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COLD WATER IMMERSION AS A METHOD SUPPORTING POST-EXERCISE RECOVERY

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Abstract The aim of the study was to assess the effect of cold water immersion on changes in blood lactate concentration during post-exercise recovery in swimmers subjected to2-minute exercise test (front crawl swimming movements) using a VASA Swim Ergometer, with the maximum arm speed movements, as during the freestyle technique. The study covered 11 professional swimmers of the MKP Szczecin club, tested twice with a two-week interval. Each participant performed an exercise test twice, once with a passive recovery period, and the second time with cold water immersion after exercise, as a method potentially supporting the post-exercise recovery process. Each time before the test, immediately after and at 3, 6 and 9 minutes after exercise, the concentration of lactate in the capillary blood was measured. Statistical analysis of the obtained results showed that cold water immersion applied immediately after exercise resulted in a faster reduction of lactate concentration. The conducted research confirms that cold water immersion used in post-exercise recovery may be an effective method of restoring optimal physical fitness as part of the training process.

Key words exercise recovery, cold water immersion, lactate concentration

Introduction

Sports competition is very often characterized by intermittent bouts of high-intensity activity, separated by short bouts of low-intensity activity. Physical exercise, depending on its nature and duration, can be classified as aerobic, anaerobic or, in most cases, of a mixed nature. The basis for the metabolic classification of physical exercise is the participation and metabolism of individual energy substrates in the acquisition of ATP during the process. Working in aerobic conditions, thanks to the balance between oxygen demand and uptake, allows the oxidation of glucose to pyruvate, then acetylocoenzyme A (acetyl-Co-A) used in the citric acid cycle without lactate accumulation. Anaerobic energy production is important in maintaining high-intensity work efficiency when the

ATP requirement is greater than the oxygen trail can provide. With the dominance of the anaerobic component, the pyruvate is reduced to lactate with the participation of nicotinamide adenine dinucleotide (NADH). This reaction is catalyzed by the enzyme lactate dehydrogenase. The anaerobic lactate is transported from the skeletal muscles to the liver and kidneys, where it is converted back into glucose. The concentration of lactic acid in the body depends on the rate of its production and the speed of its utilization. The skeletal muscles, liver, heart muscle and kidneys are mainly responsible for the lactate removal process (Klusiewicz, Zdanowicz, 2002). Among the measurements used to assess the physiological exercise tolerance and the effectiveness of the post-exercise recovery process in athletes at various levels of training, the blood lactate concentration is most often assessed at various intensities of exercise (von Duvillard, 2001). There are several hypotheses explaining the mechanism of the formation of lactic acid in the muscles during physical exercise. The main ones are oxygen deficiency hypoxia; β- adrenergic stimulation of glycogenolysis by adrenaline (Klusiewicz, Zdanowicz, 2002). If physical exercise is characterized by high intensity, lactic acid will accumulate as a result of exceeding the lactate threshold, with increased recruitment of motor units with higher excitability and increased activation of glycolysis (Astorino et al., 2019). This will contribute to the occurrence of the phenomenon of muscle fatigue, which is defined as the inability of the neuromuscular system to generate energy around the joint (Rodacki, Fowler, Bennett, 2002). Short-term impairment of neuromuscular fitness may be a result of several factors, including inhibition of muscle contractions as a result of the accumulation of metabolic end products such as lactate in the muscle (Maté-Muñoz et al., 2017), a subsequent increase in the concentration of hydrogen ions in the cytoplasm of muscle cells, which in turn reduces the ability to contract (Klusiewicz, Zdanowicz, 2002; McCully, Authier, Olive, Clark, 2002; Cairns, 2006). Currently, the very high sports level of participants resulting from the intense training load and the maximum use of the body's exercise capacity forces the coaches and swimmers to search for effective methods to improve the process of post-exercise recovery, in order to accelerate the readiness to take further loads, one of them being cold water immersion (CWI). Although this method has been used in sport for a long time, there is still a lack of data unambiguously assessing its effectiveness, the more so as it was often combined with an initial active recovery. Based on the meta-analysis from 2011, it is postulated today that CWI alleviated symptoms of DOMS at 24, 48, 72 and 96h post exercise; had a small but significant effect in reducing efflux of CK post-exercise and had no effect on recovery of muscle strength but was effective in improving recovery of muscle power (Leeder, 2011), but research outlining the efficacy of CWI facilitating recovery of muscle function seems to vary, based on the type of exercise mode used or participants of various sports disciplines. As such, the effect of CWI alone on performance and physiological recovery remains unknown. Considering that this is a strongly stimulating method, it is justified to conduct research in this area.

