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Far-Infrared Radiation with Sauna Method Improves Recovery of Fatigue and Muscle Damage in Athletes After Submaximal Physical Exercise
La radiación infrarroja lejana con método de sauna mejora la recuperación de la fatiga y el daño muscular en deportistas tras un ejercicio físico submáximo

*Oce Wiriawan, *Hari Setijono, *Shidqi Hamdi Pratama Putera, **Ghana Firsta Yosika, *Arifah Kaharina, *Anindya Mar'atus Sholikhah, ***Adi Pranoto
*Universitas Negeri Surabaya (Indonesia), **Universitas Tanjungpura (Indonesia), ***Universitas Airlangga (Indonesia)

Abstract. Muscle damage is one of the most frequent causes of decreased physical ability in training. Injuries during exercise are caused by damage to soft tissue, such as muscles. This can occur if recovery is inadequate in an exercise program. Incomplete recovery can reduce an athlete's performance. This study aims to determine the effect of far-infrared radiation (FIR) in improving fatigue and muscle cell damage in athletes after submaximal physical exercise. A total of 16 male athletes, aged 18-23 years were recruited to participate in the study and were given physical exercise at submaximal intensity (80% HR_{max}) for 30 minutes using a treadmill. The administration of FIR 45ºC was carried out immediately after submaximal intensity exercise for 30 minutes, while the recovery control group was carried out lying down without additional intervention. Measurement of fatigue levels uses the lactic acid (LA) parameter with the Accutrend Plus Meter, while measuring muscle cell damage uses the MDA level parameter using the Thiobarbituric acid reactive substance (TBARs) method. The data analysis technique uses the independent sample t-test with a significance level of 5%. The results showed that there was a significant difference in mean post-treatment LA between the control (CTR) vs. recovery group with FIR 45ºC for 30 minutes (EXP) 3.48±1.62 mmol/L vs. 3.48±1.62 mmol/L, p=0.035. Mean post-treatment MDA levels between CTR vs. EXP 0.45±0.19 ng/mL vs. 0.24±0.03 ng/mL, p=0.011. Far-infrared radiation using the sauna method has been proven effective in reducing lactic acid and MDA levels after submaximal physical exercise.
Keywords: Far-infrared radiation, lactic acid, MDA levels, submaximal physical exercise

Resumen. El daño muscular es una de las causas más frecuentes de disminución de la capacidad física en el entrenamiento. Las lesiones durante el ejercicio son causadas por daños en los tejidos blandos, como los músculos. Esto puede ocurrir si la recuperación es inadecuada en un programa de ejercicios. La recuperación incompleta puede reducir el rendimiento de un atleta. Este estudio tiene como objetivo determinar el efecto de la radiación infrarroja lejana (FIR) en la mejora de la fatiga y el daño de las células musculares en deportistas tras un ejercicio físico submáximo. Un total de 16 atletas masculinos, de entre 18 y 23 años, fueron reclutados para participar en el estudio y se les realizó ejercicio físico a una intensidad submáxima (80% FCmáx) durante 30 minutos utilizando una cinta de correr. La administración de FIR 45ºC se realizó inmediatamente después del ejercicio de intensidad submáxima durante 30 minutos, mientras que el grupo control de recuperación se realizó acostado sin intervención adicional. La medición de los niveles de fatiga utiliza el parámetro de ácido láctico (LA) con el medidor Accutrend Plus, mientras que la medición del daño de las células musculares utiliza el parámetro de nivel de MDA utilizando el método de sustancia reactiva al ácido tiobarbitúrico (TBAR). La técnica de análisis de datos utiliza la prueba t para muestras independientes con un nivel de significancia del 5%. Los resultados mostraron que hubo una diferencia significativa en la media de LA postratamiento entre el grupo control (CTR) vs. recuperación con FIR 45ºC durante 30 minutos (EXP) 3.48±1.62 mmol/L vs. 3.48±1.62 mmol/L, p=0.035. Niveles medios de MDA postratamiento entre CTR vs. EXP 0.45±0.19 ng/mL vs. 0.24±0.03 ng/mL, p=0.011. La radiación infrarroja lejana mediante el método de la sauna ha demostrado ser eficaz para reducir los niveles de ácido láctico y MDA después de un ejercicio físico submáximo.
Palabras clave: Radiación infrarroja lejana, ácido láctico, niveles de MDA, ejercicio físico submáximo

