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Effects of infrared sauna, traditional sauna, and warm water immersion on accelerated exercise recovery and prevention of cell damage: an experimental study

Efectos de la sauna de infrarrojos, la sauna tradicional y la inmersión en agua caliente en la recuperación acelerada del ejercicio y la prevención del daño celular: un estudio experimental

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Abstract. The objectives of this study were to investigate the effects of single session infrared sauna, traditional sauna, warm water immersion, and passive recovery from fatigue and muscle cell damage in athletes and nonathletes. Eight male badminton athletes and eight male nonathletes participated in this study. The study participants were treated with submaximal physical activity assessed by ergometer, then recovered with different modalities. Each treatment was separated by one week of a resting period through a randomized crossover design. The recovery modalities of infrared sauna (IRS) were 45±2°C, traditional sauna (TRS) 40±2°C, warm water immersion (WWI) 40±2°C, and passive recovery (PAS) for 20 minutes. Blood lactate, creatine kinase, blood glucose, heart rate, body temperature and level of pain were assessed, immediately after physical activity (pre), after recovery (post), and after 40 minutes of sitting (post-40min). Our findings indicated that the WWI and IRS were effective reducing fatigue in athletes and nonathletes. Moreover, PAS and TRS prevented muscle damage in nonathletes after 60 minutes of physical activity. All the thermal modalities decreased the BGL. The least amount of pain reported during the WWI modality, while the PAS modality tended to cause severe pain. Body temperature measurements were not significantly different among the modalities. According to our data, the WWI is more effective at increasing recovery and preventing muscle cell damage in athletes. Moreover, IRS and TRS are more effective for recovery in nonathletes. Further research needs to be conducted with different sports subjects, different types of exercise, different biomarkers, and physical performance tests.
Keywords: infrared sauna; traditional sauna; warm water immersion; recovery; muscle cell damage

Resumen. Los objetivos de este estudio fueron investigar los efectos de la sauna de infrarrojos de una sola sesión, la sauna tradicional, la inmersión en agua caliente y la recuperación pasiva de la fatiga y el daño celular muscular en atletas y no atletas. Participaron en este estudio ocho atletas masculinos de bádminton y ocho no atletas masculinos. Los participantes en el estudio fueron tratados con actividad física submáxima evaluada mediante ergómetro, y luego se recuperaron con diferentes modalidades. Cada tratamiento estuvo separado por una semana de período de descanso mediante un diseño cruzado aleatorio. Las modalidades de recuperación de sauna de infrarrojos (IRS) fueron 45±2°C, sauna tradicional (TRS) 40±2°C, inmersión en agua caliente (WWI) 40±2°C, y recuperación pasiva (PAS) durante 20 minutos. Se evaluaron el lactato en sangre, la creatina quinasa, la glucosa en sangre, la frecuencia cardiaca, la temperatura corporal y el nivel de dolor, inmediatamente después de la actividad física (pre), después de la recuperación (post), y después de 40 minutos sentados (post-40min). Nuestros resultados indicaron que el IAM y el SRI fueron eficaces para reducir la fatiga en atletas y no atletas. Además, el PAS y el TRS previnieron el daño muscular en no deportistas tras 60 minutos de actividad física. Todas las modalidades térmicas redujeron la BGL. El menor dolor se registró durante la modalidad ETR, mientras que la modalidad PAS tendió a causar dolor intenso. Las mediciones de la temperatura corporal no fueron significativamente diferentes entre las modalidades. Según nuestros datos, la WWI es más eficaz para aumentar la recuperación y prevenir el daño de las células musculares en los atletas. Por otra parte, el IRS y el TRS son más eficaces para la recuperación en no deportistas. Es necesario realizar más investigaciones con diferentes sujetos deportistas, diferentes tipos de ejercicio, diferentes biomarcadores y pruebas de rendimiento físico.
Palabras clave: sauna de infrarrojos; sauna tradicional; inmersión en agua caliente; recuperación; daño celular muscular

