

# Original Research The effectiveness of a cooling vest in post-exercise recovery in sprint kayaking elite male athletes

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#### Abstract

**Background**: Cooling vests are popular and widely used in many sports. There are several studies about their efficacy but there is not much evidence about their impact on the recovery of kayak sprint male athletes. **Methods**: Ten elite male sprint kayakers completed an exercise protocol on a kayak ergometer on two separate days. They were randomized to wear a cold vest during a 15 min active rest on one of these days. Following the pre designed protocol, all sessions were performed in a climate chamber with controlled temperature and humidity conditions. At both moments, the blood lactate concentration was determined, as well as urine temperature. Skin temperature in the *latissimus dorsi* muscle area was assessed several times along the protocol, using infrared thermography. Borg's rating of perceived exertion (RPE Scale) was applied to the protocol after each exercise bout and the perceived recovery scale was applied before the last moment of the protocol (500 m test). **Results**: The subjective perception of recovery was significantly higher during the cooling vest condition (p < 0.01). There were no significant differences on performance in the 500 m maximal test when comparing both days. On the other hand, after the active recovery with cold vest, the skin temperature (p < 0.01), urine temperature (p < 0.05) and blood lactate concentration were all significantly lower (p < 0.05). **Discussion**: Results revealed that the cooling vest is a suitable instrument to induce a decrease in skin and core temperature while paddling and also to reduce more quickly the blood lactate concentration. The vest should be tested under on-water conditions in order to consider other factors such as wind and solar radiation. **Conclusions**: Wearing a cooling vest during active rest after a training session or a competition seems to improve the recovery of male kayakers.

Keywords: Cooling vest; Post-exercise recovery; Kayak sprint; Male athlete; Thermography; Cryotherapy

# 1. Introduction

During kayak sprint competitions, athletes often compete in 2 to 4 events a day, and, most of the time, there is only a short period for them to recover between races. Therefore, a complete recovery is unlikely to occur. On this account, finding a way to quickly cool down the athletes' bodies is a major request, so that they can recover better in the brief interval between races. This will prevent heat stress from happening, which can impair aerobic performance when hyperthermia occurs [1]. Since the major international kayak sprint championships take place in the summer season this has an even greater impact. This type of competition schedule promotes incomplete athletes' recoveries between races, which are associated with the levels of blood lactate concentration (BLC) above the rest values [2]. Therefore, these values are positively correlated with muscular fatigue, and a greater probability of injury occurrences [3,4]. It is common to use active recovery (AR) after submaximal and maximal intensity efforts in order to decrease BLC levels, thus reducing the muscular fatigue [5]

and, consequently, the rate of injuries.

Cryotherapy is a recovery modality that is usually applied to speed up the regeneration of tissues and to prevent swelling of acute musculoskeletal injuries [6-8], especially for the athletes who have a training and competition schedule that requires several bouts of exercises within one day or in environments of extreme heat and humidity [6]. Cryotherapy can be used with two different purposes that are related between each other: to recover between exercise bouts or to recover during heat stress [9]. In kayak sprint events both situations have to be considered, so cryotherapy is a valuable tool in this sport. Cold stimulation shows positive effects on muscle enzymes, creatine kinase and lactate dehydrogenase [1,10]. Furthermore, there is an increase in  $\beta$ -endorphin secretion by the pituitary gland and a decrease in nociceptive response, mainly in C fibers. On that account, cryotherapy can reduce the fibers damage, the delayed onset muscle soreness (DOMS), the pain's perception and it may also have a placebo effect on the sense of recovery [11,12]. Most scientists and practitioners in health



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sciences agree that it is important to understand subjective symptoms and how they relate to objective findings. In sport the same principle can be applied, considering that perceived exertion is closely related to the heart rate, among other strain variables such as blood lactate levels [13]. The Borg's rate scale (6 to 20) is considered to be the most appropriate to be applied in studies of perceived exertion, both for exercise testing and prediction [14].

According to Racinais *et al.* [12] the decrease in the core temperature is smaller with a cooling vest than with cold water immersion or mixed-cooling methods. However, without directly reducing muscle temperature, cooling garments present the advantages of lowering the skin temperature, thus reducing cardiovascular strain and heat storage. Since they provide a fast reduction of the skin temperature, athletes can wear them during the recovery breaks. A delayed effect on temperature reduction in deeper tissues can be expected due to the lowering of the skin temperature.

