

Muscle activity at varying intensity loads in canoe paddlers

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Abstract:

Canoe sprint continues to be an area within sports research that is not thoroughly explored, resulting in a limited number of studies that examine muscle activity across varying intensities and the dynamic changes in peak muscle activation over a distance. This study aims to bridge this gap by providing comprehensive insights into muscle engagement among canoe paddlers, with a specific focus on simultaneously assessing 16 muscles. This study is the first in Latvia to use electromyography to analyze canoe paddlers' muscle activity. The study's main objective is to evaluate muscle electromyographic activity and the sequence of achieving peak activity in canoe paddlers at loads of varying intensity. To accomplish the research objectives of examining the electromyographic activity of the brace and the sequence in which muscles reach their peak activity in canoe paddlers at loads of varying intensity and to evaluate differences in electromyographic muscle activity and the sequence of reaching peak muscle activity at loads of varying intensity, a laboratory study was undertaken at the Healthcare in Sport Research Centre of Latvian Academy of Sports Education (LASE). The study involved five adult canoe paddlers who are masters of the sport, possess extensive experience in international competitions, and have been engaged in canoeing for more than six years. The primary methods employed include electromyography (FreeEMG1000 with 16 wireless surface electrode sensors), video analysis (BTS SMART DX infrared cameras), and ergometry (Dansprint canoe ergometer). Significant differences in a brace's average and peak muscle activity at loads of varying intensity were observed. For example, Participant No. 2 exhibited a *mid-trapezius* peak activity of 701 units at the start of the 2-min test, which decreased to 421 units by the end of the test. The muscle activity during paddling was asymmetric, with notable differences between the paddling and opposite sides. For instance, in the 200-m test for Participant No. 4, the average *gluteus medius* peak muscle activity on the opposite side was 722 units, whereas on the paddling side, it was 199. Additionally, by the conclusion of the 200-m test, Participant No. 5 experienced a rapid decline in *gluteus* muscle activity, coinciding with a reduction in paddling power. Across all participants, the *gluteus medius* and *gluteus maximus* muscles on the opposite side exhibited significantly higher peak activity than those on the paddling side. This finding may explain the observed asymmetry in pelvic musculature among canoe paddlers.

Keywords: canoe sprint, electromyography, ergometry, canoe stroke, muscle activity

Introduction

Canoe sprint is a cyclic sport, which requires continued technical and rotational movements (Pelham & Holt, 1995b; Plagenhoef, 1979). Due to the climatic conditions of Latvia, it is not possible to practice canoe sprint all year round, thus the training process also includes other sports – skiing, running, gym sessions, and paddling on an ergometer. In turn, this makes the fitness of paddlers well-rounded. Of the mentioned activities, paddling on an ergometer is the closest in terms of muscle activity to paddling on water (Bazzucchi et al., 2013; Bunc & Heller, 1991; Villarino-Cabezas et al., 2013; Von Someren et al., 2000). Therefore, the method selected in this study – paddling on an ergometer – is considered suitable for analysing the activity and the activation sequence of the muscles involved in a stroke. An effective canoe stroke is a cyclical, dynamic and complex movement that involves a large number of muscles, joints and body segments (Nakashima et al., 2019; Pelham & Holt, 1995b). In order to be competitive, high-performing canoe paddlers require a well-rounded fitness level that includes endurance, speed, coordination and strength, while achieving high results requires refined technical performance (Dokumacı & Çakır-Atabek, 2015; Mann & Kearney, 1983; Pelham & Holt, 1995b; Plagenhoef, 1979).

Historically, the canoe sprint technique varies considerably among high-performing canoe paddlers, as well as among representatives of different countries, and it must be continuously improved. Over the years, the paddling technique often changes as paddlers modify the boat and paddle designs, and adapt the technique (Szanto, 2014). Canoe paddlers often try to match their technique to the best paddlers of that time, but they usually fail to improve their result, as visually the stroke may look the same, but the distribution of strength and the angle of the paddle blade may differ. The study shows that each canoe paddler needs to adapt the technique individually to suit their body type and characteristics, but it is also necessary to follow the principles of biomechanics (Szanto, 2014). A bit recent research on kayak athletes suggests that methods of improving the

rowing technique of qualified canoeists should be based on models of quantitative characteristics rowing locomotion technique with regard to structural interrelationships between them and the changes occurring with the growth of sports qualifications (Zhurnov et al., 2017).