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Introduction

High-intensity physical activity causes an increase in the lactic acid concentration in muscle and blood, which is an indirect marker of fatigue (Hall et al., 2016; Manosalva et al., 2022; McDougle et al., 2023; Ríos et al., 2021; Supruniuk et al., 2023; Theofilidis et al., 2018). Lactic acid levels must be lowered to a normal threshold again to reduce the degree of fatigue that occurs. If not lowered by recovery, this can trigger further muscle damage (Li et al., 2022; Manosalva et al., 2022). Adequate recovery is one of the determinants of successful physical performance, especially in professional sports. Various recovery modalities are increasingly used by sports practitioners to minimize fatigue and accelerate recovery. This accelerated recovery is especially important for preparing athletes for the next training or competition. Adequate recovery can improve competition performance, allow greater training loads to be received, or enhance the effects of a given training load, and prevent sports injuries (Doherty et al., 2021; Ihsan et al., 2024; Versey et al., 2013). Excessive training and competition volume, especially with short recovery times, can have a major physiological impact on the musculoskeletal, nervous, immune, and metabolic systems (Kreher & Schwartz, 2012; Rey et al., 2012; Scheffer & Latini, 2020). Optimal recovery is needed to prepare athletes physically and mentally for their next training or competition. Athletes with inadequate recovery are prone to increased risk of injury, illness, and overtraining (Nédélec et al., 2015; Watson et al., 2017). Sports practitioners need to know the right type of recovery modality according to their needs, characteristics, and types of sport.

One of the commonly used modalities for recovery is thermal therapy. Thermal therapy has been effectively used to relieve certain diseases and discomfort (Rey et al., 2012). Passive recovery modalities with thermal therapy that can be used include infrared sauna (IRS), traditional/steam sauna (TRS), warm water immersion (WWI), and sitting still/passive (PAS).

Infrared energy is a wave energy that complements or fills the electromagnetic spectrum and has been used effectively to treat or alleviate certain diseases (Vatansever & Hamblin, 2012). Infrared light, also known as infrared light, consists of electromagnetic radiation with wavelengths shorter than those of microwave radiation and longer than those of visible light (750 nm to 1 mm). Higher temperatures produce higher amounts of infrared radiation with higher frequencies and shorter wavelengths (NASA, 2009). IRS heats the air to approximately 40-60°C and emits heat with wavelengths between 1–2 μm (Beever, 2009; Vatansever & Hamblin, 2012). The International Commission on Illumination (CIE) has divided infrared data into three bands according to their physical properties: near infrared (IR-A, 700–1400 nm), mid infrared (IR-B, 1400–3000 nm), and far infrared (IR-C, 3000 nm–0.1 mm) (Val et al., 2006; Vatansever & Hamblin, 2012).

The effects of infrared radiation in the medical field have been researched for a long time. Many infrared devices have been used for medical therapy, but infrared research on sports recovery is still limited, and the results are conflicting (Kaharina et al., 2017; Mero et al., 2015; Wahjuni et al., 2019; Wiriawan et al., 2022, 2024). One type of infrared device is the infrared sauna, which is a type of far infrared (FIR) device. Infrareds for exercise recovery are known to have been researched, with most studies focusing on phototherapy and ceramic materials that emit infrared, whereas few studies have used infrared saunas.

Traditional sauna bathing has been a tradition in Finland for thousands of years. It is commonly used for pleasure and relaxation. The temperature used ranged from 45°C to 100°C (113°F to 212°F). Sauna exposure contributes to restoring homeostasis and conditioning the body to address future stressors (J. A. Laukkanen et al., 2018). Many studies have demonstrated the beneficial health effects of TRS, which include reducing inflammation and oxidative stress through reduced systemic inflammation; reducing kuopio ischemic heart disease (KIHD) such as high blood pressure, cardiovascular disease, and neurocognitive disease; nonvascular conditions such as pulmonary disease; mortality; and improving conditions such as arthritis, headache, and flu (Kunutsor et al., 2018; J. A. Laukkanen et al., 2018; T. Laukkanen et al., 2015, 2018). Sessions lasting 19 minutes were more effective than those lasting 11 to 18 minutes in reducing mortality (T. Laukkanen et al., 2015).

WWI has been widely used as a modality to accelerate recovery. WWI is a thermotherapeutic intervention in which the body is immersed in water at a temperature greater than 36°C (Wilcock et al., 2006). Several studies examining the effects of postexercise WWI have reported conflicting findings. The effect of WWI on performance recovery remains unclear (Pournot et al., 2011; Vaile et al., 2008b, 2008a; Versey et al., 2013). Many studies have revealed the effects of IRS, TRS, and WWI on health, but studies on their effects on accelerating recovery, such as the optimization of physical performance, are minimal and still unclear. This study compared the effects of the IRS, SS, and WWI on athletes and nonathletes. This study aimed to investigate the effects of one session of infrared sauna, steam sauna, warm water immersion, and passive recovery on recovery from postexercise muscle soreness, fatigue biomarkers, and muscle cell damage biomarkers in athletes and nonathletes.

