Journal of Physical Education and Sport ® (JPES), Vol. 24 (issue 7), Art 201 pp. 1807 - 1813, July 2024
online ISSN: 2247 - 806X; p-ISSN: 2247 – 8051; ISSN - L = 2247 - 8051 © JPES

Original Article

Muscle oxygenation and energy substrate utilization in 200m and 500m sprint paddling in elite dragon boat athletes

PATCHAREEYA JARDSAKUL[1], NUTCHAREE SENAKHAM[2], PORNTHEP RATCHANAVY[3], WATUNYOU KHAMROS[4], TANORMSAK SENAKHAM[5]
[1,2,4,5] Department of Sports Science, Faculty of Physical Education, Sports and Health, Srinakharinwirot University, Nakhon Nayok, THAILAND
[3] School of Sports Science, Institute of Science, Suranaree University of Technology, Nakhon Ratchasima, THAILAND
[1,2,3,4,5] The Rowing and Canoeing association of Thailand (RCAT), Bangkok, THAILAND

Published online: July 31, 2024
Accepted for publication : July 15, 2024
DOI:10.7752/jpes.2024.07201

Abstract:
The presence of oxygen in active muscles dictates substrate metabolism which is crucial for sport performance. However, it's information in dragon boat races is limited. This study aimed to evaluate muscle oxygenation and energy substrate utilization during 200-m and 500-m dragon boat races among elite athletes. Ten male dragon boat athletes participating in international competitions (age 26.60 ± 3.20 years, weight 79.54 ± 3.36 kg, height 174.80 ± 5.67 cm) completed 200-m and 500-m simulated race trials on an ergometer in a randomized, counter-balance, crossover fashion, with a 2-day separation. Near-infrared spectroscopy (NIRS) monitors were placed on the biceps brachii (BB) and latissimus dorsi (LD) to investigate tissue saturation index (TSI), oxyhemoglobin concentration (O2Hb), deoxyhemoglobin concentration (HHb), and total hemoglobin (tHB) during the trials, and gas analyzer was employed to evaluate energy substrate utilization. The results revealed that during 200-m and 500-m races, TSI, O2Hb, and tHb in the BB significantly decreased ($P<0.05$), whereas HHb significantly increased ($P<0.05$). In the LD, this change was observed only in 200-m race ($P<0.05$). When comparing between the distances, all oxygen parameters in the BB were significantly higher in 500-m than 200-m ($P<0.05$), while in the LD, TSI, O2HB, and tHb were significantly higher ($P<0.05$). Total energy and energy from carbohydrate were also significantly higher in 500-m than 200-m race ($P<0.01$). The results of this study indicate that there is difference in muscle oxygenation and energy substrate expenditure during 200-m and 500-m dragon boat races. This disparity may be resulted from different muscle recruitment patterns, as indicated by difference in oxygen parameters in the BB and LD during the races. This study provides new knowledge to the area of paddle sports and offers practical insights that can help coaches and related persons to optimize athletic performance during training and competitions. More researches are required to clarify the mechanisms underlying the differences in muscle oxygenation in different dragon boat race distances.
KeyWords*:*water sport, oxygen saturation, substrate metabolism, power output, endurance performance.

Introduction

Dragon boat is a sport that relies on paddling as a team, using muscle power to transmit force to the paddle blades, thus propelling the boat across the water from one point to another. The physical activity involves moving back and forth while paddling over the race distance and working together using multiple muscles to overcome water resistance with repeated maximum muscle contractions for speed (Sirisinghe, 1995). A study of the physiology of dragon boats was conducted by analyzing dragon boat skills together with electromyography (EMG), which found that the main muscles that affect dragon boat performance are the shoulder muscles and the base muscles, including the front arm and back muscles (Ho et al., 2013; Natthawat, 2016; Paulauskas et al., 2022; Senakham et al., 2015). Working muscle groups must be efficient in their use of oxygen, ions, and energy substances to enable rapid contraction and relaxation as well as preparation for repeated contractions. Therefore, muscle oxygenation is extremely important for muscular endurance and power (Ferrari et al., 2011). The proportion of oxygen used by active muscle groups will have a higher oxygen demand than inactive muscles (Verratti et al., 2020).