Research have also focused on the differences between kayak and canoe sprint. Considering the fact that the canoe paddler supports himself/herself on one knee and is in a higher position than a kayak paddler, the canoe paddler can engage more core and leg muscles in the stroke. Unlike kayak paddlers, the canoe paddler is in a forward lean for a large part of the brace. The pelvis is in an asymmetric position and performs a significant rotation of the torso (Dobos, 2019; Yong-ming, 2015).

In various sources of information, the division of a stroke into phases is reflected differently. The stroke can be most easily divided into the brace (*propulsive*) and unsupported (*recovery*) phase. The brace phase is the time during which the paddle is in contact with water. Moreover, the brace phase can be further divided into three more detailed phases: 1) the *catch* phase – it takes place at the beginning of the brace, when the paddle makes contact with water until it is completely submerged; 2) the *draw* phase – this is when the paddle is moved along the side of the canoe, thus giving it acceleration; 3) the *exit* phase – it takes place in the final part of the brace. Canoe paddling technique can always be improved as it cannot be perfect. However, there are various nuances that are worth taking into consideration when looking for ways to improve it. It is essential to apply strength in the stroke in such a way that the boat moves efficiently. Important factors that influence the technique are balance, division of the strength of the stroke, coordination, efficiency, rhythm, as well as paddling style (Szanto, 2014).

Canoe sprint involves specific muscle activity, and one of the most important things to emphasize in the context of this study, and when discussing canoe sprint in general, is that the abdomen and back muscles on the paddling side do more work than the muscles on the opposite side. Research also indicate that muscle tension decreases as the speed of the boat increases (Dobos, 2019). While in the boat, the canoe paddler is constantly in an asymmetric position and the athlete paddles only on one side of the boat. As a result, muscle imbalances can occur from interactions between muscle antagonists and agonists, which can affect the associated joints (Negrete et al., 2013).

Such muscle imbalances can cause various posture and movement deviations, and cause structural damage to the joints. It is from the fact that muscle agonists lack mobility and strength that antagonists or neighbouring muscles have to compensate for it, which can lead to their malfunction (Calmels & Minaire, 1995). During the annual training cycle, high-performing kayak and canoe paddlers cover more than 3000 km. However, canoe paddlers paddle only on one side of the boat, thus their body receives a long-term asymmetric load (McKenzie & Berglund, 2019). Therefore, the functional and morphological asymmetry in canoe paddlers is an important aspect.

Research includes modern methods for analysing the biomechanics of a canoe paddler's stroke, but the results of a computer-simulated muscle activity are significantly different from the results obtained with an electromyograph. It was found that the muscle performance in canoe sprint is significantly influenced by the morphological and anthropometric profiles of athletes. In order to determine the muscle activity of Latvian canoe paddlers during canoe sprint, the following tasks were set: To determine the electromyographic activity of a brace and the sequence in which the muscles reach their peak activity in canoe paddlers at loads of varying intensity, and to evaluate the differences in the electromyographic muscle activity in canoe paddlers and the sequence of reaching peak muscle activity at loads of varying intensity.

Material & Methods

In order to fulfil the research tasks, a laboratory study was conducted on October 2021 in the laboratory of the Research Centre of the Latvian Academy of Sports Education at Brīvības gatve 333, Riga. The research participants were 5 high-performing athletes who are at least masters of the sport with experience in international competitions. At the time of the study, the average age of the participants was 25.6 years, weight – 82.8 kg, and height – 178 cm. The “Dansprint” canoe ergometer, which is also used in world-class competitions, was used for the study.

The subjects of the study had to perform 2 tests. Test 1 involved paddling for 120 seconds, while increasing the paddling power every 30 seconds. During the test, the athletes had to paddle for the first 30 seconds (0-30) with a power of 80 to 90W, then for the next 30 seconds (31 to 60) with a power from 90 to 100W, followed by 30 seconds (61 to 90) with a power of 100 to 110W, and the final 30 seconds (91 to 120) with a power of 110 to 120W. Test 1 was followed by 8 minutes of rest. Then Test 2 was conducted, where the athletes had to perform a 200-meter test with peak stroke strength and a pace of 57 to 65 strokes per minute.