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Oce Wiriawan
ocewiriawan@unesa.ac.id

Introduction

Submaximal intensity physical exercise (80% HR_{max}) is the high intensity used in most sports and causes a significant increase in lactic acid (LA) levels in the blood (McDougle et al., 2023). High-intensity training has advantages in terms of time efficiency (Kunz et al., 2019; Stankovic et al., 2023). Otherwise, Submaximal exercise has been known to cause muscle fatigue (Supruniuk et al., 2023). However, sports practice is inevitably linked with the appearance of injuries (Prieto-González et al., 2021). A key characteristic of fatigue is the "sense of weariness," which is the mental or physical depletion that arises when the needs of the brain or muscles exceed their capacity (Lee et al., 2023a). Musculoskeletal injuries in elite sports are among the most significant issues due to their profound effect on performance (Romero-Morales et al., 2024). On the other hand, malondialdehyde (MDA) and LA were significantly greater during fatigue than during rest (Wan et al., 2017). Lactate has been regarded as a metabolic waste end product that causes fatigue during exercise, its lactate production differs depending on exercise intensity and is not limited to muscles (Lee et al., 2023b). High lactate concentrations may also cause lactic acidosis (Li et al., 2023). Moreover, High LA levels pose a risk of muscle tissue damage (Zhao & Sim 2023) which can be seen from increased MDA levels (Mohideen et al., 2023; Pranoto et al., 2023a). During exercise, LA points begin to accumulate faster than the body's ability to excrete or clear them, referred to as the LA threshold (McDougle et al., 2023). At the highest standards of competitive match play, there has been an evolutionary advance in high-intensity workload profiles for athletes

(Aughey, 2013; Barnes et al., 2014; Bradley et al., 2013; Bradley et al., 2016; Harper et al., 2019). High-intensity physical activity requires high body performance for muscle contractions, so it tends to cause fatigue and the resulting cell damage will increase. Muscle damage is one of the most frequent causes of decreased physical ability in training. Injuries during exercise are caused by damage to soft tissue, such as muscles (Aicale et al., 2018). This can occur if recovery is inadequate in an exercise program (Noponen et al., 2015). Moreover, most sports competitions in Indonesia are held over a short period so that an athlete can play one match every day. In certain competitions, they can even play several matches in one day. Incomplete recovery between one physical training and the next physical training or between one match and the next will reduce an athlete's performance (Alba-Jiménez et al., 2022).

Muscles that continuously contract will cause the activity of xanthine oxidase (XO) and NADPH oxidase (NOX) to increase so that the formation of oxygen radicals/reactive oxygen species (ROS) also increases (He et al., 2016). High-intensity exercise can trigger an increase in ROS levels in the body, causing fatigue and muscle damage (Wang et al., 2021). This is characterized by pain; this term is called Delayed onset muscle soreness (DOMS). DOMS is an event that often occurs as a muscle response to high-intensity physical activity or activities that are not usually done. DOMS is a marker of the remodeling process due to muscle damage (Wilke & Behringer, 2021). One of the efforts made to reduce fatigue and muscle damage after high-intensity exercise is by carrying out optimal recovery after exercise (Laurino et al., 2023).