Materials and methods

The study included 11 professional swimmers aged 18 to 23 from the MKP Szczecin club. The study was also approved by the local Ethics Committee (Ethics Committee of the Pomeranian Medical University; Ref. No. KB-0012/36/13). The research was carried out in two stages, two weeks apart. In the first stage of the research, the participants completed a questionnaire, from which information was obtained on age, gender, length of their swimming experience, swimming style and training load. The youngest participant was 18 years old and the oldest 23 years old. The mean age of the whole group was 18.81 years (±1.72). Individual measurements of height and weight were taken for each participant. Based on anthropometric data, the following indices were calculated: BMI

(Body Mass Index) using the formula: body weight[kg]/height[m]^2. The crawl swimming style dominated, as many as 8 out of 11 participants chose this style as preferred in everyday training. The remaining 3 participants indicated breaststroke, backstroke, or butterfly swimming style. The shortest swimming experience was 11 years and included 3 years of amateur swimming and 8 years of professional swimming, including participation in international competitions. The longest experience amongst the studied group was 16 years and included 4 years of amateur swimming and 12 years of professional swimming, including participation in the Summer Olympics. Subsequently, the procedures related directly to the planned exercise test were initiated. Each participant was subjected to a fingertip resting capillary blood lactate measurement taken using a lactic acid analyzer, which uses an enzymatic-amperometric determination of capillary lactic acid concentration as a measurement. Then the participant began a two-minute resistance exercise test on a Swim Bench Ergometer (Vasa Inc., Essex Junction, VT, USA). Figure 1 shows the position of the swimmers during the test. The Swim Bench swimming trainer reproduces the movements performed during training in the water. The use of the ergonometer is based on its excellent movement reproducibility, as evidenced by the optimal correlation between the results of tests on the ergonometer and during swimming at distances of 25, 50, 100, 200 and 400 m. Even if the exercises performed on the ergonometer show biomechanical and physiological differences from the actual swimming practices (Guilherme, Guglielmo, Denadai, 2000).

Figure 1. Resistance exercise test on a Swim Bench Ergometer

The duration of the exercise test, during which the swimmers had to maintain maximum arm speed using freestyle technique, was 2 minutes for each swimmer and the athlete's task was to maintain the maximum intensity (frequency) of swimming movements throughout the exercise test. Such assumptions correspond to the efforts made during the 200 m freestyle competition in which the swimmers partake most often. The ergometer was calibrated before each subsequent test. During the test, the muscles of the upper limbs, chest and back muscles were involved. The lower limbs did not play a significant role during the exercise, because their movement was limited by the bench on which the participant was lying. The total work performed by the participants was assessed each time [W]. Following the exercise test, the concentration of lactate was measured at the following time points: immediately after exercise and to assess post-exercise recovery at 3, 6 and 9 minutes since finishing the exercise test.

Stage II of the research

There was a two-week break between the research stages. The procedures carried out in the second stage of the research were identical to the first stage, except for the use of cold water immersion immediately after the physical exercise amongst all participants.

Cold water immersion procedures (CWI)

The immersion in cold water (9°C ±1°C) was applied once and individually for each of the participants immediately after their post-exercise lactate concentration was measured. During the procedure, participants wore shorts only. The start time of the CWI was monitored from the moment the participant assumed a seated position in the bathtub. The submersion to the neck level lasted 3 minutes, during which no movements were performed. The water temperature was monitored after each treatment and, if necessary, it was adjusted to the correct temperature by adding ice cubes. After the procedure, consecutive measurements of lactate concentration were taken for each of the researched participants.

Statistical analysis

Statistical calculations were made with the use of the Statistica 13.3 software (Statistica 13 PL, StatSoft). The distribution of results was tested using the Shapiro-Wilk test. As the features of the normal distribution were confirmed, the characteristics of the analyzed variables were presented as arithmetic means and standard deviation. The analysis of variance and the Tukey's HSD and Newman-Keuls post-hoc tests were used to assess the changes in lactate concentration over time. The p value < 0.05 was considered statistically significant.

