



Comparing the Effectiveness of Various Recovery Method Combinations on Improving Leg Muscle Power and Blood Lactic Acid Level

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Abstract

Objectives. This study aimed to investigate the impact of various recovery methods on improving lower extremity muscle power and decreasing lactic acid levels among student-athletes.

Materials and Methods. This study employed a randomized control group with a pretest and posttest design. The participants of this study were selected using simple random sampling, consisted of forty students who were divided into four groups: the sports massage and hot water group (MHW), sports massage and cold water (MCW), hot water immersion (HWI), cold water immersion (CWI). Data were collected using a force plate to measure lower extremity muscle power (watt), while a lactate meter was used to determine lactic acid level (mmol/l). Data were analyzed using the Wilcoxon signed-rank test to examine the difference of measured variables before and after treatment. Subsequently, the Kruskal-Wallis test was performed to investigate between-groups differences, followed by post-hoc testing using the Mann-Whitney test.

Results. The results indicated that all groups (MHW, MCW, HWI, and CWI) experienced an increase in lower extremity muscle power, and reduced lactic acid levels. MHW was most effective in increasing lower extremity muscle power by 11.63 watt, while HWI had the most positive influence on reducing lactic acid levels by 7.16 mmol/l.

Conclusions. These findings demonstrate the value of combining sports massage with hot and cold-water therapies as a rehabilitation strategy. The researchers emphasize the significance of these therapies in improving lower extremity muscle power and reducing lactic acid accumulation, which contributes to optimal physical conditioning and performance during sports competitions.

Keywords: lactate, power, recovery, sports massage, students, water immersion.

Introduction

Fatigue is a state resulting from both physically and mentally exertion that leads to a reduced in performance (Pageaux & Lepers, 2016). Muscular fatigue often results from intense physical activity or excessive exercise, diminishing muscle power due to accumulation of metabolic byproducts (Lucertini et al., 2017). Two of the most significant processes causing exercise-induced fatigue are ATP depletion and fibers acidosis, resulting in significant changes in the level

of metabolites such as lactate (Finsterer, 2012). Lactate is no longer assumed to promote fiber acidosis, but rather to protect against this process (Robergs et al., 2004). However, it remains a good indirect indicator for the onset of fatigue since its exercise-induced blood rise corresponds with fiber acidosis (Finsterer, 2012; Robergs et al., 2004). The build-up of lactic acid in the muscle inhibits the function of enzymes essential for chemical reactions, ultimately weaken muscle contractions and reducing muscle power (Wan et al., 2017). This accumulation occurs when lactic acid is produced faster than it can be removed during recovery. If this condition were not effectively resolved, excessive exercise—often referred to as overtraining—can lead to significant lactic acid build-up, which may contribute to sports-related injuries in athlete (Kreher & Schwartz, 2012; Rusdiawan et

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al., 2020; Wan et al., 2017). Thus, rapid recovery is important for athletes performing high-intensity loads in many type of sports (Budak, 2023).

Several methods of therapy are used by athletes to prevent injury and speed up the recovery process, including active and passive recovery (Kellmann et al., 2018). Active recovery involves low-intensity exercise such as walking, jogging, and stretching designed to prevent muscle spasms, cramps, and muscle stiffness (Fares et al., 2022; Li et al., 2024). Meanwhile, passive recovery relies on external stimulation rather than engaging in physical action. Common technique includes temperature-based therapies, compression garments, nutrient supplements, and massage (Li et al., 2024). Massage—which is the application of pressure to muscles, tendons, or ligaments (Hermoko & Sulastrri, 2023)—is widely used by many people to reduce pain (Poppendieck et al., 2016), as well as relaxing muscles and improving blood circulation (Yuniana et al., 2022). When athletes receiving massage treatment, the hand pressure helps to break down lactic acid that has accumulated in the muscles, facilitating its transport into the bloodstream for removal (Wiltshire et al., 2009). To summarize, massage treatment aids recovery by stimulating blood flow, which accelerates the removal of lactic acid from the muscles (Prasetya et al., 2023; Weerapong et al., 2005).

