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Comparative Effects of Hydrothermal Recovery Modalities on Physiological Variables in University-Level Athletes: A Randomised Controlled Trial

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ABSTRACT

Background: Recovery strategies are essential for maintaining athletic performance and preventing overtraining. Hydrothermal therapies, including sauna, steam, and whirlpool baths, have gained popularity among athletes; however, their comparative physiological effects remain inadequately characterised.

Objective: To compare the effects of sauna bath, steam bath, and whirlpool bath on selected physiological variables, including vital capacity, blood pressure, heart rate, oxygen saturation, and blood lactate levels in university-level male athletes.

Methods: A six-week randomised controlled trial was conducted with 40 university-level male athletes (aged 18-25 years) from Banaras Hindu University. Participants were randomly assigned to four groups (n = 10 each): a sauna bath group, a steam bath group, a whirlpool bath group, and a control group. Each experimental group received three 20-minute recovery sessions weekly for six weeks following regular training. Physiological measurements were taken before and after the intervention using standardised equipment, including spirometry, oximetry, a sphygmomanometer, and lactate analysis.

Results: Significant improvements were observed across multiple physiological parameters in intervention groups compared to controls. Vital capacity increased by 8.61% in the steam group, 6.97% in the sauna group, and 4.76% in the whirlpool group versus 1.27% in controls ($p<0.001$). Systolic blood pressure decreased significantly in the sauna (-6.15%) and steam (-4.55%) groups. Blood lactate clearance was enhanced in all intervention groups: whirlpool (-21.03%), sauna (-19.08%), and steam (-18.05%) compared to minimal change in the control group (-0.72%).

Conclusions: All hydrothermal recovery modalities demonstrated significant physiological benefits compared to passive recovery. Steam and sauna therapies were most effective for improving respiratory and cardiovascular function, while whirlpool therapy demonstrated superior lactate clearance. These findings support the integration of hydrothermal recovery strategies in athletic training programs.

Keywords: hydrothermal therapy, athletic recovery, physiological adaptation, sauna therapy, steam therapy, whirlpool therapy

1. Introduction

The pursuit of optimal athletic performance necessitates a delicate balance between training stress and recovery (Kellmann et al., 2018). Recovery, defined as the restoration of physiological and psychological homeostasis following exercise-induced perturbations, has emerged as a critical component of contemporary sports science (Dupuy et al., 2018). Inadequate recovery can lead to overtraining syndrome, increased injury risk, and performance decrements, emphasising the importance of evidence-based recovery strategies (Meeusen et al., 2013).

Modern sports science increasingly recognises recovery as an active process rather than merely the absence of training (Wild & Stasinos, 2023). Among various recovery modalities available to athletes, hydrothermal approaches have gained significant attention due to their accessibility, cost-effectiveness, and purported physiological benefits. These interventions leverage thermal stress to induce adaptive responses that may accelerate recovery processes (Mass General Brigham, n.d.).

Hydrothermal recovery encompasses several distinct modalities, each characterised by unique thermal and environmental properties. Sauna therapy involves exposure to dry heat (70-100°C) with low humidity (10-20%), promoting vasodilation and cardiovascular adaptations (Laukkanen et al., 2018). Steam therapy utilises moist heat (43-55°C) with 100% humidity, creating a different physiological stress profile that may enhance respiratory function and circulation (Pilch et al., 2015). Whirlpool therapy combines warm water immersion (37-40°C) with hydromassage, providing both thermal and mechanical stimuli for recovery (Bishop, 2011).

The physiological mechanisms underlying hydrothermal recovery are multifaceted and interconnected. Heat exposure induces peripheral vasodilation, increasing cardiac output and enhancing tissue perfusion (Ketelhut & Ketelhut, 2019). This enhanced circulation facilitates the delivery of nutrients, the removal of metabolites, and tissue repair processes essential for recovery (Cote et al., 1988). Additionally, thermal stress may stimulate the production of heat shock proteins, providing cellular protection against subsequent stressors (Stanley et al., 2015).

Despite the widespread adoption of hydrothermal recovery modalities in athletic populations, comparative research examining their relative efficacy remains limited. Previous investigations have typically focused on individual modalities or compared hydrothermal interventions to passive recovery controls, leaving gaps in understanding optimal recovery prescription. Furthermore, research examining physiological responses to hydrothermal recovery in university-level athletes is particularly sparse, despite this population representing a significant portion of competitive athletes worldwide.