Results

The anthropometric characteristics of the study group has been presented in Table 1. The mean value of BMI in the tested swimmers was 22.05 ±1.28 (ranging from 18.72 to 23.22 kg/m²). A summary of individual results of work performed on the Swim Bench swimming ergometer for I and II stage is presented in Tables 2 and 3. To standardise the load of physical exercise, the same resistance and duration of exercise were used for all participants. In the first stage, the athletes performed at the average value of 157.27 (±2.28) W. The lowest result was 154 W, and the highest was 161 W. The second exercise test took place two weeks later, and the same training load and the duration of exercise was used on a swimming ergonometer, with an additional CWI procedure post-exercise. The average value of the work was comparable with the value obtained during the first stage of the research, and amounted to 157.36 (±2.01) W. The lowest value obtained was 154 W, and the highest 161 W.

Table 1. Anthropometric characteristics of the participants

n = 11	Mean value	Minimum	Maximum
AGE (years)	18.82 ±1.72	18	23
BODY MASS (kg)	71.71 ±6.68	62	80
BODY HEIGHT (m)	1.81 ±0.07	1.67	1.88
BMI (kg/m^2)	22.05 ±1.28	18.72	23.22

BMI – Body Mass Index.

Table 2. Individual values of lactate concentrations in the I stage of research

No	Swim bench			Lactic acid measurement				
	Resistance (MET)	Work rate (W)	Time (min)	Pre (mmol/l)	Post (mmol/l)	3 post	6 post	9 post
1	5	158	2	1.9	12.7	9.9	6.1	5.2
2	5	157	2	1.7	13.4	8.7	7.9	7.3
3	5	155	2	1.7	11.8	11.7	11.1	10.9
4	5	155	2	1.5	11.6	9.6	11.7	10.9
5	5	160	2	1.5	12.1	10.9	7.8	7.3
6	5	154	2	1.6	12.4	9.9	9.5	9.1
7	5	161	2	1.5	11.3	7.2	6.8	5.4
8	5	157	2	1.9	12.1	10.6	11.2	9.3
9	5	160	2	1.9	12.6	5.7	6.1	5.2
10	5	157	2	1.8	11.5	4.8	4.8	2.9
11	5	156	2	1.8	11.9	7.0	7.0	6.1
X	5	157.27	2	1.71	12.13	8.73	8.18	7.24
±SD	±0	±2.28	±0	±0.16	±0.61	±2.25	±2.35	±2.58

Table 3. Individual values of lactate concentrations in the II stage of research

No	Swim bench			Lactic acid measurement					Bathtub	
	resistance (MET)	work rate (W)	time (min)	pre (mmol/l)	post (mmol/l)	3 post (min)	6 post (min)	9 post (min)	water temp. (°c)	duration (min)
1	5	157	2	1.8	12.8	6.2	4.4	4.3	9	1
2	5	155	2	1.5	13.0	5.9	4.4	4.2	9	1
3	5	155	2	1.6	12.3	5.0	4.9	3.9	9	1
4	5	161	2	1.7	12.0	4.6	4.6	3.8	9	1
5	5	158	2	1.7	12.3	4.8	4.4	3.9	9	1
6	5	156	2	1.9	12.5	5.9	5.5	3.8	9	1
7	5	158	2	1.4	11.3	3.9	3.2	2.3	9	1
8	5	160	2	1.9	12.2	5.9	6.1	5.6	9	1
9	5	159	2	1.7	12.3	3.9	5.0	3.9	9	1
10	5	156	2	1.8	11.6	2.7	2.4	2.4	9	1
11	5	156	2	1.7	11.9	5.0	5.1	5.0	9	1
X	5	157.36	2	1.7	12.2	4.89	4.55	3.92	9	1
±SD	±0	±2.01	±0	±0.15	±0.49	±1.08	±1.02	±0.96	±0	±0

The first resting measurement of the concentration of lactate in the capillary blood (mmol/l) was taken from each participant immediately before starting the exercise test. The mean values at rest were similar, not significantly different between the study stages, amounting to 1.84 ±0.43 mmol/l and 1.55 ±0.61 mmol/l, respectively. Further measurements were made immediately after and at 3, 6 and 9 minutes after the end of exercise, while in the second stage, between the measurement immediately after exercise and at 3 minutes, a one-minute cold water immersion was applied.

There was a significant difference in post-exercise lactic acid concentration values between stages. The use of CWI as a form of post-exercise recovery significantly influenced the rate of lactic acid metabolism in the blood after the training session. The highest statistical significance in the measurements of the concentration of lactic acid in capillary blood was recorded 6 minutes after the end of the CWI procedure (p = 0.0004065).