Materials and Methods

Subjects

The subjects included eight badminton athletes and eight nonathletes (active people), male, aged 18-23 years, with a normal resting heart rate (60–100 bpm), normal BMI (18.5–22.9 kg/m²), healthy and not suffering from injuries, and provided written consent to participate in this study. The citerion for the athlete group was that they had won at least at the regional level. Ethical approval for this study was obtained from the health research ethics committee of the Faculty of Public Health, Universitas Airlangga (number: 178/EA/KEPK/2023).

Research Design

The subjects were treated with four recovery modalities separated by one week, namely the IRS, TRS, WWI, and PAS, for 20 minutes. The subjects were prohibited from consuming any food 8 hours before the measurement, they could only drink water, and fluid intake was controlled during the experimental trial. The use of nonsteroidal anti-inflammatory drugs and other recovery methods is prohibited.

The subjects performed physical activity with an ergometer at a submaximal intensity of 80–90% pulse rate maximum (HRM). The following parameters were measured: blood lactate level (BLL), body temperature (BT), and visual analog scale (VAS) score as biomarkers of fatigue; creatine kinase for muscle level (CKML) score as a biomarker of muscle cell damage; and blood glucose level (BGL) score as a marker of energy use. Blood samples were collected immediately after

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physical activity (Pre), immediately after recovery (Post), and after 40 minutes of sitting still (Post-40 minutes), as shown in Figure 1.

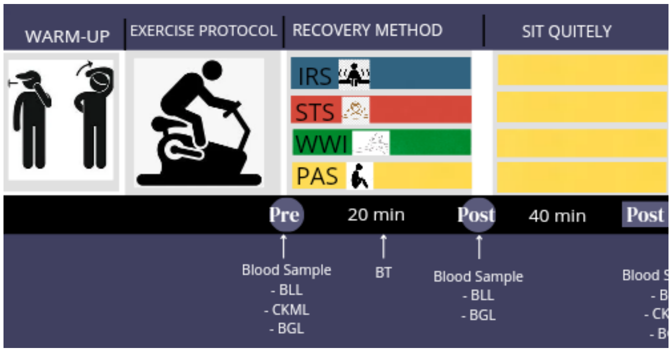

Figure 1. Schematic view of research design

Procedures

Physical activity protocol

The subjects performed physical activity by pedaling on an ergometer (TechnoGym Excite 700 Bike, TechnoGym, Rhode Island, USA) starting at a speed of 50 rpm for 5 minutes. This was followed by an increase in speed of 10 rpm per minute until reaching submaximal intensity to the limit of 85% HRM, which was then maintained in the submaximal pulse range (80–90% HRM) for 5 minutes. After that, the speed is gradually decreased for 5 minutes.

Recovery session

All modalities were given one week apart. Recovery modalities were administered immediately after physical activity for 20 minutes. The temperature were as follows: IRS, 45 ± 2°C (infrared sauna room Orans SN-96116I/65ºC/1.5 kW); TRS, 40 ± 2°C (dry sauna room Smartmak SMT-041/65ºC/2.7 kW); WWI, 40 ± 2°C; and PAS, room temperature. The subject continued to wear sportswear during the recovery modality, except for WWI where the subject only wore shorts. WWI was performed by immersing the subject's entire body (with the exception of the neck and head).

Body temperature and muscle soreness

Body temperature was measured by the noncontact method with an infrared thermometer on the forehead and muscle soreness was measured with a visual analog scale questionnaire.

Collection and analysis of blood samples

Blood samples were collected to analyze the BLL, CKML, and BGL. BLL and BGL were measured with a metabolic detector (Accutrend® Plus system, Roche, Rotkreuz, Switzerland). The CKML was measured by drawing blood from the antecubital vein (2 ml). The blood was centrifuged at 2000–30000 RPM (ID-Centrifuge L, Bio-Rad, California, USA) for 20 min. After serum separation, samples were frozen at -80°C until analysis. CKML was assessed via an enzyme-linked immunosorbent assay (iMark™ Microplate Absorbance Reader, Bio-Rad, California, USA).