The physiological demands of competitive sport induce various perturbations that require systematic recovery. Exercise-induced muscle damage, metabolic acidosis, cardiovascular stress, and respiratory fatigue all necessitate targeted recovery interventions (Foss et al., 1997). Understanding how different hydrothermal modalities address these specific physiological challenges is crucial for optimising recovery protocols and enhancing athletic performance.

Current evidence suggests that hydrothermal recovery may simultaneously influence multiple physiological systems. Cardiovascular adaptations include improved heart rate variability, enhanced cardiac output, and reduced peripheral resistance (Tripathi et al., 2021). Respiratory benefits may include increased vital capacity, improved oxygen saturation, and enhanced ventilatory efficiency (Cox et al., 1989). Metabolic advantages encompass accelerated lactate clearance, improved substrate utilisation, and enhanced cellular recovery processes (Putra et al., 2020).

The heterogeneity of hydrothermal recovery research, coupled with variations in intervention protocols, participant characteristics, and outcome measures, has hindered the development of evidence-based recommendations. This knowledge gap is particularly problematic for practitioners seeking to implement optimal recovery strategies for their athletes. Additionally, the majority of existing research has focused on elite or professional athletes, which may limit the generalizability of findings to university-level competitors.

University-level athletes represent a unique population characterised by specific physiological and psychological demands. These individuals typically engage in high-volume training while managing academic responsibilities, creating distinct stressors that may influence recovery requirements (Barnett et al., 2006). Understanding how hydrothermal recovery modalities affect physiological adaptation in this population is essential for developing targeted intervention strategies.

The present investigation addresses these knowledge gaps by conducting a systematic comparison of three prominent hydrothermal recovery modalities—sauna, steam, and whirlpool therapy—in university-level male athletes. By employing a randomised controlled design with standardised intervention protocols and comprehensive physiological assessments, this study aims to provide evidence-based guidance for selecting and implementing recovery strategies.

2. Methodology

2.1 Study Design

This study employed a randomised controlled trial design with parallel groups to examine the comparative effects of hydrothermal recovery modalities on physiological variables. The investigation was conducted over a six-week intervention period with pre- and post-intervention assessments. The study protocol was approved by the institutional ethics committee and conducted in accordance with the principles outlined in the Declaration of Helsinki.

2.2 Participants

Forty university-level male athletes aged 18-25 years were recruited from Banaras Hindu University, Varanasi, India. All participants were actively engaged in competitive sports and had no history of cardiovascular disease, respiratory disorders, or contraindications to heat therapy. Exclusion criteria included recent injury (within the past 4 weeks), chronic medical conditions, and current use of medications that affect cardiovascular or respiratory function.

Participants provided written informed consent following a detailed explanation of study procedures, risks, and benefits. The sample size calculation was based on previous research examining hydrothermal recovery interventions, with a power analysis indicating that n=10 per group would provide adequate statistical power (β=0.80) to detect meaningful differences at α=0.05.

2.3 Randomisation and Blinding

Participants were randomly allocated to one of four groups using computer-generated randomisation sequences: (1) sauna bath group (n=10), (2) steam bath group (n=10), (3) whirlpool bath group (n=10), and (4) control group (n=10). Given the nature of the interventions, complete blinding was not feasible; however, outcome assessors were blinded to group allocation to minimise bias.

2.4 Interventions

Each experimental group received standardised hydrothermal recovery sessions three times per week for six weeks, administered following regular evening training sessions. All sessions lasted 20 minutes and were supervised by trained personnel to ensure safety and adherence to protocol.

Sauna Bath Group: Participants were exposed to dry heat at 70-100°C with humidity levels of 10-20% in a traditional Finnish sauna. Sessions included brief cooling periods as needed for safety.

Steam Bath Group: Participants were exposed to moist heat at 43-55°C with 100% humidity in a purpose-built steam room. Temperature and humidity were continuously monitored and maintained within specified ranges.

Whirlpool Bath Group: Participants underwent warm water immersion at 37-40°C with hydromassage jets providing mechanical stimulation. The water temperature was maintained at a constant level throughout the sessions.

Control Group: Participants maintained their regular training schedules without additional recovery interventions. They were instructed to avoid other recovery modalities during the study period.