For muscles to be able to work continuously and efficiently, they need to have a good cardiovascular system to create a balance between oxygen delivery and muscle oxygen demand (Yoshiko et al., 2020). At present, the near-infrared spectroscopy (NIRS) technique has been used to assess the oxygen status of muscles in various parts of the body in real-time, directly measuring the amount of oxygen used by muscles. The instrument relies on the absorption of infrared radiation through the muscle to measure the difference in arterial oxygen, reflecting the local muscle oxygen consumption. The distribution of blood flow to the working muscle, tissue

Corresponding Author: TANORMSAK SENAKHAM, E-mail address: tanormsakse@gmail.com

saturation index, indicates an imbalance in oxygen delivery that will result in decreased muscle performance, an important parameter used in explaining and predicting exercise limitations (Ferrari et al., 2011; Kirby et al., 2021; Paulauskas et al., 2022; Verratti et al., 2020).

In dragon boat races, distances of 200 and 500 meters are exercised with a level of intensity close to maximum (Submaximal), using a competition time of approximately 30 seconds to 2 minutes with energy from both aerobic and anaerobic systems simultaneously (Ho et al., 2013; Medbø & Tabata, 1989), which results in high levels of lactic acid. Blood lactate impairs muscle function and remains within the muscles for several minutes after even short periods of high-intensity paddling (Khamros et al., 2023; Senakham et al., 2020). The proportion of aerobic energy used will increase depending on the distance of the race (Medbø & Tabata, 1989; Zamparo et al., 1999).

Previous studies have found that 200- and 500-meter dragon boat races involve high-intensity, short-duration sprints with similar energy expenditures. However, there has been no study or comparison of the effects of muscle oxygenation and energy substrate utilization in 200 and 500-meter dragon boats. The results of the study can be used as information for training planning, nutrition planning, and evaluating the results of the training program for those interested in studying dragon boats.

Material & methods

This study was experimental research using a randomized, counter-balance, crossover design approach. The study was approved by the Human Research Committee of Srinakharinwirot University, Thailand, with research project certification number of SWUEC-661010. All participants signed a declaration of consent on the anonymous utilization of the collected data prior to the study.

Participants

Ten well-trained athletes from the Rowing and Canoeing association of Thailand (RCAT) were recruited into the study. Their physical characteristics are shown in Table 1. Inclusion criteria consisted of male athletes, with at least 2 years of training experience and at least 2 years of competitions in the international level. The participants must have continuous training for at least 6 months prior to attendance in the study. Exclusion criteria comprised having injuries or illness during the experiment, and intention to withdraw from the study.

Procedures

The participants reported to a laboratory on 3 occasions for 1 preliminary test and 2 main tests. All tests were separated by 2 – 3 days and conducted between 7:00 a.m. and 9:00 a.m. under a controlled condition (25°C ± 2°C and 50% ± 10% relative humidity). To standardize the tests, the participants were asked to refrain from high-intensity exercise for 48 hours before the test, abstain from consuming foods and beverages containing caffeine and alcohol for 24 hours before the test, get sleep at least 7 hours before the test, and refrain from consuming any type of foods or drinks providing energy after 8:00 p.m. on the day prior to the test, thus they were allowed to drink water as needed. Moreover, in the main test stage, they recorded their food intake and physical activities for 24 hours before the 1st test and replicated these before the 2nd test.