Recovery can be carried out actively and passively (Spierer et al., 2004). One of the passive recovery modalities is the administration of far-infrared radiation (FIR) (Chen et al., 2023). Infrared radiation is an energy wave that is part of the electromagnetic spectrum with a wavelength of 3-100 µm (Vatansever & Hamblin, 2012). Infrared classification according to wavelength is divided into the near-infrared, mid-infrared, and far infrared. One of the infrared devices is an infrared sauna (Ahokas et al., 2023), which is included in the far infrared category with a wavelength between 5.6-1000 µm (Noponen et al., 2015). Loturco et al. (2016) revealed that giving FIR reduced the DOMS felt after plyometric training. Several studies state that heat therapy speeds up recovery more than cold therapy or passive recovery by sitting still. However, the mechanism of administering FIR is not yet known (Lin et al., 2008), but the same wavelength between FIR and the human body could be one of the possible factors for FIR to penetrate deeper into the body (Noponen et al., 2015). The study conducted by Loturco et al. (2016) reported that administering FIR could reduce DOMS after plyometric training in soccer players. Administration of FIR has also been reported to reduce the accumulation of muscle damage and improve recovery in professional soccer players (Hsieh et al., 2022). However, until now it is not known how the mechanism of administering FIR improves recovery from muscle fatigue and muscle cell damage in athletes, therefore this research aims to determine the effect of administering FIR in improving the level of fatigue and muscle cell damage in athletes after submaximal physical exercise.

Materials and Methods

This research was true-experimental research with a randomized pretest-posttest control group design. The subjects used in this research were Surabaya State University students, members of the Pencak Silat Student Activity Unit (UKM) as partners who actively participate in championships and have been champions at least at the provincial level, with inclusion criteria: male, aged 18-23 years, has a body mass index of 19-23 kg/m^2, normal blood pressure, normal oxygen saturation, normal heart rate, does not smoke, vape, or consume alcohol, and has no history of chronic disease. Before participating, all subjects were explained about the research and the subjects consciously filled out and signed informed consent. All procedures for this research have been approved by the Health Research Ethics Committee, Faculty of Public Health, Universitas Airlangga, Surabaya No: 156/EA/KEPK/2022.

The training program was implemented and supervised by professional officers from the Faculty of Sports and Health Sciences, Universitas Negeri Surabaya. A total of 16 people were randomly divided into two groups, including CTR (n = 8; control group without intervention), and EXP (n = 8; recovery group with FIR 45ºC for 30 minutes). Exercise with submaximal intensity (80% HR_{max}) was carried out once for 30 minutes using a treadmill (Pranoto et al., 2024; Puspodari et al., 2022). The administration of FIR 45ºC was carried out immediately after submaximal intensity exercise for 30 minutes, while the recovery control group was carried out lying down without additional intervention. After a 12-hour overnight fast, 4 ml of blood were collected from the cubital vein, then the blood was centrifuged for 15 minutes at a speed of 3000 rpm for serum separation (Sari et al., 2024), and examination of MDA levels using the Thiobarbituric acid reactive substance (TBARs) method (Pranoto et al., 2023b). FBG examination uses Accu-Chek Performa (Roche, Mannheim, Germany) with concentration units mg/dL, while LA examination uses Accutrend Plus Meter (Accutrend® lactate meter, Roche Diagnostics, Mannheim, Germany) with concentration units mmol/L (Rusdiawan et al., 2020).

Statistical analysis used a statistical software package for social science (SPSS) version 21 (Chicago, IL, USA). The normality test uses the Shapiro-Wilk test, while the difference test uses a paired sample t-test, independent sample t-test, and followed by effect size evaluation using Cohen's d. All statistical analyzes use a significance level of 5%. All data are presented as mean±SD.

Results

The results of statistical analysis of subject characteristics generally showed that there were no significant differences between the two groups which can be seen in Table 1.

Table 1.
Description of characteristics subjects studies

Parameters	CTR (n = 8)	EXP (n = 8)	p-Value
Age, yrs	20.50±1.93	20.88±1.25	0.652
Weight, kg	59.39±5.55	63.75±6.36	0.166
Height, m	1.65±0.07	1.69±0.06	0.176
BMI, kg/m^2	21.93±1.20	22.21±1.03	0.631
BT, °C	36.61±0.44	36.65±0.56	0.883
SpO_2, %	98.00±1.31	98.38±0.74	0.496
SBP, mmHg	119.00±8.29	117.25±8.81	0.689
DBP, mmHg	74.38±3.42	73.38±8.58	0.764
HR, bpm	67.63±5.21	68.00±9.18	0.921

Description: BMI: Body mass index; BT: Body temperature; SpO_2: Oxygen saturation; SBP: Systolic blood pressure; DBP: Diastolic blood pressure; HR: Heart rate.