Statistical Analysis

The data were analyzed via IBM SPSS Statistics 26 (IBM Corp. Armonk, NY, USA). Independent samples tests with the Mann-Whitney U and related samples with the Wilcoxon test were used. The data are presented as the means ± SDs. Statistical significance was set at $p < 0.05$. Changes before, after, and after 40 minutes were calculated as delta (Δ).

Result

Table 1.
Subject Characteristics

	G1		G2	
Variable	Mean	SD	Mean	SD
Age (year)	21.00	0.926	20.750	0.886
Weight (kg)	62.475	8.018	59.238	4.043
Height (cm)	171.500	7.0051	168.750	3.454
BMI (kg/m^2)	21.1940	1.815	20.806	1.381
HR rest (bpm)	73.13	10.816	76.125	11.813
Body Temperature (°C)	36.250	0.256	36.163	0.130

Abbreviation: G1 = athlete group; G2 = non-athlete group.

Table 2.
Result (1)

	G1				G2			
	IRS	TRS	WWI	PAS	IRS	TRS	WWI	PAS
BLL (mmol/L)								
Pre	7.63 ± 2.65	6.56 ± 1.75	8.66 ± 2.28	7.90 ± 2.95	9.70 ± 1.58	8.01 ± 3.17	8.40 ± 2.98	8.71 ± 2.92
Post	3.75 ± 1.88[a]	4.33 ± 1.66[a]	3.19 ± 1.20[a]	4.11 ± 0.87[a]	4.88 ± 1.20[a]	4.63 ± 2.56[a]	3.93 ± 1.31[a]	5.85 ± 2.69
Post-40 min	2.83 ± 0.71[a]	2.69 ± 0.76[abc]	3.26 ± 0.98[a]	2.65 ± 0.62[ab]	3.04 ± 0.48[ab]	3.45 ± 0.59[a]	2.98 ± 1.16[ab]	3.41 ± 0.85[ab]
CKML (nmol/mL)								
Pre	1.09 ± 0.13	0.98 ± 0.39	0.93 ± 0.38	0.91 ± 0.40	0.56 ± 0.49	0.67 ± 0.55	0.49 ± 0.52	0.64 ± 0.61
Post-40 min	1.13 ± 0.18[c]	1.05 ± 0.42	1.02 ± 0.43	1.00. ± 0.42	0.63 ± 0.50	0.57 ± 0.46	0.55 ± 0.54	0.53 ± 0.52[a]
BGL (mg/dL)								
Pre	105.62 ± 20.82	105.13 ± 16.19	109.38 ± 22.16[c]	99.88 ± 30.17	98.25 ± 10.70	103.50 ± 22.68	94.75 ± 7.69	79.60 ± 33.03
Post	92.38 ± 10.14[c]	97.00 ± 12.07	90.25 ± 16.95[a]	96.50 ± 12.69	76.50 ± 8.37[ad]	89.38 ± 11.99	79.13 ± 22.27[d]	100.25 ± 11.71
Post-40 min	111.25 ± 14.59[b]	95.88 ± 27.79	118.75 ± 23.57[bc]	106.38 ± 17.38	95.38 ± 16.98[b]	96.63 ± 9.12	91.63 ± 10.64	87.13 ± 19.02
HR (bpm)								

Pre	108.88 ± 15.94	103.75 ± 4.3[c]	113.63 ± 16.85	107.88 ± 13.08	113.38 ± 14.48	119.25 ± 9.65	117 ± 9.18	107.25 ± 11.25
Post	89 ± 12.52[a]	86 ± 9.06[a]	91.25 ± 9.48[a]	88.12 ± 13.69[a]	90.75 ± 10.26[a]	94.5 ± 6.61[a]	94.63 ± 7.46[a]	91.25 ± 7.27[a]
Post-40 min	78.87 ± 10.49[ab]	75.5 ± 13.48[abc]	80.75 ± 7.44[abc]	80.88 ± 13.69[a]	85.88 ± 11.56[a]	94.13 ± 9.17[a]	90.38 ± 6.55[a]	83.13 ± 6.42[ab]
				VAS				
Post-40 min	1.75 ± 0.89	1.50 ± 1.51	1.63 ± 1.06	2.63 ± 1.77	2.13 ± 1.25	2.00 ± 1.93	1.25 ± 0.46[d]	3.0 ± 1.31
				BT (°C)				
Pre	36.14 ± 0.27	36.46 ± 0.23	36.25 ± 0.21	36.31 ± 0.36	36.18 ± 0.18	36.34 ± 0.20	36.31 ± 0.18	36.23 ± 0.19
Post	36.45 ± 0.21[a]	37.59 ± 0.62[a]	36.61 ± 0.27[a]	36.45 ± 0.26	36.41 ± 0.28	37.76 ± 0.57	36.53 ± 0.28[a]	36.38 ± 0.17
Post-40 min	36.54 ± 0.25[a]	36. 54 ± 0.31[b]	36.51 ± 0.31	36.60 ± 0.17[a]	36.44 ± 0.29	36.46 ± 0.30[a]	36.55 ± 0.21[b]	36.59 ± 0.34[a]