In addition to massage, Thorpe (2021) reported the benefit of thermal water-based therapy to improve body recovery. Warm water immersion is known to induce many benefits such as reduce fatigue and muscle tension (Cullen et al., 2024; Ghadicolaei et al., 2019). Conversely, immersing in cold water can help to minimize inflammation and muscle soreness following intense exercise while providing a refreshing sensation (An et al., 2019; Leeder et al., 2011). The physiological response triggered by the immersion method can lead to improved nutrient distribution and byproduct removal from muscle tissue. Furthermore, the psychological benefits of water immersion should not be overlooked; warm water's soothing effects can improve mood, reduce stress and anxiety levels, contributing to a general sense of well-being during the recuperation process (Cullen et al., 2024). As a result, adding different immersion techniques into recovery methods can provide athletes with a more holistic approach in improving their physical and mental recovery after excessive exercise (Cochrane, 2004).

Given that competitive athletes may have limited time for recovery strategies and that speedy performance restoration is the most important factor, scientific clarification is required to determine whether and under what conditions massage may be a useful tool for enhancing post-exercise recovery (Poppendieck et al., 2016). In recent years, a large number of review articles have been published that analyze the findings of studies aimed at improving post-exercise recovery with massage therapies (Dakić et al., 2023; Karadavut & Acar, 2024). Despite being a common and widely used recovery technique among athletes (Nédélec et al., 2013; Poppendieck et al., 2016), massage alone is generally thought to have mild and inconclusive effects on performance recovery. Therefore, coaches and athletes often tried to combine sport massage with various recovery method to seek the most effective method to speed up the recovery. In addition to that, the order of the recovery is thought to affect the recovery process itself. Therefore, researchers are searching for the

most effective strategies to restore performance and speed up post-exercise recovery. This study aims to investigate the effect of various combination of recovery methods in lowering extremities power and blood lactic acid among student-athletes.

Materials and Methods

Research Design and Participant

This study was experimental research using pre-test and post-test control group design. Forty healthy male student-athletes who were selected from population using systematic random sampling with inclusion criteria as follows: (1) age between 18-24 years old; (2) actively participated in any endurance sport competition during the last three years; (3) did not suffer from orthopedic injuries in lower extremities within a year of the study; (4) did not experienced any other condition that could significantly impact the result of power muscle and lactic acid measurements; (5) did not have history of disease related to the nervous or musculoskeletal system, and (6) did not take ergogenic aids or dietary supplements during the study period. All subjects meeting the criteria received information about the research protocols, including its risks and benefits, which adhered to the ethical guidelines of the Declaration of Helsinki prior to their participation in the study. After that, a written informed consent was obtained from each student as an agreement to participate as a research subject in this study. All research procedures were approved by the ethic committee of Universitas Airlangga.

Procedure

Forty subjects were randomly assigned into four equal groups which was tested by same researchers, same treatment, and same measurement tools. The first group received sports massage followed by hot water immersion group (MHW), second group received sports massage followed by cold-water immersion (MCW), third group underwent hot water immersion (HWI), and the last group received cold-water immersion only (CWI). The experimental design is illustrated in Figure 1.

Each subject began the activity with a standardized warm up consisting of five minutes of static stretching targeting the hamstring, quadriceps, and calf, followed by another five minutes of an alternating repetition of extension and flexion of lower limb. After ten minutes of warming up, subjects performed a high intensity bout of exercise on a cycle ergometer for 30 minutes on 85% of their repetition maximum (RM). Heart rate and blood pressure were thoroughly monitored during exercise using polar heart rate (polar H10 Bluetooth Heart Rate Sensor & Fitness Tracker, Kempele, Finland) and digital sphygmomanometer (Omron Deluxe HEM-8712, Osaka, Japan). Temperature was assessed using 3-in-1 Infrared Thermometer (Omron MC720, Osaka, Japan).