Table 1 Physical characteristics of the participants

Physical Characteristics	
Age (year)	26.60 ± 3.20
Body Weight (kg)	79.54 ± 3.36
Height (cm)	174.80 ± 5.67
Body Fat (%)	16.82 ± 4.38
Blood Pressure (mmHg)	134 ± 9.18 / 75 ± 6.00
Resting Heart Rate (beat/min)	56.50 ± 9.40
VO_2max (ml/kg/min)	45.27 ± 10.28

Preliminary test

This test comprised physical examination and determination of VO_2max of each participant. The physical examination was measures of body weight (Tania, UM-073, Tokyo, Japan), height (Meterex II D97, UNICEF, Copenhagen, Denmark), body fat percentage (Maltron BioScan916, Rayleigh, UK), resting blood pressure (BP), and resting HR (Omron HEM-7130, Kyoto, Japan). The measurement of body fat, BP, and HR was conducted after the participants relaxed in a supine position for 10 minutes.

To assess VO_2max, each participant performed the Step Test 3-minute method (Mekhdieva et al., 2019) on an ergometer (Kayak ergometer, Weba Sport, Vienna, Austria), using canoe mode with the airbrake resistance set at level 7. This test consisted of warm-up session at 80 watts for 3 minutes, after which participant paddled at 100 watts for 3 minutes and increased intensity by 30 watts every 3 minutes. Participant was verbally encouraged to paddle at their maximum effort, and the test was terminated when 3 of the following criteria were met (Khamros et al., 2023): (1) an increase in VO_2 <150 ml/min despite increasing paddling intensity; (2) respiratory exchange ratio (RER) higher than 1.1; (3) an attainment of 95% of the aged-predicted maximum heart rate; (4) rating of perceived exertion (RPE) at 18 based on a 6 – 20 scale (Borg, 1982); or (5) inability to maintain the desired intensity despite strong encouragement. During the test, pulmonary gas exchange was measured using an automatic gas analyzer (PNOE, Endo Medical, Palo, Alto, CA, USA) with the PNOE program. The gas analyzer was automatically calibrated for barometric pressure, temperature, and humidity before each test. The ergometer was also calibrated before each test according to the manufacturer's instructions, and rope tension was checked regularly.

Main tests

The participants performed 2 trials to investigate muscle oxygenation, energy substrate expenditure, and mechanical parameters. These trials consisted of resting for 5 minutes, warm-up by stretching for 5 minutes, resting until HR returned to the baseline, and simulation of 200-m, and 500-m dragon boat race, followed by cool down by paddling at self-selected stroke on an ergometer (Figure 1). The simulation of dragon boat races was performed on an ergometer (Kayak ergometer, Weba Sport, Vienna, Austria) using canoe mode at level 7 airbrake resistance. The trial was initiated by having the participant in a preparation position and then paddling as fast as possible following the verbal signals “Are you ready”, “Attention”, and “Go” from the researcher. The participants were verbally encouraged to paddle at their maximal effort throughout the race with a technique typically used during on-water competition.

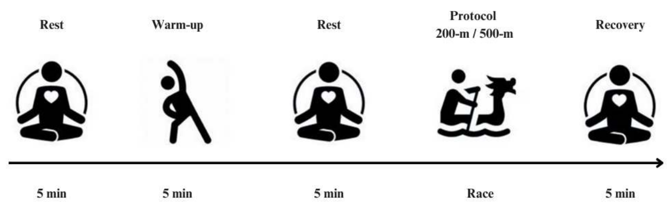

Figure 1 Protocol of the main tests to investigate muscle oxygenation, energy substrate expenditure, and biomechanical parameters during 200-m and 500-m dragon boat races.