Abbreviation: IRS = infrared sauna; TRS = traditional sauna; WWI = warm water immersion; PAS = passive/sitting still; BLL = blood lactate level; CKML = creatine kinase of muscle level; BGL = blood glucose level; BT= body temperature; VAS= visual analog scale; [a] Indicates difference from pre ($p<0.05$); [b] Indicates difference from post ($p<0.05$); [c] Indicates difference compared to G2 ($p<0.05$); [d] Indicates difference compared to G2 PAS ($p<0.05$).

Table 2 shows the data results for all the variables. BLL variable G1 was significantly different before and after all modalities, whereas G2 was significantly different except for the PAS modality. There was a significant decrease from pre- to post-G1 (TRS, PAS) and pre- to post-G2 (IRS, WWI, PAS). All modalities played a role in reducing BLL after physical activity in both athletes and nonathletes.

There was an increase in CKML in G1 among all the modalities, although this increase was not significant. There was a significant decrease from pre- to post-40 min G2 of the PAS modality, and a significant difference post-40 min IRS modality between G1 and G2. The CKML levels tended to be greater in the athlete group than in the control group and tended to increase after 60 minutes of recovery. A unique result was that the PAS modality significantly reduced CKML in the nonathlete group. It seems that measurements taken 60 minutes after physical activity are not enough to reduce CKML. For future studies, follow-up measurements (Post-12 hours, Post-24 hours, etc.) for CKML should be conducted.

There was a decrease in the BGL after recovery in all modalities, except in the G2 modality of the PAS. There was a significant increase from post to post-40 minute G1 (IRS, WWI) and G2 (IRS). HR decreased after recovery. There was a significant decrease in HR after recovery for all modalities in both groups. VAS scores were significantly different between the WWI and PAS modalities in the nonathlete group. BT measurements revealed no significant difference between the groups in any of the modalities, as further shown in Figure 2.

Table 3.
Result (2)

	G1 (n=8)				G2 (n=8)			
	IRS	TRS	WWI	PAS	IRS	TRS	WWI	PAS
				BLL (mmol)				
Δ1	-3.88 ± 3.29	-2.24 ± 1.36[a]	-5.48 ± 2.77	-3.79 ± 2.71	-4.83 ± 1.57	-3.38 ± 2.17	-4.46 ± 3.51	-2.86 ± 3.11
Δ2	-0.93 ± 1.41	-1.64 ± 1.63	0.08 ± 1.79[b]	-1.46 ± 1.27	-1.84 ± 1.16	-1.19 ± 2.29	-0.96 ± 1.17	-2.44 ± 2.50
Δ3	-4.80 ± 2.95	-3.88 ± 1.74	-5.40 ± 1.66	-5.25 ± 2.85	-6.66 ± 1.78	-4.56 ± 2.88	-5.43 ± 2.89	-5.30 ± 2.74
				CKML (mmol)				
Δ3	0.04 ± 0.13	0.06 ± 0.18	0.09 ± 0.17	0.09 ± 0.15[c]	0.07 ± 0.11[cd]	-0.10 ± 0.23	0.06 ± 0.12[c]	-0.11 ± 0.10
				BGL (mg/dL)				
Δ1	-13.25 ± 24.09	-8.13 ± 22.34	-19.13 ± 23.45	-3.38 ± 31.72	-21.75 ± 14.18[c]	-14.13 ± 20.50[c]	-15.63 ± 24.61[c]	20.63 ± 35.81
Δ2	18.88 ± 13.62	-1.13 ± 37.23	28.50 ± 28.27	9.88 ± 21.06	18.88 ± 11.78[cd]	-6.88 ± 23.31	12.50 ± 22.76	-13.13 ± 27.27
Δ3	5.63 ± 14.81	-9.25 ± 29.63	9.38 ± 24.19	6.50 ± 19.52	-2.88 ± 16.54	-6.88 ± 23.31	-3.13 ± 11.91	7.50 ± 29.87
				HR (dpm)				
Δ1	-19.88 ± 11.64	-17.75 ± 11.07	-22.38 ± 11.45	-19.75 ± 9.98	-22.63 ± 16.73	-24.75 ± 10.57	-22.38 ± 8.96	16 ± 8.64
Δ2	-10.13 ± 10.32	-10.5 ± 12.82	-10.5 ± 7.84	-7.25 ± 13.63	-4.88 ± 5.36	-0.38 ± 11.59	-4.25 ± 7.62	-8.13 ± 8.63
Δ3	-30 ± 12.38	-27.5 ± 20.93	-32.88 ± 11.28	-27 ± 9.97	-27.5 ± 20.93	-25.13 ± 11.41	-26.63 ± 12.75	-24.13 ± 8.94
				BT (°C)				
Δ1	0.31 ± 0.33	1.13 ± 0.57	0.36 ± 0.32	0.14 ± 0.3	0.24 ± 0.36	1.43 ± 0.63	0.21 ± 0.37	0.15 ± 022
Δ2	0.09 ± 0.27	-1.05 ± 0.64	-0.1 ± 0.49	0.15 ± 0.19	0.03 ± 0.19	-0.13 ± 0.74	0.03 ± 0.35	0.21 ± 0.39
Δ3	0.4 ± 0.38	0.08 ± 0.18	0.26 ± 0.35	0.29 ± 0.31	0.26 ± 0.2	0.13 ± 0.24	0.24 ± 0.21	0.36 ± 0.35