All participants were fitted with 16 wireless surface electromyograph sensors (“FreeEMG1000”) before testing. They were attached to the following muscles (see Figure 1): left *posterior deltoid* (1- the number marked in the figure below), right *posterior deltoid* (2), right *mid-trapezius* (3), left *mid-trapezius* (4), right *triceps long head* (5), left *triceps long head* (6), paddling side *latissimus dorsi* (7), paddling side *serratus anterior* (8), left *external obliques*, right *external obliques* (9), left *longissimus thoracis* (10) (in order to determine the activity of *longissimus thoracis*, the sensor was attached to the chest part of the *erector spinae* muscle group), right

longissimus thoracis(11), left *gluteus medius* (12), right *gluteus medius* (13), left *gluteus maximus* (14) and right *gluteus maximus* (15).

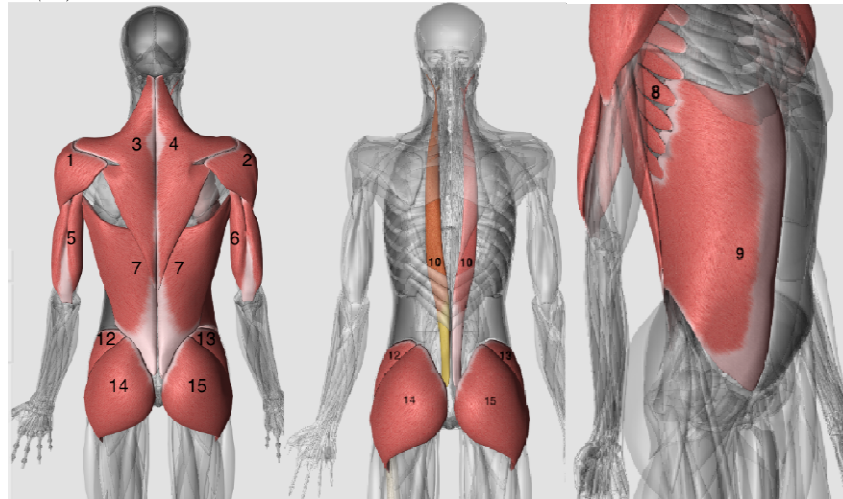


Fig. 1. Muscles Tested in the Study (image created in “3D Organon” programme)

Before attaching the electromyography sensors, the surface of the skin over the muscles to be tested was shaved and thoroughly cleaned to improve the accuracy of the electromyograph results.

The movements of the participants were captured by 6 infrared cameras that capture up to 1000 frames per second, as well as a video recording device that captures up to 60 frames per second. A biomechanical model of the canoe paddler was created with reflective markers to determine the beginning and the end of a brace (see Figure 2).

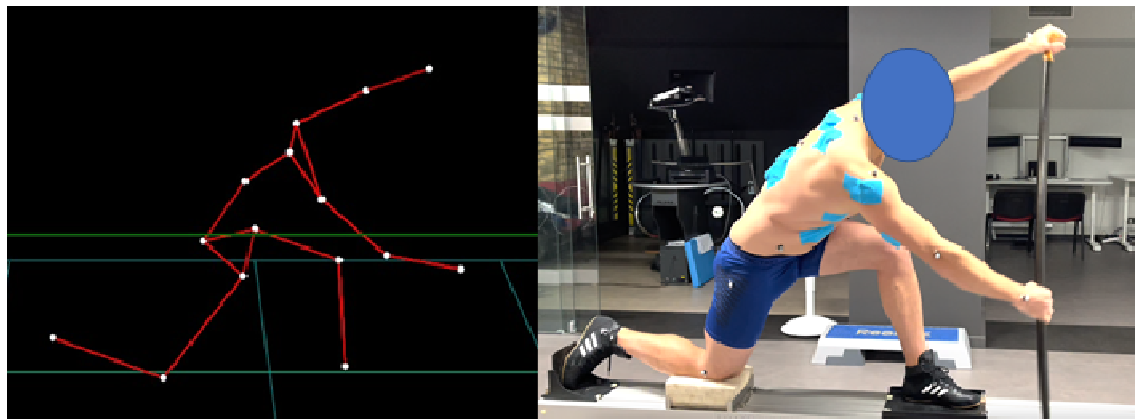


Fig. 2. Biomechanical Model of a Canoe Paddler

The electromyographic results were normalized to the highest electromyographic activity of each muscle. In order to make the obtained results more transparent, the normalized units were multiplied by 1000 (hereinafter – units).