Muscle oxygenation measures

Muscle oxygenation variables consisted of tissue saturation index (TSI), deoxyhemoglobin concentration (HHb), oxyhemoglobin concentration (O2Hb), and total hemoglobin (tHb). These variables were evaluated on the participant’s dominant side during the trials using NIRS monitor, including muscle oxygen measuring sensors and Oxysoft software (Portamon; Artinis Medical Systems, BV, Zetten, Netherlands). For evaluation, three sensors (three infrared light source transmitters with wavelengths of 760 and 850 nm) were placed on 2 muscles: the BB – middle of the muscle measured from the point of attachment at the coracoid process of the scapula to the point of attachment at the radial tuberosity of the lower arm or 8 to 12 cm above the elbow fold (Billaut & Buchheit, 2013) and the LD – middle of the muscle measured from the point of origin in the spinous processes of the thoracic spine (T7) to the point of attachment at the intertubercular groove of the humerus or midpoint between the inferior border of the scapula and posterior axillar fold (Borges et al., 2015). Before installing the sensors, the area of the sensor attachment was shaved and wiped with alcohol to remove sweat and ensure that the LED status bar of the sensors was closely contacted with the skin. The instrument was then wrapped tightly with stretchy cloth to prevent movement or loss during testing. Another layer of black cloth was used to prevent light from interfering with the operation of the instrument, and then the tool was connected to the Oxysoft program and set up according to the user’s manual. The sensors were installed by one experienced sports scientist to prevent erroneous data.

Energy substrate expenditure measures

Variables of energy substrate expenditure, including total energy expenditure, carbohydrate energy, and fat energy, were evaluate before and during the simulated races using a gas analyzer (PNOE, Endo Medical, Palo Alto, CA, USA) which was connected to a HR monitor (Polar H10, Polar Electro, Kempele, Finland). These devices were synchronized. The gas analyzer was calibrated for barometric pressure, temperature, and humidity before each test according to the manufacturer’s instruction.

Mechanical parameter measures

Time to complete the simulated 200-m and 500-m races was recorded. Stroke rate, maximal power, and average power during the simulated trials were also measured using the ergometer (Kayak ergometer, WEBA Sport, Vienna, Austria), which was calibrated before each test according to the manufacturer's instructions.

Statistical analysis

Data were presented as mean ± standard deviation. Paired samples *t*-test was used to determine differences of muscle oxygenation, energy substrate expenditure, and mechanical variables between the trials. Two-way analysis of variance (ANOVA) with repeated measures was used to evaluate the effects of trial distance (200-m and 500-m) and time (before and during the races) on muscle oxygenation and energy substrate expenditure variables. Significant interactive effects were followed up with paired samples *t*-test. Statistical significance was set at P < 0.05.

Results

The results revealed that during 200-m and 500-m races, TSI, O2Hb, and tHb in the BB significantly decreased (P<0.05), whereas HHb significantly increased (P<0.05). In the LD, this change was observed only in 200-m race (P<0.05). When comparing between the distances, all oxygen parameters in the BB were significantly higher in 500-m than 200-m (P<0.05) (Figure 2), while in the LD, TSI, O2HB, and tHb were significantly higher (P<0.05) (Figure 3).

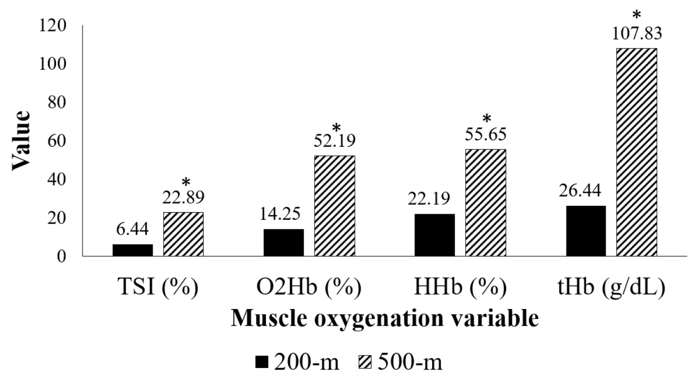

Figure 2 Muscle oxygenation variables of the biceps brachii muscle during 200-m and 500-m dragon boat races
Note. **Significant difference when compared with 200-m (P<0.05), TSI; Tissue saturation index, O2Hb; Oxyhemoglobin concentration, HHb; Deoxyhemoglobin concentration; tHb; Total hemoglobin*