Afterward, subjects were asked to do countermovement jump (CMJ) on a portable force plate (PACO PS-2142, Roseville, USA) to measure leg muscle power. Subjects were asked to stand in a stationary position with bodyweight evenly distributed between both feet, positioned shoulder-width apart, with hips and knees extended. They were

instructed to put both hands on the hips, bend their knees, then jump as high as possible and land simultaneously on both feet. They were given three attempts, and the average score was recorded for data analysis. CMJ was measured twice, before (pre-test) and after (post-test) the treatment was given. The concentration of lactic acid was also examined during pre-test and post-test using ROCHE Accutrend Plus (Roche Diagnostic, McKesson, Germany). A trained nurse collected fingertip blood samples using a lancet which immediately place into the test strip. After a few seconds, the device displayed the results.

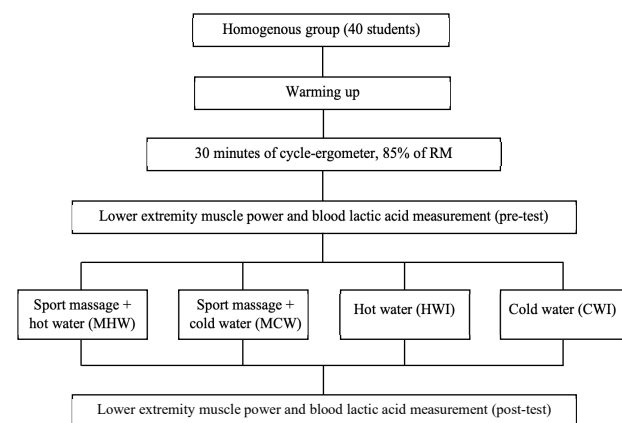


Fig. 1. Experimental Design

In addition to power and lactic acid, anthropometric measurements were assessed prior the research period, including age (years), bodyweight (kg), height (m), and body mass index (kg/m²). Bodyweight was measured using digital scale at the nearest 0.1 kg and height was measured using portable stadiometer at the nearest 0.1 cm.

The interventions were given according to the respected group. Subjects in MHW received twenty minutes of sport massage, followed by indoor hot bath for ten minutes. MCW received sport massage for twenty minutes and cold-water immersion for ten minutes. HWI received indoor hot bath for ten minutes. And last group was CWI who received cold-water immersion for ten minutes. Sport massage was performed by national certified masseurs, consisting of

effleurage, petrissage, friction, and effleurage applied on the lower extremities for five minutes each. Hot bath was done in sauna room, with water temperature was set on 35oC ± 1oC and relative humidity was 90%. Meanwhile, cold water immersion was done individually in cold-water bathtub which temperature was set on 9oC ± 1oC. Cold water immersion was started from the moment subject placed in seated position in the bathtub. The temperature was continuously adjusted to 9oC by adding ice cubes.

Statistical Analysis

Leg muscle power and blood lactic acid level were analyzed using SPSS 30 for Mac and GraphPad Prism for Mac. Saphiro-Wilk test was performed to analyze the normal distribution. Wilcoxon Signed Rank test was done to investigate the difference of measured variables before and after treatment. Afterward, Kruskall-Wallis test were performed to investigate between groups differences, followed by post-hoc test using Mann-Whitney to seek which pairs showed significant different. All data were presented as mean and standard deviation. All statistical analyses were done at a = 0.05.

Results

All subjects were male student athletes with average age of 20.26 ± 1.45 years. The average bodyweight, height, and body mass index were 61.80 ± 3.75 kg, 165.50 ± 4.33 cm, and 22.67 ± 0.95 kg/m². No report of injuries to the spine of lower extremities during the experimental period. Kruskall-Wallis test showed that all baseline characteristics were similar between groups (p > 0.05) (Table 1).