In recent years some elite teams began to wear cooling vests combined with the active rest after competition, in order to accelerate recovery and prevent injuries in hot environments. However, there are few studies approaching the evaluation of their efficacy in kayak sprint. Finding an effective strategy is important to avoid the potential maladaptive physiological and psychological effects of overtraining [15]. Therefore, the main goal of this study was to evaluate the cooling vest's impact on the recovery process of kayak sprint male athletes, by means of the analysis of the BLC, Borg's rate of perceived exertion (RPE), performance and differences in infrared thermographic imaging distributions.

# 2. Methods

#### 2.1 Participants

Ten kayak sprint elite male athletes took part in this study. The subjects were characterized by the following biometric characteristics (mean  $\pm$  SD): age, 21.63  $\pm$  2.85; height, 177.9 cm  $\pm$  7.33; body mass, 75.18  $\pm$  7.33 kg; arm span, 180.92  $\pm$  9.5 cm; fat mass %, 10.19  $\pm$  4.65. The inclusion criteria were: (1) participation in at least one international event in the last two years, in order to be considered an elite athlete; (2) be included in a training plan which aimed the participation in international competitions. The exclusion criterion was: having a fat mass percentage higher than 20%, considering that fat can interfere in the cold impact on deeper tissues and, consequently, in the skin temperature measurements performed [16]. Moreover, each athlete was his own control.

#### 2.2 Experimental protocol

The study protocol was completed in a climate chamber with controlled temperature and humidity, using a windbraked kayak ergometer (Dansprint® PRO kayak, Hvidovre, Denmark) that has already been used on previous studies [17,18]. The participants reported to the laboratory on three occasions with a week in between. On the first occasion each subject performed a 4 minutes test to determine his maximal average power (MAP). This test defined the power output of the training session (TS) and active recovery (AR) performed during the protocol. On the second and third occasions, the participants reported to the laboratory in order to follow the same protocol, with a single difference: the randomized wearing of a cold vest during the AR on one of the occasions.

The protocol (Fig. 1) consisted of a 15 min acclimatization, a warm-up (5 min at 40% MAP), an aerobic TS (5 times 3 min work with 3 min of passive rest) at 75% of the MAP, similar to what the athletes were used to do in their daily training routine. After it, they had a 5 min passive rest (PR) and then paddled for 15 min (40% MAP) as an AR. Depending on the randomization, the AR was performed wearing or not a colling vest (Inuteq Siku PAC<sup>®</sup> & H2O<sup>®</sup>, Deventer, The Netherlands). This cooling vest had pockets to put 4 cold accumulators inside, 2 pockets in the front side and 2 in the back. The recommendations of the cooling vest brand, on how to get the most out of the garment's wearing, were followed. After resting passively for 15 min, athletes finally performed a 500 m race simulation in order to evaluate their performance. The distance of 500 m was chosen because it is the distance used on national team selection races. The wearing of the cooling vest was decided randomly by means of a calculator in an Excel 2013 spreadsheet.

Prior to the test, the body characteristics such as height, body mass, arm span and skinfolds were measured to estimate the body density (BD) based on *Jackson and Pollock's equation*. This is a generalized equation for the calculation of the BD of men aged between 18 and 61 years old, and it uses the sum of seven skinfolds (subscapular, triceps, abdominal, suprailiac, thigh, chest and medium axillar). The BD's result enabled the estimation of the fat mass percentage with *Siri's formula* [19].

During the protocol the skin temperature was assessed five times, the BLC was measured four times, while the urine temperature was measured twice. In each phase of the study the perceived exertion was questioned by using Borg's RPE. Prior to the 500 m race simulation, all kayakers were asked to classify their perceived recovery, in a scale ranging from 0 to 10 (in which 10 represents completely recovered).

The air temperature of the chamber throughout the three phases of the test varied between 20.9 °C and 21.2 °C. The optimal temperature for the use of the infrared camera in the study of the human body is 21 °C [20]. The relative humidity during all the tests ranged from 66.0% to 68.9%. The usual values for the use of the infrared camera ranged between 40% and 70% of relative humidity, but there are not established norms yet [20].