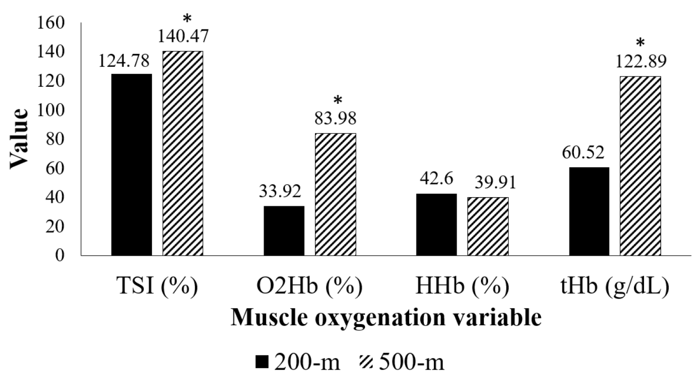

Figure 3 Muscle oxygenation variables of the latissimus dorsi muscle during 200-m and 500-m dragon boat races
Note. **Significant difference when compared with 200-m (P<0.05), TSI; Tissue saturation index, O2Hb; Oxyhemoglobin concentration, HHb; Deoxyhemoglobin concentration; tHb; Total hemoglobin*

When comparing the energy substrate utilization between the races, it was found that total energy and energy from carbohydrate were significantly higher in the 500-m race than the 200-m race (P<0.01), while energy from fat was not different (Table 2).

Table 2 Energy substrate utilization during 200-m and 500-m dragon boat races

Energy variables	200-m	500-m	P-value
Total energy (kcal)	7.23 ± 1.47	27.60 ± 4.88	0.001*
Carbohydrate (kcal)	3.11 ± 1.40	22.14 ± 5.95	0.001*
Fat (kcal)	4.12 ± 1.55	4.12 ± 1.55	0.169

Note. **Significant difference when compared with 200-m (P<0.05)*

Mechanical parameters during the trials are shown in Table 3. The 500-m race took longer time than the 200-m race (P<0.01), whereas maximal power, average power, and paddling frequency during the former were significantly lower (P<0.05).

Table 3 Energy substrate utilization during 200-m and 500-m dragon boat races

Mechanical variables	200-m	500-m	P-value
Time (Sec)	46.99 ± 1.16	126.60 ± 2.33	0.001*
Maximal power (Watt)	324.20 ± 8.36	274.40 ± 18.49	0.04*
Average power (watt)	250.20 ± 10.75	188.00 ± 5.64	0.01*
Paddling frequency (Stroke/min)	79.70 ± 2.45	57.40 ± 2.17	0.01*

Note. **Significant difference when compared with 200-m (P<0.05)*

Discussion

From the results of a comparative study of dragon boat distances of 200 and 500 meters among elite male dragon boat athletes, it was found that the biceps brachii muscle had a decrease in tissue saturation index while racing and total hemoglobin in both stages of rowing. Latissimus dorsi had a decrease in tissue saturation index and total hemoglobin only at a distance of 200 meters. The cause for this decreased is that the 200-meter distance has a higher rowing frequency than the 500-meter distance. Paddling at a high stroke causes the main muscles to contract quickly and repeatedly, causing blood vessels to constrict, thus leading to the restriction of blood flow (Yoshiko et al., 2020) and resulting in poor oxygen transport, which is related to exercise intensity (Ferrari et al., 2011). Moreover, the arm muscles are small muscles that are constantly moving according to the stroke length (Gomory, 2018; McDonnell et al., 2013). Force is exerted and acts all the time as an important factor in propelling the boat forward (Gomes et al., 2022; Sirisinghe, 1995). These factors result in a reduced ability to deliver oxygen to the muscles (Kirby et al., 2021; Paquette et al., 2018; Paulauskas et al., 2022; Perrey et al., 2024).

During the test, it was found that the 500-meter distance consumed more energy from carbohydrates than the 200-meter distance, but there was no difference in the energy expenditure from fat. The higher proportion of energy demand varies with the duration of the competition (Medbø & Tabata, 1989; Paquette et al., 2019). While competing, Glycogen is created and stored in muscles (Henderson et al., 2007; Jung et al., 2021; Kuo et al., 2005) and oxygen stored in the body are used according to the intensity of the activity. Regarding the amount of oxygen in the muscles in the first 2 minutes of rowing 200 meters, it was found that total hemoglobin and oxyhemoglobin concentration in the biceps brachii muscle and latissimus dorsi muscle remained low because blood vessels were still contracted and blood flow was still reduced. If it does not recover, it will begin to adapt to a steady state after 4 minutes.

