comparison to kayak paddling. These tested movements included kayak paddling motions, rope pull-ups and the training of kayak paddling. Artificial movements and their role in imitating the natural conditions of movements in the sports environment always tend to show a certain level of specifiers based on how much they differ from the so called "coordination map of the target movement". Coordination mappings are different for each individual. However, some similarities can be detected (i.e., the phylogenetic framework). Further comparison of the cyclical movement used during paddling with other kinds of motion has been quite often discussed among a variety of studies. The main focus has tended to be comparisons between training indoors and in a natural water environment. Ergometers are frequently used as a part of the training process during winter months. The results of such studies, however, point to quite staggering differences in muscle activation [8–11].

This particular study focused mainly on the comparisons of the muscle activity levels during kayak paddling against the counterflow in a water pool versus paddling without any current using surface electromyography as the main analytical tool. The level of muscle activity was observed in relation to the maximal intentional (will-based) muscle contraction (MVC) done according to Janda [12] The study also focused on different timings of muscle activation based on their behaviour in two different environments during movement [13,14].

MATERIAL AND METHODS

Participants

The tested group of participants was not a random, but a selected, sample of test subjects. The set included 8 subjects (age 24±4 years, 78.5±3 kg, 178±6 cm) with a steadily fixed movement stereotype (these were kayaking specialists and professional athletes). In this way it was possible to minimize any possible deviation during the measurement process caused by incorrect paddling techniques.

Protocol

The study is based on a descriptive analytical comparison with both an intra- and an inter-individual data result comparison. The research was conducted on a sample of eight subjects who were professional athletes (kayakers) and who agreed to have twelve selected muscles analysed via a surface electromyograph and to observe the muscle activity during stroke motions in a pool with counterflow and also one with no current.

The observed muscles (n=12) were selected based on their basic functions, according to Čihák [15], Travell, Simons [16], and also based on their functions during kayak paddling, as previously stated by Buchtel [17] The selection was also based on sequencing inside the muscle chain, as previously mentioned by Véle [4, 18] always taking into account both the right and left parts of the body (flexores, extensores, biceps brachii, triceps brachii, pectoralis major, latissimus dorsi). Before the electrode application, the skin surface had to be shaved and cleaned, including getting rid of any excess moisture by means of rubbing alcohol. Electrodes were placed so that the couplings of their centres were aligned with the muscle fibres, placing them at the point of the highest muscle tone, which was judged by a physiotherapist, as recommended by Travell, Simons [16].

The results were gained based on a comparative analysis of the EMG muscle activity signals combined with a kinetic analysis which was possible by having a synchronised 2-D video recording of the movement. The surface electromyography (SEMG) is an analytical tool which allowed us to judge the sequence of muscle activation timing and the levels of muscle activation in relation to the maximal intentional muscle contraction (MVC) which was based on a muscle test [12].

The measurement process was done inside a k1 (Prijon Soča) kayak always starting on a calm water surface or inside a pool with counterflow located at the Department of Physical Education and Sport in Ústí nad Labem (Pool flum Super for A7). In order to compare two types of locomotion, maximal paddling intensity for 1 minute was set as a time period during which every high performance athlete is typically able to paddle without any significant errors or unnecessary involuntary movements in order to maintain kayak stability. The measurement took place for all locomotion types and was always done twice. The first measurement was regarded as an initiation and warm-up and the gained data were not processed because this attempt was regarded as a trial. A greater number of measurements was not completed in order to avoid fatigue. Each Subject took a 30-minute break in between different motion type measurements due to the necessity of placing electrodes onto a different part of the body.

Mobile EMG device technical specifications

We used an independent polyelectromyography mobile device for muscle electricity potential screening. It was manufactured by Megawin Biomonitor ME 6000 (Meg Electronics, Finland). Its technical specifications are: signal rough/average/RMS/joined with the range of ± 8192 μV for EMG, number of channels: 4/8/12/16, pattern frequency: 1.000/2.000/10.000/250/100 Hz.

Statistics

Intra-individual analysis of the gained results was done based on a curve conversion into absolute values. The specific time period in which an individual movement cycle included both a periodic muscle activation and a deactivation (n = 50 cycles) was set for the following data processing as an experimental part of the data processing. Excluded were movement cycles which occurred at the beginning and end of locomotion during which time the muscle activity is not yet fully stabilized. Excluded were also threshold values, as the Galton median calculation example suggests, for better

reliability of the results. The analysed data were then calculated for the average EMG curve, which was implemented to one distance length (interpreted as a percentage of 0–100% of the paddling cycle) as previously suggested by a variety of authors [19–22].

In order to specify the time shift of the muscle activity initiation in comparison to the intra-individual analysis of the selected time period, the so-called triangular detection of beginning and end of the muscle activity visible via EMG signal was set at the EMG threshold of 25% of the maximal muscle activity [23]. Such values of muscle activity timing were detected via scripts in Matlab software (version 7.8.0, R2009a) which calculated the maximal cross correlation coefficient. In relation to the maximal cross correlation coefficient we are then able to set phase shift timings of when individual muscles begin their activity [14]. The similarity comparison is then set based on the timing sequencing via the Spearman's rank correlation [24].