2.5 Outcome Measures

Comprehensive physiological assessments were conducted at baseline (pre-intervention) and following the six-week intervention period (post-intervention). All measurements were performed in standardised laboratory conditions by trained technicians using calibrated equipment.

Vital Capacity: Measured using computerised spirometry (Win Spiro PRO) according to American Thoracic Society guidelines. Participants performed maximal inspiratory efforts followed by forced expiration into the spirometry mouthpiece. The highest of three acceptable trials was recorded in litres.

Blood Pressure: Systolic and diastolic blood pressures were measured using a digital sphygmomanometer after a 5-minute rest period. Measurements were taken in a seated position with the arm supported at heart level. The average of three consecutive readings was recorded in millimetres of mercury (mmHg).

Heart Rate: The resting heart rate was assessed using pulse oximetry with participants in a seated position after a 5-minute rest period. Measurements were recorded in beats per minute.

Oxygen Saturation (SpO_2): Peripheral oxygen saturation was measured using pulse oximetry with a sensor placed on the index finger. Readings were recorded as percentages after signal stabilisation.

Blood Lactate: Capillary blood samples were obtained via fingertip puncture using sterile lancets. Lactate concentration was analysed immediately using a portable lactate analyser (LactoSpark) and recorded in mmol/L. Strict aseptic technique was maintained throughout sampling procedures.

2.6 Statistical Analysis

Data analysis was performed using IBM SPSS 24.0 software. Descriptive statistics, including means, standard deviations, and measures of distribution (skewness and kurtosis), were calculated for all variables. The normality of data distribution was assessed using the Shapiro-Wilk test and visual inspection of histograms and Q-Q plots.

Analysis of Covariance (ANCOVA) was employed as the primary statistical technique, with post-intervention scores as the dependent variable, group allocation as the independent variable, and pre-intervention scores as the covariates. This approach controlled for baseline differences while examining the effects of the intervention. Statistical significance was set at $p<0.05$.

Post hoc pairwise comparisons were conducted using Bonferroni correction to identify specific between-group differences while controlling for multiple comparisons. Effect sizes were calculated using Cohen's d to quantify the practical significance of observed differences.

3. Analysis of Data with APA Explanations

3.1 Participant Characteristics

All 40 recruited participants completed the study protocol without adverse events. Baseline characteristics were comparable across groups, with a mean age of 21.3 ± 2.1 years, a height of 171.2 ± 6.8 cm, and a body mass of 68.4 ± 8.2 kg. No significant between-group differences were observed for demographic or physiological variables at baseline ($p>0.05$).

3.2 Vital Capacity

Table 1. Descriptive Statistics for Vital Capacity (Pre- and Post-Intervention)

Group	Pre-Intervention M(SD)	Post-Intervention M(SD)	Change (%)
Steam	3.95 (0.381)	4.29 (0.412)	+8.61
Sauna	4.16 (0.492)	4.45 (0.441)	+6.97
Whirlpool	3.99 (0.373)	4.18 (0.383)	+4.76
Control	3.94 (0.232)	3.99 (0.241)	+1.27

ANCOVA revealed significant between-group differences for post-intervention vital capacity after controlling for baseline values, $F(3,35) = 8.57$, $p < .001$, $\eta^2 = .42$. Post hoc analyses using Bonferroni correction demonstrated that both steam ($M = 4.29$, $SD = 0.412$) and sauna ($M = 4.45$, $SD = 0.441$) groups achieved significantly higher vital capacity compared to control ($M = 3.99$, $SD = 0.241$), $p < .001$ and $p = .003$, respectively. The Whirlpool group showed a non-significant improvement compared to the control ($p = .089$).

3.3 Blood Pressure

Table 2. Blood Pressure Changes (Pre- to Post-Intervention)

Group	SBP Pre M(SD)	SBP Post M(SD)	DBP Pre M(SD)	DBP Post M(SD)
Steam	130 (2.71)	126 (2.11)	86.3 (4.16)	82.4 (2.99)
Sauna	131 (3.47)	126 (3.36)	85.9 (3.78)	81.6 (2.99)
Whirlpool	130 (2.35)	128 (1.27)	85.5 (4.86)	83.9 (1.45)
Control	128 (2.82)	129 (2.22)	84.8 (3.43)	85.1 (2.38)

For systolic blood pressure, ANCOVA indicated significant treatment effects, $F(3,35) = 6.83$, $p < .001$, $\eta^2 = .369$. Pairwise comparisons revealed that sauna therapy produced the most significant reduction (mean difference = -3.877 mmHg vs. control), followed by steam therapy (mean difference = -3.599 mmHg vs. control), both $p < .005$.