The trend of oxygen deficiency increases over time in exercise (Kirby et al., 2021). Deoxyhemoglobin decreases immediately after exercise. However, within 500 meters, the above-mentioned adjustments were found only in the biceps brachii muscle (Ferrari et al., 2011; Osawa et al., 2017;).

Oxygen deficiency will continue to increase even with short periods of exercise, but it will result in an increase in oxygen consumption after high-intensity exercise as well if those activities are of high intensity, because exercising at a high intensity stimulates the metabolism more. This causes stress within the muscles and increases the activation of the sympathetic nervous system. When entering the initial recovery period after the test, the physical state will continue to use high levels of carbohydrate energy for the next period of rapid recovery (Alactacid component). During this period, the body synthesizes adenosine triphosphate and phosphocreatine, adjusts blood balance, increases the amount of oxygen in the blood, and balances hormones to a normal level. It takes 30 seconds for the synthesis of phosphocreatine to complete within 3 minutes (Laforgia et al., 2006), and then there is a slow recovery period (Lactacid component). As the physical gradually adjusts to its pre-exercise state, it will switch to using fat as its main source of energy and must use a greater amount of energy to recover to a steady state (Zamparo et al., 1999).

In the 200-meter distance, physical intensity and high-paddling strokes may cause higher fatigue levels, which may not have a positive effect on the body's oxygen levels when measured from muscle oxygenation, especially considering the important muscle groups used in paddling.

The muscles work by contracting repeatedly all the time. Paddling continuously at a rapid pace leaves no period for muscle relaxation, resulting in the blood vessels being unable to transport oxygen to the muscles for energy metabolism, which may limit performance. This effect of reduced rowing efficiency may only be used to explain the 200-meter rowing limit. Moreover, carbohydrate fueling is still very important for dragon boat athletes, although the 500 meters used more energy substrate than the 200 meters with similar levels of fat being used. The results of the study on energy substances may lead to nutritional planning because the levels of energy consumption at distances of 200 meters and 500 meters are different.

Conclusions

Interpretation of the physiological mechanisms from this study may lead to the consideration of adjustments for athletes' training programs or competition strategies, especially in 200-meter events. It appears that elite athletes have relatively high levels of physical performance and are different when performing in two distances of competition. Further studies should consider other factors to account for the physiological factors affecting the performance of elite dragon boat athletes.

Acknowledgement

The authors would like to thank the Department of Sports Science, Srinakharinwirot University, School of Sports Science, Institute of Science, Suranaree University of Technology, and The Rowing and Canoeing association of Thailand (RCAT), for support the sports science equipment and sport science laboratory for experiment this research.

Conflicts of interest

All authors not have any conflicts of interest.

References:

Billaut, F., & Buchheit, M. (2013). Repeated-sprint performance and vastus lateralis oxygenation: effect of limited O_2 availability. *Scandinavian Journal of Medicine & Science in Sports, 23*(3), e185-193. https://doi.org/10.1111/sms.12052

Borg G. A. (1982). Psychophysical bases of perceived exertion. *Medicine and science in sports and exercise, 14*(5), 377–381.