Various video recording equipment was used in the study. A video camera recording 60 frames per second was used to analyse the canoe paddling technique. “BTS SMART DX” hardware available at the laboratory was used to precisely determine the beginning and the end of a brace for each athlete. It captures athletes’ movements with 6 infrared high-speed cameras and works synchronously with the “FreeEMG” electromyograph. The system is internationally recognized and used in clinical trials (Kopeć et al., 2015). Moreover, its accuracy is up to 0.1 mm and it captures up to 1000 frames per second.

A data processing protocol of 20Hz, 400Hz and 6Hz LP filter was used for electromyography data processing. After filtering, approximately 14 000 000 electromyography recordings were obtained, which were then normalized by dividing them by the peak value of each muscle. For each canoe paddler, 6 braces were analysed in depth, including 3 braces in the 2-minute test at 3 loads of varying intensity. In the 200-meter test, 1 brace was analysed at the beginning, middle and end of the test. The study reflects approximately 67 000 electromyography recordings for each of the participants.

The obtained results were processed with the “MS EXCEL” programme. Descriptive statistics was performed, - arithmetic mean and standard deviation was also determined for the data and values were determined to follow normal distribution: variation coefficient <10 %. Furthermore, an “F-test” was performed

using the “RStudio” programme, followed by “Student’s T-test” for related sets with different variations in 1 case, and “Student’s T-test” for related sets with similar variations in 26 cases. In order to make the results more reviewable, tables and graphic visualizations were created.

Results

Initially, the results of the electromyographic activity and the sequence of reaching peak activity for each of the 5 participants were obtained. The brace time of canoe paddlers varies considerably between the tests and participants. The duration of the braces analysed in the test is between 0.456 seconds and 0.884 seconds. Attention was also paid to the time after which peak activity was reached and its place in the sequence. The time to reach peak activity in the tables is shown in seconds and the adjacent column indicates the place in the sequence. Sequence variation, as well as average and peak activity indicators were also analysed. The results presented by each study participant are reflected in two tables – (the time and sequence of reaching peak muscle activity in one table, and the average and peak activity in units in the other). The units are obtained by normalizing the data obtained in millivolts with peak activity of the respective muscle, thus obtaining normalized units and multiplying them by 1000. The data obtained by Participant No. 4 are shown below (all 5 study participants and all 16 studied muscles are examined in this way), in a shortened version for only one of the 16 studies muscles (see Table 1 and Table 2).

Table 1. Time and Sequence of Reaching Peak Muscle Activity for Participant No. 4

Muscle	2 minute test						200 meter test						Mean n ^A (SD)
	Start		Middle		Finish		Start		Middle		Finish		
	t,s	n ^A	t,s	n ^A	t,s	n ^A	t,s	n ^A	t,s	n ^A	t,s	n ^A	
P.s.posterior deltoid*	0.33	14	0.36	13	0.40	12	0.29	13	0.35	13	0.37	13	13.0 (±0.6)
O.s.posterior deltoid**	0.23	9	0.30	11	0.36	11	0.45	16	0.50	16	0.47	16	13.2 (±3.2)

* paddling side muscle

** opposite side muscle

^A sequence at which the muscle started to work at maximum capacity based on presented muscles in Section M&M

Table 2. Time and Sequence of Reaching Peak Muscle Activity for Participant No. 4 (normalized units)

Muscle	Test	Activity	Muscle of the Paddling Side				Muscle of the Opposite Side			
			Start	Middle	Finish	Average	Start	Middle	Finish	Average
<i>M. posterior deltoid</i>	2 min.	Average	47	55	74	59	95	114	150	120
		Peak	113	174	271	186	202	205	261	223
	200 m	Average	279	248	196	241	270	285	234	263
		Peak	592	714	647	651	621	543	481	548