Fig. 1. Study's protocol: expressing the procedures and the assessments made in each phase. IRT, infrared thermography; BLC, blood lactate concentration; TS, training session.

#### 2.3 Skin temperature and core temperature

Since the latissimus dorsi along with the upper and lower abdominals, pectoralis magnus, anterior serratus and other torso muscles are some of the primary and supporting muscles of the paddling technique [21]. The radiant temperature of the human body can be measured by means of an infrared thermographic imaging (IRT), which is a contact-free technology used to monitor the skin temperature [22]. The temperature distribution of large areas of skin can be quantified quickly and accurately [23], thus enabling the transformation of body's radiation into temperature values [22]. The use of IRT needs to follow some recommendations [20,24]. Therefore, an infrared camera (FLIR® SC660; FLIR Systems, Notting Hill, VIC, Australia) on a tripod was used to take infrared pictures of the posterior part of the upper body of each subject. The region of interest (ROI) in the pictures was the skin area above the latissimus dorsi muscle (one of the most important muscles in the paddling technique). Special attention was given to five different moments: the initial resting conditions after acclimatization, TS, AR, and before and after the 500 m race simulation. During heavy physical exercise, there is an increased metabolic rate and, consequently, a rise in the internal heat production. With the continuity of the exercise, an increase of the blood flow rate between the human body core and the skin occurs, in order to exchange more heat with the surrounding environment [25]. All participants were aware of the recommendations before the IRT screening. During the assessment, the subjects were on the upright position and placed 1.5 m away from the camera.

The calculated value was an average of the thermograms of the ROI.

A non-invasive evaluation of the core temperature based on skin surface measurements may be biased by multiple factors such as the measurement location, local evaporation and clothing conditions [26]. As a result, the urine temperature (Checktemp® digital thermometer 1HI98509, Hanna Instruments, Woonsocket, RI, USA) was determined in order to reduce error in the evaluation of the core temperature. Using the urinary outpour to measure the urine temperature is a less invasive technique and is better accepted by the athletes than other techniques, such as the rectal or esophageal temperature. According to Lefrant et al. [27], the urinary bladder technique is more accurate than others to measure the core temperature. Kawanami et al. [28] state that measuring the urine's temperature is a good method to assess the human body core temperature and that there are small differences when comparing it with other techniques. In our study the urine temperature was assessed twice, firstly prior to the TS and secondly before the 500 m simulation race.

#### 2.4 Blood lactate concentration

The BLC was measured after the TS, before the AR and before and after the 500 m race simulation. Capillary finger blood samples were collected and the BLC was determined by means of a spectrophotometric method that has a high degree of specificity for lactic acid [29,30]. The instrument used was the Miniphotometer plus LP20, Dr. Lange, Bavaria, Germany.



**Fig. 2.** Infrared thermograms along the protocol – example of two sequences of thermographic images collected in different moments of the protocol, with and without the cooling vest. (a) Without cooling vest. (b) With cooling vest. TS, training session; AR, active recovery.

Table 1. Skin temperature above the right (RL) and left (LL) *latissimus dorsi* muscle (ROI) and the core temperature registered during the protocol (before and after the training session, after the active recovery and before and after the 500 m test) for the two active AR conditions.

	With cooling vest (temperature °C)			Without cooling vest (temperature °C)			
	RL	LL	Core	RL	LL	Core	
Before TS	$35.28\pm0.79$	$35.29\pm0.93$	$36.3\pm0.22$	$34.61\pm0.89$	$34.74\pm0.77$	$36.7\pm0.26$	
After TS	$34.93\pm 0.89$	$34.95\pm \textit{0.90}$	-	$34.84\pm 1.26$	$34.65\pm1.39$	-	
After AR	$\textbf{30.09} \pm \textbf{2.12}$	$\textbf{29.15} \pm \textbf{2.39}$	-	$\textbf{34.22} \pm \textbf{0.94}$	$\textbf{34.19} \pm \textbf{1.05}$	-	
Before 500 m	$33.9\pm0.97$	$33.64 \pm 1.01$	$\underline{37.1\pm0.46}$	$\underline{34.67 \pm 0.86}$	$34.55\pm 0.81$	$37.4 \pm 0.32$	
After 500 m	$33.62\pm 0.88$	$33.64 \pm 1.02$	-	$33.51\pm0.82$	$33.62\pm 0.88$	-	

TS, training session; AR, active recovery; RL, right *latissimus dorsi*; LL, left *latissimus dorsi*; underlined for differences in the skin temperature (p < 0.01); the statistical differences in the core temperature after AR are indicated in bold (p < 0.05).