Inter-individual comparison of the results was then further processed via a percentage differential of the measured muscles during paddling in the pool with both counter flow and no current. The percentage levels of muscle activation in individual muscles in relation to the MVC were rounded to whole numbers and in case of two peak muscle activations the mean value of these two activations was calculated [12,23,25].

RESULTS

Table 1 include the percentage differences of the measured muscles between paddling in the pool with counterflow and the pool without any current. The percentage values of the muscle activation in relation to the MVC were rounded to whole numbers. In the case of two peak muscle activation, the mean value of both activations was calculated.

The results showed higher muscle activation of the forearm muscles (flexores bilateral and extensores) in the pool with counterflow when compared to the pool with no current. The biceps brachii show more bilateral opposite tendencies than other measured muscles. The right upper limb activated this muscle more often on the calm water surface in five out of eight subjects, the left upper limb then activated this muscle, as detected in six out of eight subjects. The tendency toward higher activity in the counterflow pool was detected among these muscles as well: triceps brachii, bilateral pectoralis major and latissimus dorsi as can be seen in the figure 1.

Table 1. Muscle activation percentage differences among individual subjects

Muscle (in Latin)	Subjects							
	1	2	3	4	5	6	7	8
Mm. flexores dx.	8.5%	20%	15.5%	21.5%	13%	10%	4%	11%
Mm. flexores sin.	13%	29.5%	10.5%	25.5%	10%	5%	2%	5%
Mm. extensores dx.	9%	11%	6%	16%	1%	15%	-2%	6%
Mm. extensores sin.	6%	8%	-3%	24%	2%	7%	21%	3%
M. biceps brachii dx.	-7%	36%	-10.5%	5.5%	-1%	3%	-13%	-18%
M. biceps brachii sin.	-3%	-9%	-15%	5.5%	-3%	11%	-20%	-9%
M. triceps brachii sin.	7%	12%	17%	3.5%	3%	4%	1%	-44%
M. triceps brachii dx.	7%	25.5%	6.5%	-0.5%	1%	7.5%	1%	-30%
M. pectoralis major dx.	15%	26.5%	20%	4.5%	-3%	15.5%	8%	-15%
M. pectoralis major sin.	12%	21.5%	1%	5%	2%	16.5%	4%	-12%
M. latissimus dorsi dx.	18%	2%	4%	3%	5%	9%	0%	-7%
M. latissimus dorsi sin.	25%	9%	3%	14%	7%	14%	9%	-6%

Positive values - increased muscle activation in the pool with counterflow, Negative values - increased muscle activation with no current, 0 shows no value - equal muscle activation in both counterflow and no current