Borges, T. O., Dascombe, B., Bullock, N., & Coutts, A. J. (2015). Physiological characteristics of well-trained junior sprint kayak athletes. *International Journal of Sports Physiology and Performance, 10*(5), 593-599. https://doi.org/10.1123/ijspp.2014-0292

Diachenko, A., Rusanova, O., Huang, Z., Gao, X., Guo, J., & Ye, C. (2021). Functional and physical capacity indicators of kayakers racing 1000, 500, and 200 m distances: a randomized study. *Journal of Physical Education and Sport, 21*(3), 1325-1330. https://doi.org/https://doi.org/10.7752/jpes.2021.03168

Ferrari, M., Muthalib, M., & Quaresima, V. (2011). The use of near-infrared spectroscopy in understanding skeletal muscle physiology: recent developments. *Philosophical transactions. Series A, Mathematical, physical, and engineering sciences, 369*(1955), 4577–4590. https://doi.org/10.1098/rsta.2011.0230

Gomes, B. B., Ramos, N. V., Conceição, F., Sanders, R., Vaz, M., & Vilas-Boas, J. P. (2022). Paddling time parameters and paddling efficiency with the increase in stroke rate in kayaking. *Sports biomechanics, 21*(10), 1303–1311. https://doi.org/10.1080/14763141.2020.1789204

Gomory, Joseph (2018). *The Biomechanics of Dragon Boat Paddling*. [Master thesis], Victoria University. https://vuir.vu.edu.au/39512/

Henderson, G. C., Fattor, J. A., Horning, M. A., Faghihnia, N., Johnson, M. L., Mau, T. L., Luke-Zeitoun, M., & Brooks, G. A. (2007). Lipolysis and fatty acid metabolism in men and women during the postexercise recovery period. *The Journal of physiology*, 584(Pt 3), 963–981. https://doi.org/10.1113/jphysiol.2007.137331

Ho, S. R., Smith, R. M., Chapman, P. G., Sinclair, P. J., & Funato, K. (2013). Physiological and physical characteristics of elite dragon boat paddlers. *Journal of Strength and Conditioning Research*, 27(1), 137-145. https://doi.org/10.1519/JSC.0b013e318252f612

Ho, S. R., Smith, R., & O'Meara, D. (2009). Biomechanical analysis of dragon boat paddling: A comparison of elite and sub-elite paddlers. Journal of sports sciences, 27(1), 37-47. https://doi.org/10.1080/02640410802491350

Jung, W. S., Park, H. Y., Kim, S. W., Kim, J., Hwang, H., & Lim, K. (2021). Estimating excess post-exercise oxygen consumption using multiple linear regression in healthy Korean adults: a pilot study. *Physical activity and nutrition, 25*(1), 35–41. https://doi.org/10.20463/pan.2021.0006

Khamros, W., Peepathum, P., Senakham, T., Sriramatr, S., & Phongsri, K. (2023). Post-activation performance enhancement: Acute effected after activation in kayak sprint. *Journal of Physical Education and Sport,* 23, 457-462. https://doi.org/10.7752/jpes.2023.02056

Kirby, B. S., Clark, D. A., Bradley, E. M., & Wilkins, B. W. (2021). The balance of muscle oxygen supply and demand reveals critical metabolic rate and predicts time to exhaustion. *Journal of applied physiology (Bethesda, Md. : 1985), 130*(6), 1915–1927. https://doi.org/10.1152/japplphysiol.00058.2021.

Kuo, C. C., Fattor, J. A., Henderson, G. C., & Brooks, G. A. (2005). Lipid oxidation in fit young adults during postexercise recovery. *Journal of applied physiology (Bethesda, Md. : 1985), 99*(1), 349–356. https://doi.org/10.1152/japplphysiol.00997.2004

LaForgia, J., Withers, R. T., & Gore, C. J. (2006). Effects of exercise intensity and duration on the excess post-exercise oxygen consumption. *Journal of sports sciences, 24*(12), 1247–1264. https://doi.org/10.1080/02640410600552064

McDonnell, K. L., Hume, A. P., & Nolte, V. (2013). Place time consistency and stroke rates required for success in K1 200-m sprint kayaking elite competition. *International Journal of Performance Analysis in Sport,* *13*(1), 38–50. https://doi.org/10.1080/24748668.2013.11868630

Medbø, J. I., & Tabata, I. (1989). Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. *Journal of Applied Physiology (1985), 67*(5), 1881-1886. https://doi.org/10.1152/jappl.1989.67.5.1881