## 2.5 Statistical analysis

The body mass percentage was calculated by using Excel 2013 for Windows 7. The statistical analysis was done using the IBM SPSS Statistics version 24 (IBM Corp., Chicago, IL, USA) for Windows 7. The descriptive statistics were performed for all the variables. The comparison between the two moments of the study was performed using Wilcoxon's test and the correlation was tested with Spearman's test. Both with and without the cooling vest, five time points of analysis of the independent variables were considered (IRT, core temperature, BLC, Borg RPE scale, average power and distance), has presented on Fig. 1. Values of  $p \leq 0.05$  were considered statistically significant.

## 3. Results

Both on the protocol with and without the cooling vest, the average skin temperature above the *latissimus dorsi* muscle dropped after the AR. Comparing the thermogram after the TS with the one after the AR (Fig. 2a and b), the temperature decrease (Table 1) was higher with the wearing of the cooling vest than without it. The ROI temperature after the AR with the wearing of the cooling vest was significantly lower on both sides (z = -2.803; p < 0.01 (0.005)) (Fig. 3 – *asterisk*). There were no significant differences in the skin temperature after the 500 m race simulation (Fig. 2).

Regarding the core temperature, there were no significant differences between the measures before the TS. On the other hand, after the AR the core temperature was sig-



Fig. 3. Skin temperature along the protocol – variation during the whole protocol in both situation of the study (AR with and without the cooling vest). Grey lines represent the protocol where the kayaker performed the AR with the cooling vest and black lines the AR without wearing it. Continues and dashed lines represent right or left *lattisimus dorsi*, respectively. The asterisk is indicating that after the AR there is a significant difference (p < 0.01) in the temperature values between AR conditions. RL, right *latissimus dorsi*, LL, left *latissimus dorsi*.

nificantly lower, 15 minutes after the wearing of the cooling vest (z = -2.014; p < 0.05 (0.044)), when compared with the moment at which the athletes did not wear the cooling vest. All temperature values are registered in Table 1.

The values, which are statistically different when comparing the wearing of the cooling vest with the ones at which it was not being worn, concerning the skin temperature (p < 0.01) are underlined and, in bold regarding the core temperature (p < 0.05). Mean  $\pm$  SD.

There were no significant differences in the values of the BLC after the TS when comparing the moments wearing the cooling vest with the ones without wearing it. The changes in the BLC at all the moments of the protocol are presented in Fig. 4.



Fig. 4. Blood lactate concentration along the protocol for both AR conditions, with and without wearing the cooling vest. The asterisk indicates that there was a significant difference (p < 0.05), for the respective measurement time point. BLC, blood lactate concentration; TS, training session; AR, active recovery.

After the AR with the cooling vest, the BLC was significantly lower (z = -2.191; p < 0.05 (0.028)) comparing

with the values obtained at the same moment without the cooling vest (Table 2) (Fig. 4 - asterisk).

Table 2. B	SLC values	during	the	protocols	with	and	without
		the coo	oling	vest.			

	8	
	BLC	BLC
	With cooling vest	Without cooling vest
	(mmol/L)	(mmol/L)
After TS	$6.78\pm2.61$	$6.86\pm2.86$
After AR	$\underline{2.29 \pm 1.10}$	$2.77 \pm 1.11$
Before 500 m	$1.89 \pm 1.01$	$2.13\pm1.13$
After 500 m	$12.13\pm2.70$	$14.31 \pm 3.87$

TS, training session; AR, active recovery; BLC, blood lactate concentration.

The values which are statistically different (p < 0.05) are underlined. Mean  $\pm$  SD.

Although there were no statistical differences between the BLC before the 500 m race simulation (z = -1.481; p =0.139), after the AR wearing the cooling vest the average BLC was lower, compared with the protocol at which the cooling vest was not worn. The same happened with the BLC after the 500 m test (z = -1.836; p = 0.066), where, although the mean value was lower when the cooling vest was worn during the AR comparing with no cooling vest, it was not verified a significant statistical difference (Table 2). The variation of the BLC values before and after the 500 m for each athlete are specified in Fig. 5.