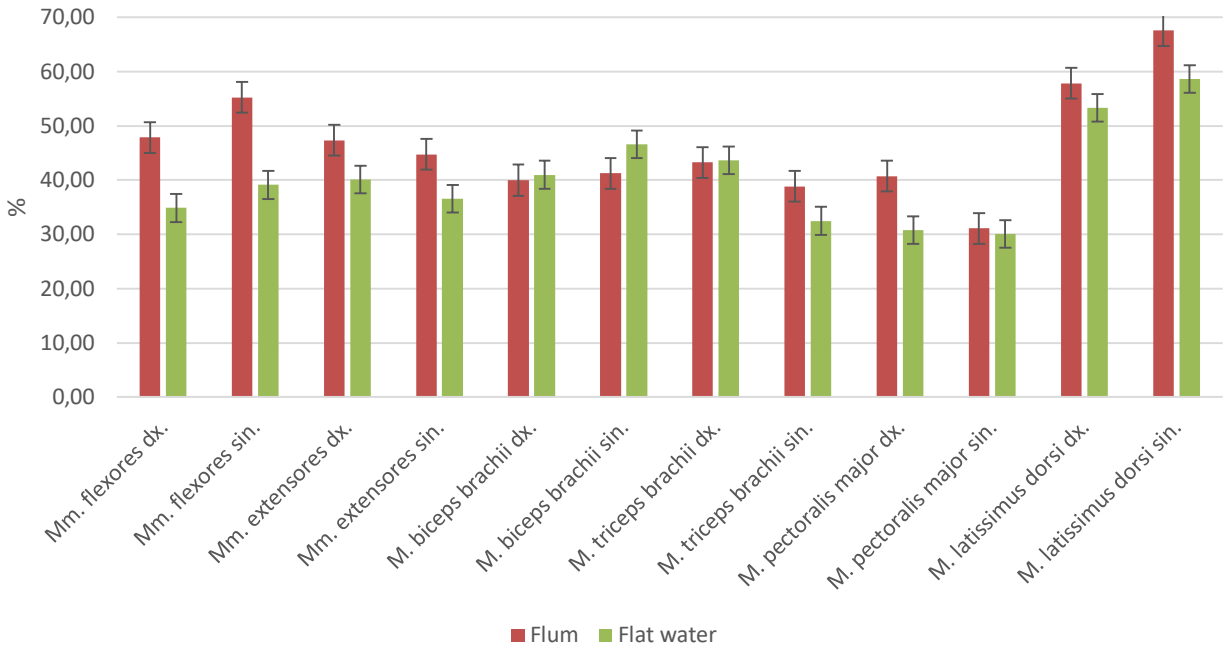

Figure 1. Muscle activation percentage differences relative to the MVC

Table 2. Muscle activation ration

Subject	1	2	3	4	5	6	7	8
ω	1.27	1.46	1.18	1.26	1.08	1.30	1.04	0.78

ω > 1 inform increased activity of the measured muscles during counterflow paddling
ω < 1 inform increased activity of the measured muscles during paddling with no current

Table 3. The relation of muscle activation sequencing based on the Spearman coefficient (α<0.002)

Subject	1	2	3	4	5	6	7	8
Spearman coefficient	0.98	0.96	0.95	0.98	0.98	0.96	0.87	0.94

Table 2 presents the percentage value ratio of muscle activation between paddling in the pool with counter current and in the one with no current among individual subjects. All of the values are shown in relation to maximal voluntary muscle contraction. Table 2 also contains that the selected muscles were more activated in the pool with counterflow than on a calm surface. This was verified in seven out of eight subjects. The following table 3, include the results of the Spearman coefficient of the sequential correlation between muscle activation sequencing during paddling with a counter current and with no current among individual subjects.

DISCUSSION

Overall, it is possible to surmise that some inter-individual tendencies have been spotted. However we must keep in mind that every kayaker has his or her individual style of performance. All Subjects equally activated forearm muscles (flexores bilateral and extensores bilateral) in the counterflow pool. This was different on a calm water surface. Forearm muscles stabilize the contact of the paddle with the water surface so the punta fixa setting is ideal for the kayaker to pull during a stroke movement [5,26]. The paddle blade has to be placed in the water in such manner as to ensure that the resistance in the water is optimal and the support point is not lost, and the kayak can thus move forward better [27]. The results show that the paddle setting is more difficult when the counterflow is in opposition to the kayaker. The waves in the water circulation crate increased the difficulty of driving the kayak and maintaining its position, which caused the selected muscles to activate more than on a calm surface, where waves are also created due to the paddling motion,

however these occur behind the kayak and thus make it easier for a steady and fast movement. Our study results are in agreement with the subjective athlete assessment previously conducted by Busta [28], where athletes evaluated the counterflow paddling as more demanding for the forearm than paddling on a calm surface. This included triceps brachii, pectoralis major and latissimus dorsi. It is possible to assume that the main reason for this is the increased difficulty of maintaining and steering the kayak as described above and also due to the increased resistance caused by the opposite/counter water current. Busta [28] shows that after kayak has left the starting line, it is necessary to invest more strength and energy into the first few strokes. Then after gaining specific kinetic energy the strength level decreases. Similar results were gained by paddling against the counterflow. Kayak paddling may seem to be a linear motion, however the speed slightly changes during overall motion. A stroke creates a peak of maximal speed, and then during the phase of paddle shift to the opposite side, the kayak loses acceleration. In an environment (pool, white water) where counterflow occurs, one cannot afford to lose speed, and since the counterflow tends to slow the kayaker down, more effort must be given to the paddling motion. This could explain the tendency for increased muscle activation among Subject who activated their muscles in the counterflow environment 8.7% more, on average, than on the calm water surface.

Significant similarities in the muscle activation timing sequences in both types of paddling were detected after a comparison of the intra-individual results of all Subjects in our study. As seen in table 3, all eight Subjects showed a significant similarity in the muscle activation timing of individual muscles, based on the Spearman coefficient of the sequential correlation. Based on these results we find ourselves in dispute with other studies which focused on the comparison of stroke movements [8–11]. Our results show that both types of locomotion are very similar. Unlike other modern substitute training tools (ergometers with handles, paddling training simulators, and paddling pools), pools with counterflow have one big advantage. This advantage is the equally fixed puncta fixa and the necessity of maintaining a firm grip in the flow of the water current. It is, however, also important to keep in mind that muscle activation levels are higher when compared to other training techniques, and thus such training should be focused more on the development of strength skills rather than on paddling techniques.

CONCLUSION

The results confirmed intra-individual and significant similarities in muscle activation timing in both environments among all tested Subjects, a result which shows this type of training tool to be more suitable for strength exercises than using simulators or training ergometers with handles due to the equal puncta fixa setting. The reverse current in pool can be recommended as a suitable training tool for kayaking and as a suitable training exercise, which has been verified in the inter-individual results comparison.

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