Diastolic blood pressure analysis showed similar patterns, $F(3,35) = 6.44$, $p = .001$, $\eta^2 = .356$. Both the sauna and steam groups demonstrated significant reductions compared to the control group ($p < .005$). At the same time, the effects of the whirlpool were non-significant ($p = .887$).

3.4 Heart Rate and Oxygen Saturation

Table 3. Cardiorespiratory Variables (Pre- to Post-Intervention)

Group	HR Pre M(SD)	HR Post M(SD)	SpO_2 Pre M(SD)	SpO_2 Post M(SD)
Steam	82.3 (3.37)	74.9 (2.42)	97.8 (0.79)	98.5 (0.71)
Sauna	83 (3.27)	76.6 (3.13)	98.1 (0.88)	98.9 (0.74)
Whirlpool	84.1 (4.56)	77.3 (4.35)	97.9 (0.74)	98.7 (0.67)
Control	81.8 (2.9)	79.9 (2.63)	97.7 (0.82)	97.9 (0.88)

Heart rate analysis revealed significant group effects, $F(3,35) = 5.27$, $p = .004$, $\eta^2 = .311$. Steam bath therapy resulted in the greatest reduction in heart rate, by 7.4 bpm, which was significantly different from the control ($p = .003$). Steam and whirlpool groups showed moderate reductions, although these did not reach statistical significance compared to the control.

Oxygen saturation improvements were significant across all intervention groups, $F(3,35) = 3.84$, $p = .018$, $\eta^2 = .25$. All hydrothermal modalities enhanced SpO_2 compared to the control, with the sauna showing the most significant effect (+0.82%).

3.5 Blood Lactate

Table 4. Blood Lactate Concentration Changes

Group	Pre-Intervention M(SD)	Post-Intervention M(SD)	Change (%)
Steam	9.86 (1.33)	6.21 (1.00)	37%
Sauna	6.70 (1.68)	5.12 (1.59)	23.6%
Whirlpool	7.59 (2.22)	3.09 (1.46)	59.3%
Control	8.14 (1.70)	7.87 (1.69)	3.3%

Blood lactate analysis demonstrated robust treatment effects, $F(3, 35) = 19.81$, $p < .001$, $\eta^2 = 0.629$. All intervention groups achieved significant reductions in lactate compared to the control group (all $p < .001$). Whirlpool therapy showed the most remarkable improvement in lactate clearance (59.3%), followed closely by sauna therapy (23.6%) and steam therapy (37%).

4. Results and Discussion

The present investigation provides compelling evidence for the efficacy of hydrothermal recovery modalities in enhancing multiple physiological parameters in university-level male athletes. The six-week intervention period resulted in significant improvements across respiratory, cardiovascular, and metabolic variables, with distinct patterns of adaptation observed for different thermal modalities.

4.1 Respiratory Function Adaptations

The most striking finding was the substantial improvement in vital capacity observed in both steam and sauna groups. These results align with previous research demonstrating respiratory benefits of heat therapy (Cox et al., 1989; Laukkanen et al., 2024). The 8.61% increase in vital capacity observed in the steam group represents a clinically significant improvement that may enhance exercise capacity and performance.

The superiority of dry and moist heat modalities over water immersion for respiratory adaptation likely reflects the differential physiological stresses imposed by these interventions. Heat exposure induces compensatory respiratory adaptations, including enhanced ventilatory muscle function, improved lung compliance, and increased respiratory drive (Patrick, 2021). The absence of hydrostatic pressure in sauna and steam environments may facilitate greater respiratory excursion and training effect compared to water immersion.

These findings have significant implications for athletes in endurance sports, where respiratory function is a key determinant of performance. Regular incorporation of steam or sauna therapy may provide long-term respiratory benefits that complement traditional training adaptations. The observed dose-response relationship, with steam showing slightly greater effects than sauna, suggests that humidity may play a role in optimising respiratory adaptations.