Fig. 5. Variation of BLC values before (black) and after (grey) the 500 m race simulation for each athlete (1 to 10) at which moment of study considering the two AR conditions. Variation = (BLC with vest) – (BLC without vest).

The analysis of the perceived exertion (Borg RPE Scale) and the power registered in the ergometer showed no appreciable correlation in any period of the study when comparing the two cooling vest conditions. However, the athletes' subjective perception of recovery before the 500 m simulation race was significantly higher after perform-

ing the AR wearing the cooling vest (z = -2.831; p < 0.01 (0.005)), compared with the protocol of AR with no vest (Fig. 6).



Fig. 6. Athlete's subjective perception of recovery before the 500 m test. Mean  $\pm$  SD with vest (6.85  $\pm$  0.94) and without vest (5.25  $\pm$  1.09) during the active recovery.

No statistical difference was observed in the average power of the maximal 500 m test between the two conditions. The same happened regarding the performance time in the 500 m race simulation test, which was not statistically different when comparing the protocols of AR wearing cooling vest and without wearing it. At both conditions, no correlation was not found between the BLC before the 500 m test and the performance time in the race simulation test.

## 4. Discussion

The results of the carried out study revealed that the cooling vest is a suitable instrument to induce a lowering in the skin temperature while paddling (Fig. 3), being at the same time light and not limiting the movement of lowintensity paddling. As described in other studies [11,23] the IRT can be used to monitor the skin temperature during physical activity and cold treatments. In Table 1 it is patent that the skin temperature above the latissimus dorsi, for the athletes wearing the cooling vest during the AR, was almost 4 degrees lower when comparing with the AR without wearing the cooling vest. After the application of the cooling vest the body needs to increase the blood flow in the covered area in order to return to the homeostasis point. The increased blood flow enables to eliminate more quickly the waste products such as lactate, thus promoting a better and faster recovery [11,27]. If it is worn regularly in the hot days, the cooling vest will reduce fatigue, by decreasing lactate levels and, consequently, the probability of developing an injury or reach an overtraining level is lower [6].

When analyzing Fig. 5 it can be verified that, before and after the 500 m race simulation, eight athletes presented lower BLC values when they wore the cooling vest during the AR, in comparison with the AR without wearing the cooling vest. One athlete (number 5 - Fig. 5) presented higher BLC values after performing the AR with the wearing of the cooling vest, and another athlete (number 6 -Fig. 5), after wearing of the cooling vest presented higher BLC values before the race simulation, but lower values after it. These changes were more evident in the values after the race simulation as indicated by the size of the grey columns, and it clearly suggests a difference in the kayakers' physiologic response to this recovery method. This fact shows a singularity of high-performance sports, the need of individualization. In addition, a different response to the same recovery method means that what is an advantage for a given athlete may not be necessarily an advantage for another, although, on overall, wearing a cooling vest presented itself as an advantage.

Both the RPE and power had similar values in the two occasions of the study, which means that the kayakers performed the TS and the AR with similar intensity and the same amount of physical and motivational resources [31]. As a result, it can be assumed that the differences found in the BLC values were independent of these variables. Since the RPE has a correlation with lactate levels [14], it was expected that the RPE of the AR with the cooling vest would be lower, but this fact did not occur.

As it is described in literature [11,12], cold increases the athletes' subjective perception of recovery with an effect similar to a placebo. This effect is linked to dopamine release from the *nucleus accumbens*, a central component of the brain reward system, and it is known that the expectation of an analgesic effect can trigger endogenous opioid systems [15]. In the current study, similar results were obtained and they confirmed that, when kayakers performed the active recovery wearing the cooling vest, they felt more recovered than when they did not wear it. The individual perception of recovery is related to the subsequent performance, and the psychometric measures can be more sensitive than the physiological markers in determining the recovery state of the athletes [15].

At the two protocol conditions the performance has not been different. This means that it was not affected by the use of the cooling vest, despite the difference in the physiological response to cold. The reason for this result may have been the small number of participants on the study. Therefore, performing the same protocol with a larger number of athletes should be considered in future studies.