The *posterior deltoid* of the paddling side reaches its peak activity in a stable sequence. In the 2-minute test, the time of peak activity gradually increases from 0.332 to 0.404 seconds, while the position of the muscle in the sequence gradually increases from the 14th place in the beginning of the test to the 12th place at the end of the test. In the 200-metre test, the time of reaching peak activity is also stable from 0.297 to 0.37 seconds, and this muscle stably maintains the 13th place in the sequence of reaching peak activity. Also, the *posterior deltoid* of the opposite side reaches peak activity of all 200-meter tests as the final 16th muscle. The muscle of the opposite side reaches its peak activity in this test between 0.459 and 0.501 seconds, therefore, no significant differences are observed. In the 2-minute test, similarly to the muscle of the paddling side, the time to reach peak activity gradually increases from 0.23 to 0.365 seconds, thus demonstrating the same trend as the muscle of the paddling side. For muscles of both the paddling side and the opposite side, the average activity increases gradually in the 2-minute test, but it is relatively low compared to the 200-meter test. For the muscle of the paddling side, the average activity in the 2-minute test is from 47 to 74 units, while in the 200-meter test it gradually decreases from 279 to 196 units. The highest activity in the 2-minute test is 271 units, so the average activity in the beginning of the 200-meter test is higher than the peak activity in the 2-minute test. The highest activity of the 200-meter test is 714 units, thus a significant difference between the average and peak values can be observed. Peak activity of the muscle of the opposite side in the 200-meter test gradually decreases. In both tests, the muscle of the opposite side has a higher average activity, as well as higher average peak activity in the 2-minute test.

Next, the sequence of reaching peak activity in all participants was evaluated separately in the 2-minute test and separately in the 200-meter test, and the variations (standard deviations) of muscle sequence in both tests

and the average and peak muscle activities were evaluated. For a more precise analysis, the sequence indicators for reaching average peak activity are depicted with a fraction (see Figure 3).

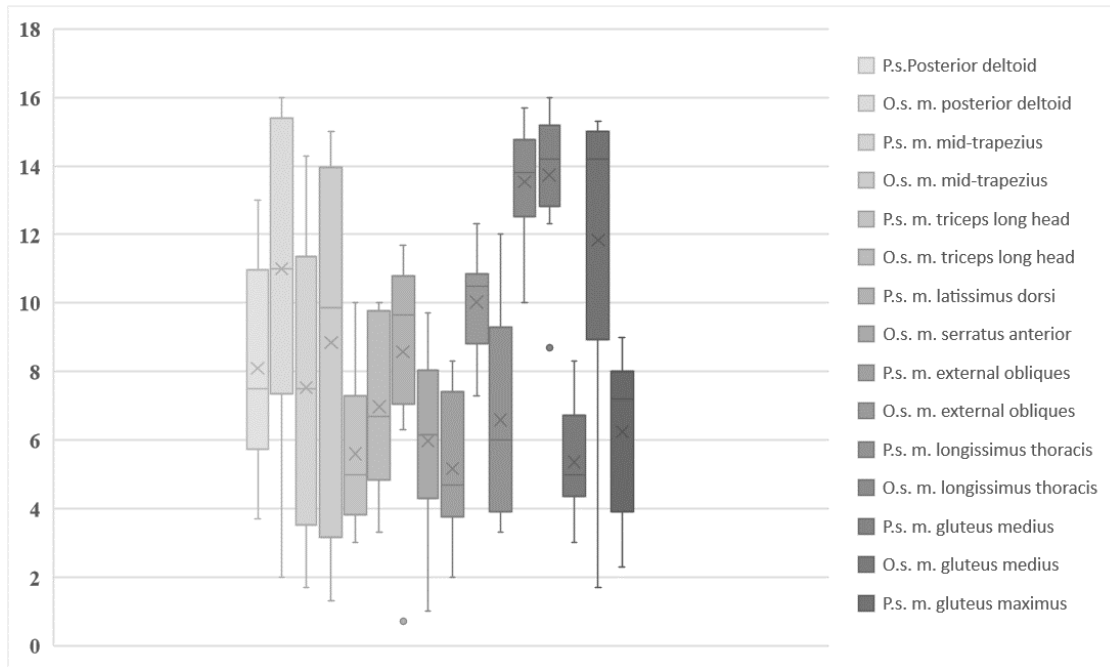


Fig. 3. Sequence of Reaching Peak Muscle Activity of All Muscles of the Participant