Figure 2 shows a comparative dynamic of changes in lactate concentrations at individual measurement points for both stages of the study. The significance level of the differences between the concentrations of lactic acid in the subsequent minutes of post-workout regeneration in relation to the baseline values in the first (passive recovery) and second (cold water immersion) stage of the research is presented in Table 4.

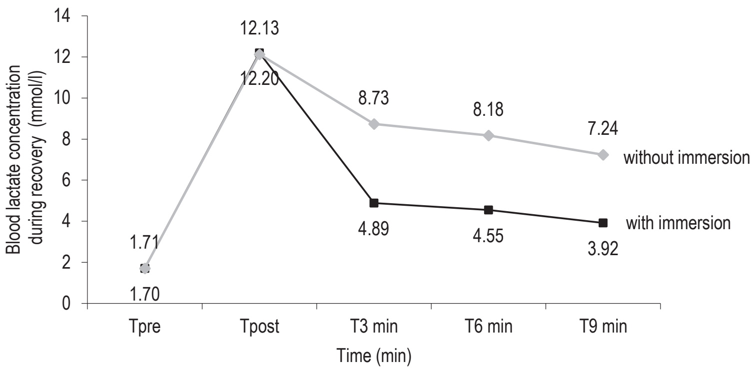

Figure 2. Dynamic of changes in lactic acid concentrations during the exercise test in the first and second stage of the tests, for all participants

Table 4. The level of significance of differences between the concentrations of lactic acid in the consecutive minutes of post-exercise recovery in relation to the resting values in the first stage (passive recovery) and the second stage of the research (cold water immersion)

Pre vs. 3 min	Pre vs. 6 min	Pre vs. 9 min
	Passive recovery	
p = 0.08729	p = 0.0004065	p = 0.001531
	Recovery with CWI	
p = 0.7972	p =0.00717	p =0.2001

Discussion

Biological renewal using natural or artificial stimuli shows a comprehensive systemic effect in post-exercise recovery. Physiotherapeutic treatments play an important role in this process because they do not only optimize recovery processes, but also prevent the occurrence of overload diseases and support faster return of injured athletes to sports training.

Among the physiotherapeutic treatments used, hydrotherapy methods are widely used in post-exercise recovery of the body, including sauna, full and partial baths, and all methods in the field of thermotherapy. Depending on the stimulus used, hydrotherapy can contribute to both calming and stimulating the body, reducing muscle and joint pain, has a hardening effect, affects muscle tone, and often improves well-being. Using the acquired knowledge, we can intervene more precisely in the process of rest and recovery, however, any intervention should be applied in accordance with the current knowledge in the field of exercise physiology, psychology, and training technology, based on evidence-based treatment (Jonak, Skrzek, 2009).

Training has an adaptive effect on the cardio-respiratory and neuromuscular systems, thus increasing the amount of oxygen supplied to the mitochondria, as well as it enables more precise regulation of muscle metabolism (Jones, Carter, 2000). However, intense, and prolonged effort with time-limited recovery may lead to the phenomenon of overtraining and, consequently, increasing the athlete's susceptibility to injuries. During training, mechanical and/or metabolic loads arise (White, Wells, 2013). High-intensity training leads to local inflammation (Roberts at el., 2015), which in the absence of full recovery before subsequent training sessions over a longer period of the training cycle may translate into secondary tissue damage, the occurrence of pain and a reduction in physical, as well as mental work efficiency (White, Caterini, 2017). Research by White and Wells shows a link between exercise and intense training and elevated levels of reactive oxygen species (ROS) in the body. Chronic high levels of ROS in relation to the antioxidant capacity of the system may result in impairment of the ability to generate strength, which in turn translates into a deterioration of sports performance (White, Wells, 2013). Due to the risk of overtraining, it is important to search for and use methods that allow you to monitor athlete's fatigue in a non-invasive way. However, this is a complicated task as fatigue is a phenomenon that is characterized by not only physical but also psychological factors. If the respiratory and cardiovascular systems cover the body's need for oxygen, breathing with a predominance of the oxygen component is the primary means of converting nutrients into the necessary energy. However, when oxygen supply is no longer maintained or less efficient, anaerobic glycolysis dominates the mode of energy production. During this process, lactic acid builds up in the working muscle cells. Hydrogen ions contribute to lowering the pH of the interstitial fluid, which in turn reduces the speed of propagation of the potential activity along the muscle fibers. Therefore, it is common to monitor blood lactate levels and the rate of oxygen consumption (VO_2) during exercise (Ražanskas, Verikas, Olsson, Viberg, 2015).