The result of Wilcoxon Sign Rank test in Table 2 indicated that all groups showed significant different in muscle leg power between pre-test and post-test measurements (p < 0.05). Students in MHW, MCW, HWI, and CWI groups all demonstrated a substantial increase in leg power, with greatest increase was found in MHW group which rise from 63.01 ± 3.85 watt to 74.64 ± 5.19 watt, representing an increase of 18.46%. The similar result was also observed in lactic acid level, where students in all group experienced significant improvement. The greatest decrease was reported in MHW group again, with lactic acid level dropping from

Table 1. Baseline Characteristic of Subjects (Mean ± SD)

Characteristic	Groups (n=40)				sig.
	MHW	MCW	HWI	CWI	
Age (year)	19.90 ± 1.22	20.20 ± 1.79	20.40 ± 1.52	19.85 ± 1.22	0.080
Weight (kg)	61.55 ± 3.06	60.32 ± 6.96	59.90 ± 4.45	60.11 ± 3.85	0.066
Height (cm)	165.80 ± 5.74	167.25 ± 9.53	166.10 ± 6.52	166.10 ± 5.20	0.320
Body mass index (kg/m ²)	22.67 ± 0.95	21.63 ± 0.65	21.78 ± 0.80	21.81 ± 0.80	0.212
Temperature (oC)	35.85 ± 0.64	34.22 ± 0.51	35.18 ± 0.50	34.95 ± 0.72	0.180
Heart rate (bpm)	79.45 ± 4.56	78.02 ± 6.00	78.77 ± 5.92	78.69 ± 7.05	0.100
Diastole (mmHg)	109.20 ± 6.82	104.56 ± 5.75	108.15 ± 5.86	107.55 ± 6.20	0.062
Systole (mmHg)	74.35 ± 5.43	74.87 ± 6.24	77.82 ± 4.29	76.76 ± 4.25	0.070
Training volume (hours/week)	7.26 ± 0.56	6.52 ± 0.88	7.50 ± 0.72	7.13 ± 0.56	0.100
Training experience (years)	6.20 ± 2.35	7.24 ± 2.02	7.67 ± 2.78	6.85 ± 3.12	0.752

11.12 ± 2.32 mmol/l before treatment to 4.27 ± 1.82 mmol/l after treatment was given, which corresponds to a reduction of 61.60%. Meanwhile, the smallest improvement in muscle leg and lactic acid level were found in group receiving passive rest and cold-water immersion or CWI, with the improvements were 11.12% and 51.95%, respectively (Table 3). These results, analyzed using the Wilcoxon Sign Rank Test, indicate that the interventions applied were effective in improving leg muscle power and reducing fatigue-related lactic acid buildup in all groups of participants.

Table 2. The Result of Leg Muscle Power and Lactic Acid Concentration Measurements

Group		Leg Power (watt)	Sig.	Lactic Acid (mmol/l)	Sig.
MHW	Pre-test	63.01 ± 3.85	0.001*	11.12 ± 2.32	0.001*
	Post-test	74.64 ± 5.19		4.27 ± 1.82	
MCW	Pre-test	60.93 ± 4.98	0.000*	10.60 ± 1.72	0.000*
	Post-test	72.11 ± 6.24		4.31 ± 0.92	
HWI	Pre-test	63.21 ± 4.20	0.000*	12.40 ± 2.46	0.000*
	Post-test	72.29 ± 5.28		5.24 ± 1.78	
CWI	Pre-test	59.60 ± 3.68	0.000*	11.30 ± 2.67	0.000*
	Post-test	66.23 ± 3.55		5.43 ± 1.49	

*significant at $\alpha = 0.05$ using Wilcoxon Sign Rank test

Table 3 presents the differences between groups in delta (change) in leg muscle power and lactic acid concentration, analyzed using the Kruskal-Wallis test. The change in leg muscle power was statistically significant in all groups ($p = 0.001$), with the MHW and MCW groups showing the highest increase ($\Delta = 11.63 \pm 4.11$ watts and 11.18 ± 4.29 watts, respectively), corresponding to an increase of ~18%. The HWI and CWI groups were followed by lower increases, especially CWI with the smallest increase ($\Delta = 6.63 \pm 2.37$ watts, 11.12%).