When analysing the two tests together, the 1st muscle to reach peak activity is the *external obliques* muscle of the paddling side with an average indicator of reaching peak activity of 5.17 and a relatively low standard deviation of 1.57. It reaches peak activity the fastest for Participant No. 1, who has an average indicator of 2.5. For the other participants, it ranges from 5.2 to 6.5, thus demonstrating low sequence variation. By analysing the results of the Student's T-test, it is concluded that all tested muscles have sequence differences between the tests (see Table 4).

Table 4. Student's T-test Results for the Sequence of Reaching Peak Activity for Related Sets with Similar Variations

Muscle to Be Compared and the Test		T-value*	P-value
P.s. <i>m. posterior deltoid</i> 2 min	P.s. <i>m. posterior deltoid</i> 200 m	0.2008	0.8438
O.s. <i>m. posterior deltoid</i> 2 min	O.s. <i>m. posterior deltoid</i> 200 m	0.0664	0.9480
P.s. <i>m. mid-trapezius</i> 2 min	P.s. <i>m. mid-trapezius</i> 200 m	3.1186	0.0075**
O.s. <i>m. mid-trapezius</i> 2 min	O.s. <i>m. mid-trapezius</i> 200 m	0.6433	0.5305
O.s. <i>m. triceps long head</i> 2 min	O.s. <i>m. triceps long head</i> 200 m	0.6046	0.5551
P.s. <i>m. latissimus dorsi</i> 2 min	P.s. <i>m. latissimus dorsi</i> 200 m	0.5865	0.5669
P.s. <i>m. serratus anterior</i> 2 min	P.s. <i>m. serratus anterior</i> 200 m	2.4867	0.0261**
P.s. <i>m. external obliques</i> 2 min	P.s. <i>m. external obliques</i> 200 m	0.3122	0.7595
O.s. <i>m. external obliques</i> 2 min	O.s. <i>m. external obliques</i> 200 m	0.8767	0.3954
P.s. <i>m. longissimus thoracis</i> 2 min	P.s. <i>m. longissimus thoracis</i> 200 m	1.4988	0.0461**
O.s. <i>m. longissimus thoracis</i> 2 min	O.s. <i>m. longissimus thoracis</i> 200 m	0.2420	0.8123
P.s. <i>m. gluteus medius</i> 2 min	O.s. <i>m. gluteus medius</i> 2 min	1.6748	0.0312**
O.s. <i>m. gluteus medius</i> 2 min	O.s. <i>m. gluteus medius</i> 200 m	-1.6422	0.0422**
P.s. <i>m. gluteus maximus</i> 2 min	P.s. <i>m. gluteus maximus</i> 200 m	1.5989	0.0493**
O.s. <i>m. gluteus maximus</i> 2 min	O.s. <i>m. gluteus maximus</i> 200 m	0.4166	0.6833

*In all cases (T<0.05)

** (p<0.05)

Statistically significant ($p < 0.05$) are the *mid-trapezius*, *serratus anterior*, *longissimus thoracis*, *gluteus medius* and *gluteus maximus* muscles of the paddling side, as well as the *gluteus medius* muscle of the opposite side. Furthermore, an evaluation of the standard deviations of both tests was carried out in order to conclude which of the study participants had the most stable sequence for reaching peak muscle activity. When analysing all muscles, the lowest standard deviation is observed for Participant No. 2, for whom it is 1.78. This participant had the lowest performance in the peak test. The highest average standard deviation of 3.07 was found in Participant No. 3, who had the second best performance, while the second highest standard deviation belongs to Participant No. 4, who showed the best result in the peak test. Higher changes in sequence can be observed in the upper body muscles, indicating the technical differences among the canoe paddlers, as well as in the *longissimus thoracis* muscle, which indicates different trends in back movements.