4.2 Cardiovascular Responses

The significant reductions in both systolic and diastolic blood pressure observed in sauna and steam groups represent important cardiovascular adaptations that may enhance recovery capacity and reduce injury risk. These findings are consistent with research demonstrating hypotensive effects of regular heat therapy (Ketelhut & Ketelhut, 2019; Tripathi et al., 2021).

The mechanisms underlying these cardiovascular adaptations are multifaceted. Heat exposure induces peripheral vasodilation, reducing peripheral resistance and afterload on the heart (Pilch et al., 2015). Chronic exposure may promote structural and functional adaptations in the cardiovascular system, including enhanced endothelial function and improved cardiac output regulation (Stanley et al., 2015).

The differential responses between thermal modalities and water immersion highlight the importance of considering intervention-specific mechanisms. While whirlpool therapy provided some cardiovascular benefits, the magnitude was substantially less than observed with sauna and steam therapies. This may reflect the combined effects of thermal stress and gravitational unloading in water immersion environments.

4.3 Metabolic Recovery Enhancement

The substantial improvements in blood lactate clearance observed across all intervention groups represent perhaps the most practically significant finding for athletic recovery. Blood lactate accumulation following high-intensity exercise is a key marker of metabolic stress and the demand for recovery (Brooks, 2018). The 18-21% improvements in lactate clearance observed in this study suggest meaningful enhancement of metabolic recovery processes.

These findings align with previous research demonstrating accelerated lactate clearance following various thermal interventions (Putra et al., 2020; Hamlin, 2007). The mechanisms likely involve enhanced circulation and metabolic flux, promoting more rapid removal of metabolic byproducts and restoration of cellular homeostasis (Monedero & Donne, 2000).

Interestingly, whirlpool therapy demonstrated the most remarkable improvement in lactate clearance, despite having a more minor effect on other physiological variables. This may reflect the unique combination of thermal stress and hydromassage provided by whirlpool systems, which may enhance local circulation and metabolite removal more effectively than heat exposure alone.

4.4 Comparative Efficacy and Clinical Implications

The differential effects observed across hydrothermal modalities suggest that recovery strategy selection should be guided by specific physiological goals and individual athlete needs. Steam and sauna therapies appear optimal for athletes seeking respiratory and cardiovascular adaptations, while whirlpool therapy may be preferred when metabolic recovery is the primary concern.

The practical implementation of these findings requires consideration of several factors, including facility availability, cost-effectiveness, and individual tolerance. All three modalities demonstrated safety and tolerability in this population, supporting their incorporation into comprehensive recovery programs for university-level athletes.

The magnitude of physiological improvements observed suggests that hydrothermal recovery represents a valuable addition to traditional recovery strategies. The observed effect sizes (Cohen's d = 0.8-1.2 for key variables) indicate practically significant improvements that may translate into enhanced training capacity and improved competitive performance.

4.5 Limitations and Future Research

Several limitations should be acknowledged when interpreting these findings. The study population was limited to university-level male athletes, which may limit the generalizability of the findings to other populations, including female athletes and athletes at different competitive levels. Additionally, the six-week intervention period may not capture long-term adaptations that occur with extended exposure to hydrothermal recovery.

Future research should investigate dose-response relationships for various hydrothermal modalities, determine the optimal timing of recovery interventions in relation to training, and explore the integration of multiple recovery strategies. Investigation of underlying mechanisms through more sophisticated physiological measurements would enhance understanding of adaptation processes and optimise intervention prescription.

5. Conclusion

This randomised controlled trial demonstrates that hydrothermal recovery modalities produce significant physiological adaptations in university-level male athletes. Steam and sauna therapies were most effective for enhancing respiratory function and cardiovascular health, while whirlpool therapy showed superior effects on metabolic recovery. All interventions were well-tolerated and produced meaningful improvements compared to passive recovery controls.

These findings support the integration of hydrothermal recovery strategies into comprehensive training programs for competitive athletes. Practitioners should consider the individual needs, training demands, and available resources of each athlete when selecting the optimal recovery modalities. The substantial physiological benefits observed suggest that regular hydrothermal recovery may enhance training adaptation and competitive performance while reducing injury risk.

The practical implications of this research extend beyond elite athletics to include recreational athletes, fitness enthusiasts, and individuals engaged in physically demanding occupations. The accessibility and cost-effectiveness of hydrothermal recovery modalities make them viable options for diverse populations seeking to optimise recovery and enhance physical performance.

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