Table 3. Between-Group Differences in Delta of Leg Muscle Power and Lactic Acid Level

Group	Δ Leg Power (watt)		Sig.	Δ Lactic Acid (mmol/l)		Sig.
	Mean ± SD	%		Mean ± SD	%	
MHW	11.63 ± 4.11	18.46	0.001*	6.85 ± 2.66	61.60	0.020*
MCW	11.18 ± 4.29	18.35		6.29 ± 2.29	59.34	
HWI	9.08 ± 3.26	14.36		7.16 ± 2.65	57.74	
CWI	6.63 ± 2.37	11.12		5.87 ± 2.95	51.95	

*significant at $\alpha = 0.05$ using Kruskal-Wallis

For lactic acid, the decrease was also shown to be significantly different between groups ($p = 0.020$), with the HWI group showing the largest mean decrease ($\Delta = 7.16 \pm 2.65$ mmol/l), while the CWI group again showed the smallest reduction ($\Delta = 5.87 \pm 2.95$ mmol/l). Overall, this table highlights those different interventions resulted in varying degrees of improvement, with MHW and MCW appearing to be most effective in increasing leg muscle power, while HWI achieved the greatest reduction in lactic acid concentrations (Table 3).

Discussion

The findings of this study prove that recovery methods that combine sports massage and water immersion—both hot and cold—have proven to be more effective than immersion in water alone in accelerating post-exercise recovery. One of the underlying factors that could explain the mechanism is due to the synergistic physiological and neurological effects provided by each method (Duñabeitia et al., 2022; Romadhona et al., 2019; Stella et al., 2024). While water immersion primarily targets systemic recovery through hydrostatic stress and temperature-induced vascular responses (Matsui & Onodera, 2013), sport massage acts locally to improve circulation, reduce muscle stiffness, and promote lymphatic drainage (Davis et al., 2020). Cold water immersion (CWI) causes vasoconstriction, which reduces inflammation, edema, and perceived muscle pain (White & Wells, 2013), while hot water immersion (HWI) improves vasodilation, improving blood flow and tissue elasticity (Jackman et al., 2023). When preceded by sport massage, this effect is even stronger: cold-water immersion and massage will support reperfusion and helps to restore mobility by increasing circulation in previously narrowed vessels (Romadhona et al., 2019), while post-hot water immersion and sport massage benefits muscles that are already warm and relaxed, allowing for deeper and more effective tissue manipulation.

This sequential treatment that combines sports massage with water immersion has been shown to maximize the removal of metabolic waste—especially lactic acid (Wismanadi et al., 2024)—and accelerate the delivery of oxygen and nutrients to damaged muscle tissue (Moovenhan & Nivethitha, 2014). This process directly supports muscle cell regeneration and recovery of physical performance after intense exercise. Physiologically, water immersion utilizes the principle of hydrostatic pressure that increases venous blood flow back to the heart, as well as accelerates the removal of waste products such as hydrogen ions and lactic acid from the muscles (B. E. Kauffman & Kauffman, 2014). When combined with massage, this effect is amplified through mechanical stimulation of soft tissues that facilitate circulation, improve lymphatic drainage, and reduce muscle tension. A study by Afandi et al. (2023) showed that the combination of CWI and massage was more effective in reducing delayed muscle pain (DOMS) than CWI alone, while Angelopoulos et al. (2022) found that the combination of these interventions resulted in more optimal recovery in a shorter time.

In addition to the physiological aspect, the psychological benefits are also significant; massage is able to lower stress hormones such as cortisol and activate the parasympathetic nervous system (Baek et al., 2022; Lindgren et al., 2010), thereby helping athletes feel more relaxed and mentally recovered. This is especially important in the context of high-frequency sports training, where mental and physical endurance are equally crucial (Dakić et al., 2023). Therefore, this multimodal recovery approach not only provides immediate benefits in accelerating muscle strength recovery and lactic acid clearance, but also creates holistically optimal conditions for readiness for the next workout. The effectiveness of this approach is evident in the results of increased muscle strength and significant reduction in lactic

acid levels in the MHW and MCW groups in Tables 2 and 3 of this study.