Mekhdieva, K., Zakharova, A., & Timokhina, V. (2019). Exercise Testing of Elite Rowers: Comparison of Methods and Protocols. *International Congress on Sport Sciences Research and Technology Support.* https://doi.org/10.5220/0008166900970102

Moniz, S. C., Islam, H., & Hazell, T. J. (2020). Mechanistic and methodological perspectives on the impact of intense interval training on post-exercise metabolism. *Scandinavian journal of medicine & science in sports, 30*(4), 638–651. https://doi.org/10.1111/sms.13610

Samokham, N., & Sitilertpisan, P. (2016). Effect of dynamic core stability exercise on physical performance in male dragon boat paddlers. *Journal of Associated Medical Sciences, 49*(1), 146. https://doi.org/10.14456/jams.2016.4

Osawa, T., Shiose, K., & Takahashi, H. (2017). Delayed Onset of Reoxygenation in Inactive Muscles After High-Intensity Exercise. *Advances in experimental medicine and biology, 977,* 255–260. https://doi.org/10.1007/978-3-319-55231-6_35

Paquette, M., Bieuzen, F., & Billaut, F. (2018). Muscle Oxygenation Rather Than VO2max as a Strong Predictor of Performance in Sprint Canoe-Kayak. *International journal of sports physiology and performance, 13*(10), 1299–1307. https://doi.org/10.1123/ijspp.2018-0077

Paquette, M., Bieuzen, F., & Billaut, F. (2019). Sustained Muscle Deoxygenation vs. Sustained High VO2 During High-Intensity Interval Training in Sprint Canoe-Kayak. *Frontiers in sports and active living, 1*, 6. https://doi.org/10.3389/fspor.2019.00006

Paulauskas, R., Nekriošius, R., Dadelienė, R., Sousa, A., & Figueira, B. (2022). Muscle Oxygenation Measured with Near-Infrared Spectroscopy Following Different Intermittent Training Protocols in a World-Class Kayaker-A Case Study. *Sensors (Basel, Switzerland), 22*(21), 8238. https://doi.org/10.3390/s22218238

Perrey, S., & Ferrari, M. (2018). Muscle Oximetry in Sports Science: A Systematic Review. Sports medicine (Auckland, N.Z.), 48(3), 597–616. https://doi.org/10.1007/s40279-017-0820-1

Senakham, N., Punthipayanon, S., Senakham, T., Sriyabhaya, P., Sriramatr, S., & Kuo, C. H. (2020). Physiological stress against simulated 200-m and 500-m sprints in world-class boat paddlers. *Chinese Journal of Physiology, 63*(1), 15-20. https://doi.org/10.4103/cjp.Cjp_87_19

Singh, R., Singh, H. J., & Sirisinghe, R. G. (1995). Physical and physiological profiles of Malaysian dragon boat rowers. *British journal of sports medicine, 29*(1), 13–15. https://doi.org/10.1136/bjsm.29.1.13

Verratti, V., Bondi, D., Mulliri, G., Ghiani, G., Crisafulli, A., Pietrangelo, T., Marinozzi, M. E., & Cerretelli, P. (2020). Muscle Oxygen Delivery in the Forearm and in the Vastus Lateralis Muscles in Response to Resistance Exercise: A Comparison Between Nepalese Porters and Italian Trekkers. *Frontiers in physiology*, 11, 607616. https://doi.org/10.3389/fphys.2020.607616

Yoshiko, A., Katayama, K., Ishida, K., Ando, R., Koike, T., Oshida, Y., & Akima, H. (2020). Muscle deoxygenation and neuromuscular activation in synergistic muscles during intermittent exercise under hypoxic conditions. *Scientific Reports, 10*(1), 295. https://doi.org/10.1038/s41598-019-57099-y

Zamparo, P., Capelli, C., & Guerrini, G. (1999). Energetics of kayaking at submaximal and maximal speeds. *European journal of applied physiology and occupational physiology, 80*(6), 542–548. https://doi.org/10.1007/s004210050632