Upon analysing the total average and peak muscle activity of all participants in each of the tests and respectively in different states of fatigue (at the beginning, middle and end of the test), the results confirm that all participants have significant involvement of both *triceps long head* muscles, as they have high peak and average activity. Although the *serratus anterior* muscles of the paddling side do not display a high peak activity, their average activity is high, which indicates its significant involvement in the canoe brace. In contrast, the *longissimus thoracis* and *mid-trapezius* muscles of the opposite side show high peak activity, but their average activity is low, so it can be concluded that the muscle is active for a short period of time. By analysing the results of the “Student’s T-test” for peak activity and average activity, it is concluded that they are statistically significant ($T < 0.05$) in all cases.

Discussion

It is well-known that a person’s body must overcome external forces with the help of muscles in order for the person to be able to move. It is best to use electromyography to determine muscle activity, as so far computer simulation methods are unable to provide accurate results of muscle involvement (Merletti et al., 2001; Nakashima et al., 2019; Zwarts et al., 2000). Almost all muscles of the body are involved in paddling, but canoe paddlers have a different load due to their asymmetric posture.

The greatest insight into canoe sprint is provided by a research group led by T. Pelham (Pelham et al., 1992). Using an electromyograph, the researchers determined which muscles show the highest activity in both the propulsive and the recovery phase. By comparing two high-performing canoe paddlers, the researcher found that the muscle activity of the two paddlers differed significantly despite them being of equal skill. Our study also found significant differences between the five high-performing canoe paddlers. They differed significantly in terms of physique and height parameters, paddling technique and stroke length, as well as muscle activity. Several studies have described the technical differences of high-performing paddlers (Buday, 2009; Dobos, 2019; Mann & Kearney, 1983; McKenzie & Berglund, 2019; Pelham & Holt, 1995b; Rynkiewicz & Starosta, 2011a; Szanto, 2014; Zahálka et al., 2011), as well as the fact that canoe sprint does not require a specific body type and particular physical indicators to achieve high results, as even the winners of the world championships differ significantly from each other (Ackland et al., 2003; Alacid et al., 2011; Busta et al., 2018; Carter et al., 1982; Hagner-Derengowska et al., 2014; Ridge et al., 2007).

The muscles tested in our study were mainly selected from T. Pelham’s study as most of these muscles showed high activity during some phase of paddling. However, the muscles that showed low or inter-subject variability in activity in the Canadian study were also tested (Pelham et al., 1992). These muscles were the *gluteus medius* and *gluteus maximus* of the paddling side, the *external obliques* of both sides, and the *triceps long head* muscles of the opposite side. In contrast to the study conducted by T. Pelham, where the *triceps long head* muscle of the opposite side during the brace showed an average activity in one participant and a low activity in the other participant, in our study the muscle shows a very high average and peak activity in all participants. Differences were also observed in the activity of the *external obliques* muscles. In the study by T. Pelham’s group, one participant was found to have high activity of the muscle of the opposite side and average activity of the muscle of the paddling side, while this muscle had virtually no activity in the other participant (Pelham et al., 1992). The average activity of the *external obliques* muscles on both sides was equal in our study and it was moderately high. However, the muscle of the paddling side had a relatively low peak activity. Such differences may be attributed to different paddling techniques, as the technique has been adapted to newer designs of paddles and boats over the years, and it also differs between representatives of different countries (Szanto, 2014). The differences in the *external obliques* muscles can arise from body rotation and the angle of the forward lean.

The significant differences in the *gluteus maximus* and *gluteus medius* muscle activity between the sides of the body coincided with those found in the study by T. Pelham’s research group. Also in our study, the *gluteus medius* and *gluteus maximus* muscles of the paddling side showed significantly lower average and peak activity than the muscles of the opposite side. This difference in the muscle activity of the pelvic area may account for the asymmetric changes in the pelvic area often observed in canoe paddlers (Alacid et al., 2011; Dobos, 2019; Kameyama et al., 1999; P. A. López-Miñarro et al., 2012; P. Á. López-Miñarro et al., 2013). In our study, similarly to T. Pelham’s study, the *longissimus thoracis* of both sides, and the *latissimus dorsi*, *serratus anterior*, *posterior deltoid* and *mid-trapezius* muscles of the paddling side showed a relatively high average activity,