The finding of this study showed that the combination of sport massage with hot-water bath was more effective in increasing leg muscle power and reducing lactic acid level after high-intensity exercise. Recovery using the combination of sports massage and hot water method has almost the same effect as recovery in contrast water (hot-cold), where there will be alternating vasodilation and vasoconstriction phases (Romadhona et al., 2019). The combination between sport massage followed by hot water bath is known to provide better effects than the other combinations, because alternating vasoconstriction and vasodilation are thought to work in a manner comparable to muscle pumping (vaso-pumping), increasing blood flow and removing metabolites so that it can improve recovery (Cochrane, 2004). Increased circulation will increase oxygen supply which eventually help to recycle lactic acid into an energy source (Setiawan et al., 2023).

Conclusion

The findings in this study highlight that various combination recovery strategies contribute to increasing leg muscle power and reducing lactic acid levels better than a single recovery method. When applied appropriately, this method can speed up post-workout recovery, restore muscle function more efficiently, and support overall athletic performance. Its effectiveness lies in the synergistic physiological and neurological effects provided by each method. Therefore, integrating this recovery approach into training routines can provide significant benefits for student-athletes who want to optimize recovery and maintain excellent physical condition.

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Conflict of Interest

The authors declare no conflict of interest.

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Порівняння ефективності застосування різних комбінацій методів відновлення щодо покращення потужності м'язів нижніх кінцівок та рівня молочної кислоти в крові

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Авторський вклад: А – дизайн дослідження; В – збір даних; С – статаналіз; D – підготовка рукопису; Е – збір коштів

Реферат. Стаття: 7 с., 3 табл., 1 рис., 42 джерел.

Мета дослідження. Мета цього дослідження полягала у вивченні впливу різних методів відновлення на поліпшення потужності м'язів нижніх кінцівок та зниження рівнів молочної кислоти серед студентів-спортсменів.

Матеріали та методи. У цьому дослідженні використовувалася рандомізована контрольна група з претест-посттестовим дизайном. Учасників дослідження було відібрано за методом простої випадкової вибірки, яка складалася з сорока студентів, розподілених на чотири групи: група спортивного масажу та процедури з гарячою водою (МГВ), група спортивного масажу та процедури з холодною водою (МХВ), група занурення в гарячу воду (ГВЗ) та група занурення в холодну воду (ХВЗ). Збирання даних здійснювалося за допомогою силової платформи для вимірювання потужності м'язів нижніх кінцівок (Вт), тоді як для визначення рівня молочної кислоти використовувався лактометр (ммоль/л). Аналіз даних проводився із застосуванням критерію знакових рангів Вілкоксона з метою вивчення різниці вимірюваних змінних перед початком і після завершення дослідження. Наступний етап полягав у проведенні тесту Краскела–Волліса для вивчення міжгрупових відмінностей, з подальшим застосуванням post-hoc тестування за допомогою критерію Манна–Вітні.

Результати. Результати показали, що в усіх групах (МГВ, МХВ, ГВЗ та ХВЗ) спостерігалось підвищення потужності м'язів нижніх кінцівок та зниження рівнів молочної кислоти. Застосування методу МГВ виявилось найефективнішим у збільшенні потужності м'язів нижніх кінцівок на 11.63 Вт, тоді як метод ГВЗ мав найбільш позитивний вплив на зниження рівнів молочної кислоти на 7.16 ммоль/л.

Висновки. Отримані дані свідчать про важливість поєднання спортивного масажу з терапією гарячою та холодною водою в якості реабілітаційної стратегії. Дослідники підкреслюють значущість використання зазначених методів терапії у поліпшенні потужності м'язів нижніх кінцівок та зниженні накопичення молочної кислоти, що сприяє оптимальній фізичній підготовці та результативності під час спортивних змагань.

Ключові слова: лактат, потужність, відновлення, спортивний масаж, студенти, занурення у воду.

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