Abbreviation: Δ1 = changes from pre to post measurement; Δ2 = changes from post to post-40 min measurement; Δ3 = changes from pre to post-40 min measurement; [a] Indicates difference compared to G1 WWI ($p<0.05$); [b] Indicates difference compared to G1 PAS ($p<0.05$); [c] Indicates difference compared to G2 PAS ($p<0.05$); [d] Indicates difference compared to G2 TRS ($p<0.05$).

There was a significant difference in the Δ1 BLL in TRS modality G1 with WWI, and Δ2 BLL in WWI modality G1 with PAS. There was a significant difference in the Δ3 CKML of the PAS modality between G1 and G2. The greatest decrease in CKML was found in G2 of the PAS modality. In the BGL, there was a significant difference in Δ1 among G2 IRS, TRS, and WWI modalities with the PAS, and in Δ2 among the G2 IRS modality with the PAS and the IRS modality with the TRS. No significant difference was found in the ΔHR or BT. Figure 2 shows the fluctuations body temperature during recovery from each modality. The largest increase in body temperature occurred in the TRS modality. The heat vapor produced is responded to by the body to perform a thermoregulation mechanism by raising the body's core temperature.

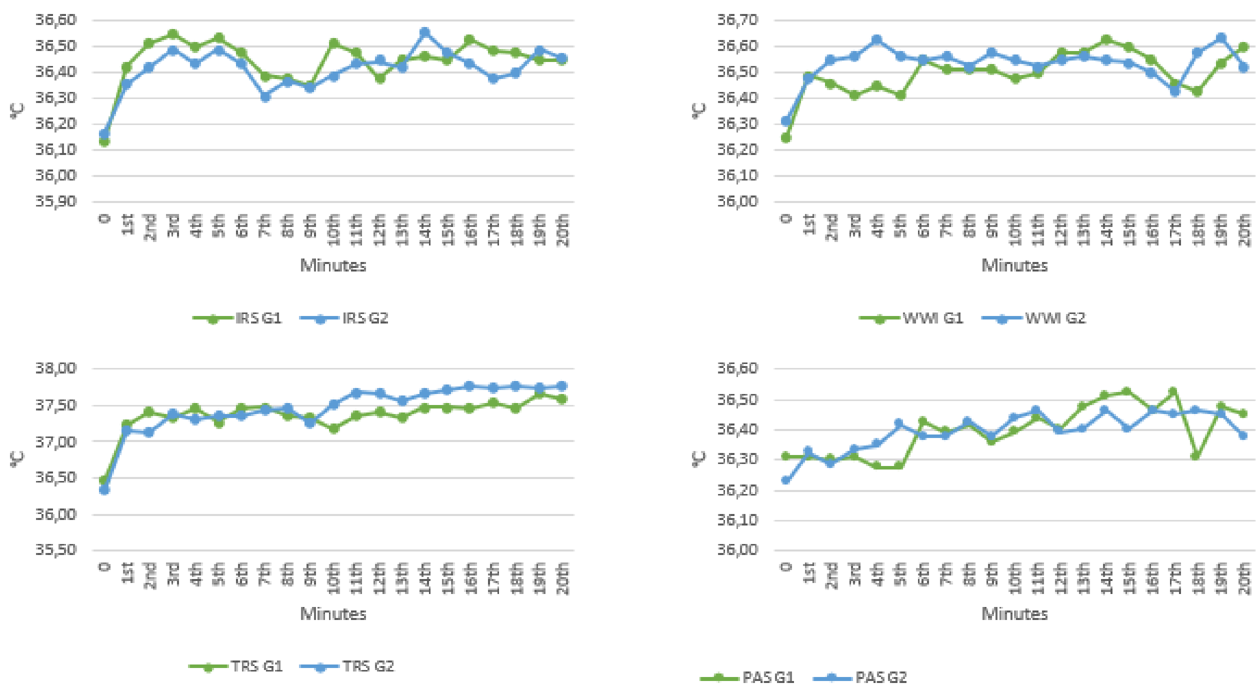

Figure 2. Changes in body temperature

Discussion

BLL

All the modalities were shown to reduce the BLL as a marker of fatigue, and no significant differences were found between all the modalities. In the athlete group, the largest decrease was in the WWI modality, and the nonathlete group was in the IRS modality. The decrease was very fast when the subject soaked (Δ1) in the WWI modality in both groups, but after the subject left the pool (Δ2), only a slight decrease occurred. It seems that WWI is effective in reducing the BLL when the subject continues to soak. Research with a longer period could be the answer. WWI is effective in facilitating recovery from muscle fatigue. The mean power frequency (MNF) on electromyography (EMG) revealed that the rectal temperature, skin blood flow, and oxygenated hemoglobin concentration were significantly greater (Lee et al., 2012). When the body is immersed, water exerts a compressive force on the body (hydrostatic pressure). This pressure can cause the displacement of fluid within a person's body from the extremities toward the central cavity, thereby increasing the translocation of substrates from the muscles, increasing cardiac output, reducing peripheral resistance, and improving the body's ability to transport substrates (Wilcock et al., 2006). This may allow WWI to properly modulate recovery.