The results of statistical analysis of the average levels of lactic acid (LA), fasting blood glucose (FBG), and malondialdehyde (MDA) in both groups can be seen in Figures 1-3 and Table 2.

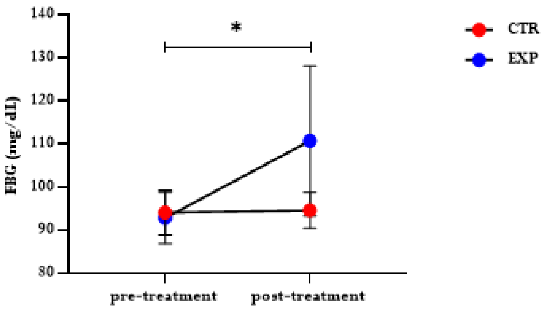

Figure 1. Fasting blood glucose (FBG) (mg/dL) in both groups

Description: (*) Significant at pre-treatment from EXP ($p \leq 0.05$).

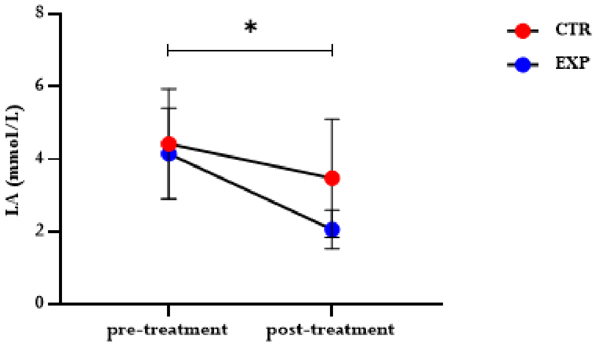

Figure 2. Lactic acid (LA) (mmol/L) in both groups
Description: (*) Significant at pre-treatment from EXP ($p \leq 0.05$).

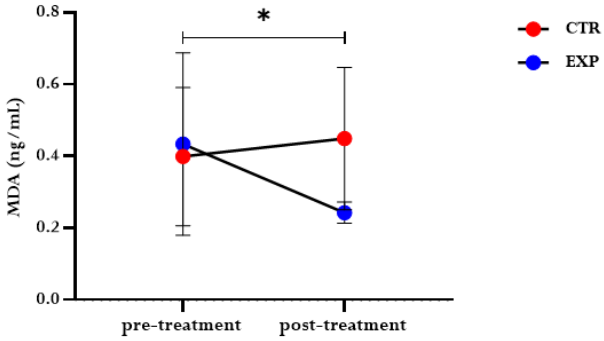

Figure 3. Malondialdehyde (MDA) (ng/mL) in both groups
Description: (*) Significant at pre-treatment from EXP ($p \leq 0.05$).

Table 2.
Differences in mean levels of LA, FBG, and MDA in the two groups

Parameters	CTR (n = 8)	EXP (n = 8)	p-Value	Mean (95% CI)	Effect size
Pre-treatment FBG (mg/dL)	94.13±5.14	92.88±5.96	0.660	-	-
Post-treatment FBG (mg/dL)	94.63±4.17	110.75±17.41*	0.023	-16.13 (-29.70 to -2.55)	1.274
Pre-treatment LA (mmol/L)	4.43±1.51	4.15±1.25	0.698	-	-
Post-treatment LA (mmol/L)	3.48±1.62	2.06±0.53*	0.035	1.41 (0.03 to 2.79)	1.169
Pre-treatment MDA (ng/mL)	0.39±0.19	0.43±0.25	0.761	-	-
Post-treatment MDA (ng/mL)	0.45±0.19	0.24±0.03*	0.011	0.21 (0.04 to 0.37)	1.455

(*) Significant at CTR ($p \leq 0.05$).