To minimize the risk of overtraining, it is not necessary only to choose an appropriate training regimen, provide sufficient time for the recovery of the body, but most importantly to accelerate the return of post-exercise recovery. For this purpose, biological regeneration methods are more and more commonly used. Properly selected regenerative therapy not only has a chance to reduce overload and fatigue resulting from training, but also prepare the athlete's body for further loads (Jonak, Skrzek, 2009). In recent years, there has been an increase in the quantity of research focusing on CWI, yet findings remain unclear. The regenerative effects during the use of CWI occur mainly based on the mechanical effect of hydrostatic pressure, the reduction of body surface temperature with subsequent hyperemia (Yeungat at el., 2016), but also the reduction of inflammation and edema (Aguiar at el., 2016). Studies by Bleakey et al. And Leeder et al. show that CWI can affect blood flow through the mechanisms of vasoconstriction and vasodilation, largely dependent on the water temperature (Bleakley et al., 2016; Leeder, Gisanne, van Someren, Gregson, Howatson, 2012). It is also believed that cold water immersion may reduce nerve conduction (Algafly, George, 2007), resulting in pain reduction in the Delayed Muscle Pain Syndrome (DOMS). The general effect of CWI is based on the ability to alleviate post-exercise hyperthermia, remove accumulated metabolic products, including lactic acid, alleviate subsequent changes in the central nervous system (CNS), reduce exercise-induced muscle damage (EIMD) and improve the functioning of the autonomic nervous system (Ihsan, Wattson, Abbiss, 2016).

In our study, the temperature of 9 ±1ºC was used for 1 minute immediately after exercise. The temperature was chosen based on previous reports regarding the effect of cold water immersion on recovery from exercise-induced muscle damage, in which it was considered unjustified to lower the temperature to a value below 10 degrees, both due to the comfort of the treatment and its effect (A. Vieira, at el., 2016). As for the duration of immersion, the literature data vary, depending on the parameters assessed (Elias at el., 2012; Poppendieck, Faude, Wegmann, Meyer, 2013). Our research seems to be particularly relevant in the short-term context, for example between startup recovery. The effect of CWI is not limited to the effect related to faster reduction of lactic acid concentration. CWI is effective in alleviating DOMS up to 96h post exercise, especially following high intensity exercise as well as in improving rate of recovery of muscle power post exercise (Leeder, 2011).

Also, research on the effects of CWI conducted by Kich proved the positive effect of CWI treatments on reducing DOMS ailments in cyclists (Kich, Krymski, Michalik, Kawczyński, 2018). Similarly, Adamczyk et al. confirmed the effect of CWI on the accelerated reduction of lactic acid concentration and the reduction of pain in DOMS (Adamczyk, Krasowska, Boguszewski, Reaburn, 2017). Scientific research has also shown that CWI affects the body's post-training response, contributing to the reduction of testosterone and cytokines levels; in particular IL-6 (Earp, Hatfield, Sherman, Lee, Kraemer, 2019). Additionally, evidence to date suggests that CWI reduces skin temperature and through the vasoconstriction and dilation may lead to changes in blood flow and reduction in swelling, inflammation, and muscle spasm (Peiffer, Abbiss, Watson, Nosaka, Laursen, 2010; Vaile at al., 2010), reduces the inflammatory response and minimizes secondary muscle damage responses (Knight, Brucker, Stoneman, Rubley, 2000).

Currently, sports medicine is developing very intensively. World records in individual disciplines are being improved increasingly more often, however, to achieve this level, athletes must undergo exhausting and long-lasting training sessions that negatively affect their health, both physical and mental, causing overtraining and increasing the risk of injury. That is why it is so important that the field of biological recovery is constantly developing. This will contribute to faster recovery and reduce the risk of undesirable training effects (Złotkowska at el., 2015).

Conclusion

The study has analyzed the issue of physical load on the body and the assessment of the possibility of accelerating the elimination of post-exercise homeostasis disorders, assessed by the concentration of lactate in the capillary blood, supported by the cold water immersion. The major finding of this investigation was that acute application of cold-water immersion after exercise was more effective than passive recovery according to post-exercise lactation treatment. In addition, in the subjective assessment of the participants in the study, the procedure of such a short duration was well tolerated and could be included in the methods of exercise recovery, especially in the starting period.

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