The BLL of the IRS and TRS modalities in the athlete group tended not to differ, although the decrease in the IRS was greater. This finding is in line with a previous study that reported no difference in the BLL after recovery between the IRS and TRS modalities (Mero et al., 2015). In the nonathlete group, the decrease in BLL was greatest in the IRS modality. Some studies have also revealed that FIR therapy is effective in accelerating recovery from muscle damage (Chen et al., 2023; Hsieh et al., 2022; Tsagkaris et al., 2022). The function of infrared saunas is based on the warming effect of infrared radiation. Heat has the potential to enhance recovery after exercise by increasing blood circulation and decreasing the stress state of the body (Noponen et al., 2015; Sawka et al., 1993). Exposure can increase blood flow to the skin by widening blood vessels (vasodilation), which can increase the supply of oxygen and nutrients to tissues (Joyner & Casey, 2015).

CKML

An increase in CKML was found in all modalities of the athlete group, with the smallest increase in the IRS modality. A decrease in CKML was found in the PAS modality of the nonathlete group; this decrease was also found in the TRS modality, although it was not significant. It appears that PAS and TRS can reduce CKML in nonathletes after 60 minutes of physical activity. In contrast, other modalities tend to cause CKML to increase. Similarly, infrared exposure did not affect CK activity (Hausswirth et al., 2011). Furthermore, there was no significant effect (CKML, CK, LDH, leukocytes, haematocrit, pain, etc.) with WWI administration (Pournot et al., 2011). Another study reported a decrease in CK after-48 of WWI (Vaile et al., 2008b). Perhaps the effect of other modalities on reducing CK requires a longer time. Follow-up measurements are needed for future studies, such as post-12 hours and post-48 hours, to clarify the conflicting findings.

There was a significant difference in the Δ3 CKML between the nonathlete group of the IRS modality and the TRS and PAS. Groups compared with TRS and PAS, IRS may not be affective at preventing muscle cell damage. This was shown by the greatest increase in CKML in this group.