Discussion

This study aims to determine the effect of administering the far-infrared radiation (FIR) sauna method in improving fatigue and muscle cell damage in athletes after submaximal physical exercise. The study results showed that FIR using the sauna method was proven to be effective in improving the level of fatigue and muscle cell damage in athletes after submaximal physical exercise. These results are in line with previous research that FIR therapy is effective in reducing muscle damage and accelerating recovery from muscle damage (Chen et al., 2023; Hsieh et al., 2022; Tsagkaris et al., 2022). The FIR sauna method can repair tissue by reducing oxidative stress, increasing vasodilation, and stimulating growth factor and extracellular matrix deposition (Tsagkaris et al., 2022). In this study, we report that FIR using the sauna method was proven to be effective in improving the level of fatigue and muscle cell damage in athletes after submaximal physical exercise by maintaining the balance of glucose in the blood and reducing lactic acid levels and malondialdehyde (MDA) levels.

High-intensity training has advantages in terms of time efficiency (Kunz et al., 2019; Stankovic et al., 2023). The application of the FIR sauna method in an exercise program with submaximal intensity (80% HR_{max}) is carried out once for 30 minutes using a treadmill (Pranoto et al., 2024; Puspodari et al., 2022). Skeletal muscle force production depends on the contraction mechanism, and failure at any of the sites upstream of the cross-bridges can contribute to the development of muscle fatigue, including the nervous, ionic, vascular, and energy systems (Kent-Braun et al., 2012; Wan et al., 2017). Exercise has been shown to have an important role in optimizing glycemic control (Shah et al., 2021). To maintain high physical activity, skeletal muscle contraction requires more substrate to produce adenosine triphosphate (ATP) which comes from muscle glycogen and blood glucose which is broken down and tightly regulated (Mul et al., 2015). Our results in the control group showed no change in blood glucose levels 12 hours after exercise. These results indicate that the balance of glucose levels in the blood decreases. However, the intervention group with the addition of FIR 45ºC for 30 minutes during recovery after exercise showed a significant increase in blood glucose levels, an increase from low blood glucose levels due to submaximal exercise back to normal levels. These results prove that administering the FIR sauna method is effective in supporting post-exercise recovery.

Lactate has been considered a metabolic end-product that causes fatigue during exercise (Lee et al., 2023b). Our results in the control group showed that lactate levels did not decrease during the 12-hour recovery period after submaximal exercise. The intervention group showed a significant reduction in lactate levels. Our results prove that administering FIR during the recovery period can support the perception of recovery after submaximal exercise. Fatigue has been shown to impact performance. According to Schwiete et al. (2023), muscle fatigue can change the running mechanics of the subject. In addition, fatigue also risks muscle damage (Cohen et al., 2015; Coratella et al., 2014; Schwiete et al., 2023), which is characterized by increased MDA levels (Zhao & Sim, 2023). Therefore, to maintain optimal athlete performance, it is important to pay more attention to recovery factors both after training and during competition. Providing the FIR sauna method during recovery has been proven to be effective in supporting recovery and improving athlete performance after submaximal physical exercise.

Conclusion

Far-infrared radiation using the sauna method has proven to be effective in maintaining the balance of glucose in the blood and reducing lactic acid levels and malondialdehyde levels. Therefore, administering far-infrared radiation using the sauna method can be an alternative that can be used to improve the level of fatigue and muscle cell damage in athletes after submaximal physical exercise.

Conflict of Interest

The authors declare that they have no potential conflicts of interest.

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Datos de los autores y traductor:

Oce Wiriawan	ocewiriawan@unesa.ac.id	Autor/a
Hari Setijono	harisetijono@unesa.ac.id	Autor/a
Shidqi Hamdi Pratama Putera	shidqihamdi@gmail.com	Autor/a
Ghana Firsta Yosika	ghana.firsta@fkip.untan.ac.id	Autor/a
Arifah Kaharina	arifahkaharina@unesa.ac.id	Autor/a
Anindya Mar'atus Sholikhah	anindyasholikhah@unesa.ac.id	Autor/a
Adi Pranoto	adi.pranoto-2020@fk.unair.ac.id	Autor/a
Rahmatya Ikhwanurrosida, S.S	lingolinkpro@gmail.com	Traductor/a