#### 5. Limitations of this study

The core temperature measurement was not assessed with a sensor inside the body because this is an invasive method and it is not practical for the performance during a protocol with intense physical activity. It was assumed that the temperature of the urinary outpour is the same as the one inside the urinary bladder. In further studies, either parameter needs to be fixed or a correlation between the urine temperature inside and outside the bladder should be done prior to the study.

This study was conducted without taking into account the wind, solar radiation and other variables that exist in real weather conditions. For that reason, there is a need to confirm these results, of the recovery method in the real environment of racing, in different weather conditions, it would be interesting to carry out this study analyzing more muscles and with other cooling vests, in order to see if there is consistency in the results. Testing the muscles and comparing their impact, by taking into account the types of muscle fibers and their less or more intense participation in the paddling technique, it would be also of interest.

## 6. Conclusions

A cooling vest may lead to a faster physiological recovery by reducing the core and skin temperature and promoting a faster lowering of the BLC levels on male kayakers. This vest can be a useful tool to apply during the AR training sessions or races with a short period to recover in between them. Nevertheless, an evident correlation between cold effects and performance improvements was not found in the present study. Regarding the used settings, the IRT revealed to be a reliable method to monitor the skin temperature before and after the exercise.

## **Author contributions**

FL, BG, AS and JP designed the research study. AS and MS prepared the set-up of the experiment. FL and NS performed the data collection. FL analyzed the data. FL, BG, AS and JP wrote the manuscript. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

## Ethics approval and consent to participate

The study was approved by the Ethics Committee of the Faculty of Medicine of the University of Coimbra, with the official reference 131-CE-2017. Each subject signed a written informed consent.

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#### **Conflict of interest**

The authors declare no conflict of interest.



## References

- Banfi G, Lombardi G, Colombini A, Melegati G. Whole-Body Cryotherapy in Athletes. Sports Medicine. 2010; 40: 509–517.
- [2] Michael JS, Rooney KB, Smith R. The metabolic demands of kayaking: a review. Journal of Sports Science & Medicine. 2008; 7: 1–7.
- [3] Tesch P, Sjödin B, Thorstensson A, Karlsson J. Muscle fatigue and its relation to lactate accumulation and LDH activity in man. Acta Physiologica Scandinavica. 1978; 103: 413–420.
- [4] Place N, Yamada T, Bruton JD, Westerblad H. Muscle fatigue: from observations in humans to underlying mechanisms studied in intact single muscle fibres. European Journal of Applied Physiology. 2010; 110: 1–15.
- [5] Monedero J, Donne B. Effect of recovery interventions on lactate removal and subsequent performance. International Journal of Sports Medicine. 2000; 21: 593–597.
- [6] Chan Y, Yim Y, Bercades D, Cheng TT, Ngo K, Lo K. Comparison of different cryotherapy recovery methods in elite junior cyclists. Asia-Pacific Journal of Sports Medicine, Arthroscopy, Rehabilitation and Technology. 2016; 5: 17–23.
- [7] Howatson G, van Someren KA. The prevention and treatment of exercise-induced muscle damage. Sports Medicine. 2008; 38: 483–503.
- [8] Kwiecien SY, McHugh MP. The cold truth: the role of cryotherapy in the treatment of injury and recovery from exercise. European Journal of Applied Physiology. 2021; 121: 2125–2142.
- [9] Duffield R. Cooling Interventions for the Protection and Recovery of Exercise Performance from Exercise-Induced Heat Stress. Thermoregulation and Human Performance. 2008; 53: 89–103.
- [10] Poppendieck W, Faude O, Wegmann M, Meyer T. Cooling and performance recovery of trained athletes: a meta-analytical review. International Journal of Sports Physiology and Performance. 2013; 8: 227–242.
- [11] Adamczyk JG, Krasowska I, Boguszewski D, Reaburn P. The use of thermal imaging to assess the effectiveness of ice massage and cold-water immersion as methods for supporting postexercise recovery. Journal of Thermal Biology. 2016; 60: 20– 25.
- [12] Racinais S, Alonso JM, Coutts AJ, Flouris AD, Girard O, González-Alonso J, *et al.* Consensus recommendations on training and competing in the heat. British Journal of Sports Medicine. 2015; 49: 1164–1173.
- [13] Borg G, Hassmén P, Lagerström M. Perceived exertion related to heart rate and blood lactate during arm and leg exercise. European Journal of Applied Physiology and Occupational Physiology. 1987; 56: 679–685.
- [14] Borg GA. Psychophysical bases of perceived exertion. Medicine and Science in Sports and Exercise. 1982; 14: 377–381.
- [15] Cook CJ, Beaven CM. Individual perception of recovery is related to subsequent sprint performance. British Journal of Sports Medicine. 2013; 47: 705–709.
- [16] Moreira DG, Costello JT, Brito CJ, Adamczyk JG, Ammer K, Bach AJE, *et al.* Thermographic imaging in sports and exercise medicine: a Delphi study and consensus statement on the measurement of human skin temperature. Journal of Thermal Biology. 2017; 69: 155–162.
- [17] Bonetti DL, Hopkins WG, Kilding AE. High-intensity kayak performance after adaptation to intermittent hypoxia. International Journal of Sports Physiology and Performance. 2006; 1: 246–260.
- [18] Gomes B, Mourão L, Massart A, Figueiredo P, Vilas-Boas J, Santos AM, *et al.* Gross Efficiency and Energy Expenditure in Kayak Ergometer Exercise. International Journal of Sports Medicine. 2012; 33: 654–660.