which confirms the significant involvement of the abdomen and shoulder area muscles in canoe brace. It should be noted that the study by T. Pelham's group did not have such advanced video recording and electromyographic activity detection devices as our study did, as 2 muscles were tested at the same time in the study conducted in Canada, thus the test had to be repeated several times, which could have negatively affected the test results (Pelham et al., 1992). The high involvement of the abdomen and shoulder area muscles is also consistent with other studies in canoe sprint, as well as studies on SUP paddling, which is related to canoe sprint (Ruess et al., 2013; Tsai et al., 2020; Kolosova & Haleavka, 2015).

Our study also compared muscle changes at loads of varying intensity. A similar study was also conducted in Belarus, where changes in muscle activity at different loads were found, but the study tested only specific muscles and did not normalize the data, therefore, the studies cannot be objectively compared (Kolosova & Haleavka, 2015). However, when comparing the trends, the differences in the activity of the *posterior deltoid* and *latissimus dorsi* muscles can be observed. In the Belarusian study, the activity of these muscles gradually decreased during the tests, but no such trend was observed in our study (Kolosova & Haleavka, 2015). As in the study conducted in Belarus, our study also analysed braces at the beginning, middle and end of the tests. In the study of a researcher group led by B. Trevithick (Trevithick et al., 2007), where the activity of the shoulder area muscles in paddlers was analysed, the data were normalized. Our study also included data normalization after the analysis of information sources (Halaki & Gi, 2012; Nicholson, 2000).

However, our study did not include anthropometric measurements, but asymmetric musculature changes could be visually observed in canoe paddlers when installing the electromyograph sensors, which have also been found in other studies worldwide (P. Á. López-Miñarro et al., 2013; Rynkiewicz et al., 2013; Rynkiewicz & Starosta, 2011a; Silva et al., 2018). In canoe paddlers, a greater muscle mass can often be observed in the muscles of the paddling side. Such asymmetric changes occur due to the specific posture and movements of canoe sprint. Our study also found that most muscles of the paddling side showed higher activity. Differences in the average and peak activity between loads of different intensity and paddling sides are statistically significant. Statistically significant differences can also be observed in the sequence of reaching peak activity in the *mid-trapezius*, *serratus anterior*, *longissimus thoracis*, *gluteus medius* and *gluteus maximus* muscles of the paddling side, as well as the *gluteus medius* muscle of the opposite side.

Conclusions

By comparing and evaluating the peak and average muscle activity of canoe paddlers, as well as the differences in the peak activity between the study participants, it can be concluded that:

The average and peak activity of the muscles differs, but there are also similar trends in the activity of the *gluteus maximus*, *gluteus medius*, *longissimus thoracis* and *triceps long head* muscles of both sides. All participants demonstrated a high average muscle activity in the *triceps long head* muscles of both sides, as well as the *latissimus dorsi*, *serratus anterior* and *longissimus thoracis* muscles of the paddling side. The lowest muscle activity was found in the *gluteus medius* and *gluteus maximus* muscles of both sides, as well as the *mid-trapezius* and *posterior deltoid* muscles of the opposite side. The *serratus anterior* and *external obliques* of the paddling side showed a high average activity, but low peak activity, indicating prolonged involvement of the muscle during the brace. The *mid-trapezius* muscle of the opposite side showed a high peak activity, but its average activity is low, thus it can be concluded that the muscle is involved in the brace for a relatively short time.

In all participants, the *gluteus medius* and *gluteus maximus* muscles of the opposite side show significantly higher peak activity than the muscles of the paddling side, which may account for the asymmetry of the pelvic musculature in canoe paddlers. Furthermore, a higher activity of the *mid-trapezius* muscle of the opposite side is observed in several participants. The *posterior deltoid* and *longissimus thoracis* muscles of the paddling side also show a significantly higher average activity than the muscles of the opposite side, which can cause shoulder and back asymmetry.

The sequence of reaching peak muscle activity varies between the participants, but similar trends can be observed for the *external obliques* and *gluteus medius* muscles of both sides, as well as the *latissimus dorsi* muscles of the paddling side and the *longissimus thoracis* muscles of the opposite side.

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