BGL

A decrease in the BGL occurred in all modalities, except for the PAS modality in the nonathlete group, which increased the BGL after sitting still for 20 minutes. The smallest decrease in the PAS score was found in the nonathlete group. The thermal modality seems to use more energy than PAS does. This is possible with the provision of thermal modalities, as the heat received will cause the body's thermoregulatory response, which results in increased body metabolism. Heat exposure positively affects glucose metabolism, increasing insulin-stimulated glucose uptake (Gupte et al., 2011; Pallubinsky et al., 2020). More effective heat is delivered to muscles, blood vessels, and nerves, which can reduce tissue temperature loss, facilitate muscle circulation and metabolism, and reduce peripheral nerve excitability (Wang et al., 2021). This may have a positive impact on accelerating recovery.

HR

All modalities are effective in reducing HR significantly, and there is no difference in the decrease in HR across modalities. The greatest decrease occurred in the WWI and IRS modalities of the athlete group. It seems that WWI is effective in reducing HR in the athlete group, which is in line with the decrease in the BLL.

VAS

The degree of pain experienced after the administration of recovery modalities was assessed via the VAS. The results revealed that the least amount of pain was felt in the WWI modality in both groups and that the PAS modality tended to cause severe pain. Immersion will provide a buoyancy effect so that there is a reduction in the force of gravity on the musculoskeletal system, thus allowing greater relaxation of the muscles of gravity and energy conservation (Vaile et al., 2008a). By taking a warm bath, the effect felt by the subjects was not only relaxed and comfortable, but also more refreshing than the effects of the IRS and TRS, which tend to cause profuse sweat excretion. This is likely to reduce perceived fatigue. The decrease in perceived fatigue is due not only to a reduced neuromuscular response during water immersion (Koryak, 2002; Pöyhönen & Avela, 2002) but also to an overall decrease in neurotransmission (Vaile et al., 2008a).

BT

BT measurements were not significant different among the modalities. There was a significant increase after modality administration, except in the IRS modality of the nonathlete group. IRS administration did not cause changes in the subject's BT. IRS provides a calming experience with a lighter and more comfortable feel with exposure to temperatures that are not too hot (Mero et al., 2015). Although sauna radiation was given up to 45ºC, the heat felt by the subjects was less pronounced and users sweated more at lower temperatures with the IRS than with the TRS (Beever, 2009). This is in line with the results of the present study, where the greatest increase in BT after modality administration was found in the TRS modality of all groups.

TRS sauna exposure elicits mild hyperthermia, an increase in core body temperature that induces a thermoregulatory response involving neuroendocrine, cardiovascular, and cytoprotective mechanisms that participate in restoring homeostasis and conditioning the body to address future stressors (J. A. Laukkanen et al., 2018). Exposure to high temperatures places stress on the body, eliciting a rapid and strong response that primarily affects the skin and cardiovascular system (Gravel et al., 2021; Kukkonen-Harjula & Kauppinen, 2006; Kunutsor et al., 2021). At the same time, approximately 50–70% of the body's circulation is redistributed from the body's core to the skin to facilitate sweating, thus causing fluid loss at a rate of approximately 0.6–1.0 kg per hour, averaging approximately 0.5 kg at moderate temperatures (80°C to 90°C) (Gravel et al., 2021; J. A. Laukkanen et al., 2019; T. Laukkanen et al., 2015; Podstawski et al., 2014). Interestingly, after the TRS session is over, BT tends to decrease and stabilize after sitting still (40 min), which is equivalent to other thermal modalities.

Conclusion

The WWI in athletes and the IRS in nonathletes were effective at reducing fatigue, as shown by decreases in the BLL and HR. PAS and TRS can prevent muscle damage in nonathletes 60 minutes after physical activity, and further measurements are needed (12 hours and 48 hours after physical activity) to clarify the findings. All thermal modalities reduce the BGL, possibly because the heat received will cause the body's thermoregulatory response which results in increased body metabolism, which will have a positive impact on recovery. The least pain was felt in the WWI modality in both groups, and the PAS modality tended to cause severe pain. BT measurements were not significantly different among the modalities. The greatest increase in BT occurred after the administration of recovery modalities in TRS. A unique finding was that after the TRS session was over, BT tended to decrease and stabilize after sitting still (40 minutes) on par with other thermal modalities. These findings suggest that the WWI is preferable for athletes. IRS and TRS are more effective for recovery in non-athletes. Further research needs to be conducted with different sports subjects, different types of exercise, different biomarkers, and physical performance tests.

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