- [19] Dourado CP, Dos Santos JL, Soares BM, Baratto I, Dos Santos EF, Bennermann GD. perfil antropométrico e comparação de diferentes métodos de avaliação da composição corporal de atletas de futsal masculino. Revista Brasileira de Nutrição Esportiva. 2012; 1–10.
- [20] Korman P, Zielinski J, Kusy K, Straburzynska-lupa A. Possible uses of infrared thermography in sport. Trends in Sport Sciences. 2016; 2: 57–62.
- [21] Cox RW. The science of canoeing: a guide for competitors and coaches to understanding and improving performance in sprint and marathon kayaking. Coxburn Press: Cheshire. 1992; 73.
- [22] Hadžić V, Širok B, Malneršič A, Čoh M. Can infrared thermography be used to monitor fatigue during exercise? A case study. Journal of Sport and Health Science. 2015; 8: 89–92.
- [23] Costello JT, McInerney CD, Bleakley CM, Selfe J, Donnelly AE. The use of thermal imaging in assessing skin temperature following cryotherapy: a review. Journal of Thermal Biology. 2012; 37: 103–110.
- [24] Gabriel J, Branco C aguiar, Ferreira AP, Ramalhão C, Vordasca R, Clemente MP. Termografia: Imagem médica e síndromas dolorosas. LIDEL. 2017; 17–24.
- [25] Neves, Eduardo Borba, Moreira, Tiago Rafael; Lemos, Rui; Vilaça-alves J, Rosa C, Reis VM. Using Skin Temperature and Muscle Thickness To Assess Muscle Response To Strength

Training. Revista Brasileira de Medicina do Esporte. 2015; 21: 350–354.

- [26] Xu X, Karis AJ, Buller MJ, Santee WR. Relationship between core temperature, skin temperature, and heat flux during exercise in heat. European Journal of Applied Physiology. 2013; 113: 2381–2389.
- [27] Lefrant J, Muller L, de La Coussaye JE, Benbabaali M, Lebris C, Zeitoun N, *et al.* Temperature measurement in intensive care patients: comparison of urinary bladder, oesophageal, rectal, axillary, and inguinal methods versus pulmonary artery core method. Intensive Care Medicine. 2003; 29: 414–418.
- [28] Kawanami S, Horie S, Inoue J, Yamashita M. Urine temperature as an index for the core temperature of industrial workers in hot or cold environments. International Journal of Biometeorology. 2012; 56: 1025–1031.
- [29] Barker SB, Summerson WH. The colorimetric determination of lactic acid in biological material. Journal of Biological Chemistry. 1941; 138: 535–554.
- [30] Vaile JM, Gill N, Blazevich A. The effects of contrast water theraphy on symptoms of delayed onset muscle soreness. The Journal of Strength and Conditioning Research. 2007; 21: 697–702.
- [31] Gamberale F. Perception of effort in manual materials handling. Scandinavian Journal of Work, Environment & Health. 1990; 16: 59–66.