Comparative Efficacy of Land- and Water-Based Active and Passive Recovery Modalities on Post-Exercise Cardiorespiratory and Metabolic Recovery in Male Swimmers

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ABSTRACT

Rapid post-exercise recovery is essential in swimming because repeated high-intensity efforts impose substantial cardiovascular, respiratory, and metabolic stress. This study compared the effects of active land-based recovery (ALR), active water-based recovery (AWR), passive land-based recovery (PLR), and passive water-based recovery (PWR) on heart rate, breathing rate, and blood lactate concentration following maximal swimming exercise. Forty male state-level swimmers aged 25–30 years from Rewa District, Madhya Pradesh, were assigned to ALR, AWR, PLR, or PWR groups, with 10 participants per group. Following a 200-m continuous maximal-intensity swim, participants completed 20 minutes of their assigned recovery modality. Heart rate, breathing rate, and blood lactate concentration were assessed before swimming, immediately after swimming, and after recovery. Data were analyzed using mixed repeated-measures analysis of variance with Greenhouse–Geisser corrections where required. Significant main effects of time were observed for heart rate, breathing rate, and blood lactate concentration (all $p < .001$). Significant time × recovery-modality interactions were also found for heart rate ($F = 138.301$, $p < .001$, partial $\eta^2 = .920$), breathing rate ($F = 17.056$, $p < .001$, partial $\eta^2 = .587$), and blood lactate concentration ($F = 22.380$, $p < .001$, partial $\eta^2 = .651$). After 20 minutes, AWR showed the lowest mean heart rate (99.50 ± 4.38 beats·min⁻¹), breathing rate (22.30 ± 1.42 breaths·min⁻¹), and blood lactate concentration (4.11 ± 0.39 units). Bonferroni-adjusted comparisons indicated significantly lower overall heart rate and blood lactate concentration in AWR than PLR ($p = .004$ and $p = .011$, respectively). No significant adjusted between-modality comparison was observed for breathing rate. Active water-based recovery was the most effective modality for facilitating post-exercise cardiovascular and metabolic recovery in the studied swimmers, particularly when compared with passive land-based recovery.

Keywords: *Active land-based, Active water based, Passive land based, Passive water based, Recovery Modality, Heart rate, Breathing rate, Blood lactate.*

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INTRODUCTION

Swimming is a highly demanding aquatic sport that requires the coordinated contribution of the cardiovascular, respiratory, and muscular systems (Holmér, 1992). During training and competition, swimmers perform repeated bouts of high-intensity exercise that place considerable physiological stress on the body (Hawley et al., 1997). The ability to recover rapidly following strenuous exercise is therefore an important component of swimming performance. Effective recovery helps restore physiological functions, reduces fatigue, and prepares the athlete for subsequent training or competition (Kellmann et al., 2018). Consequently, the selection of an appropriate recovery modality has become an important consideration in sports training and performance management.

Recovery methods used by athletes can broadly be classified according to the nature of activity and the environment in which recovery is performed. Active recovery involves low- to moderate-intensity physical activity performed after strenuous exercise (Bishop et al., 2008),

whereas passive recovery involves resting with minimal or no physical activity (Cullen et al., 2021). These approaches can further be performed on land or in water. Active land-based recovery may include light walking, jogging, stretching, or other low-intensity movements (Ortiz et al., 2018), while active water-based recovery may involve gentle swimming or aquatic movements (Vaile & Gill, 2007). Passive land-based recovery generally consists of seated or supine rest on land (Dupuy et al., 2018), whereas passive water-based recovery involves resting or performing minimal movement while immersed in water (Elias, & Varley, 2010). Each modality may influence physiological recovery through different mechanisms, including changes in circulation, respiratory function, muscle activity, and metabolic clearance (Barnett, 2006).

Cardiorespiratory and metabolic variables are important indicators for assessing post-exercise recovery following high-intensity swimming. In the present study, heart rate, breathing rate, and blood lactate concentration were selected to evaluate the recovery responses associated with different recovery modalities (Bishop et al., 2008; Dupuy et al., 2018). Heart rate was used as an indicator of cardiovascular recovery, reflecting changes in cardiovascular demand following strenuous exercise, while breathing rate served as an indicator of respiratory recovery in response to increased oxygen demand and carbon dioxide removal during intense physical activity. Blood lactate concentration was selected as a metabolic indicator to assess exercise-induced lactate accumulation and its subsequent decline during recovery (Brooks, 1986; Devlin et al., 2014). The combined assessment of these variables provides a broader understanding of cardiovascular, respiratory, and metabolic responses following maximal swimming exercise. Comparing these responses across active land-based, active water-based, passive land-based, and passive water-based recovery modalities may help identify an appropriate recovery strategy for swimmers (Barnett, 2006; Kellmann et al., 2018).

The effectiveness of a recovery modality can be assessed through several physiological indicators (Dupuy et al., 2018). Heart rate is a commonly used measure because it reflects cardiovascular stress and the rate at which the cardiovascular system returns toward its resting state following exercise. A faster decline in heart rate after strenuous exercise may indicate more efficient cardiovascular recovery. Breathing rate is another important indicator, as strenuous exercise increases the demand for oxygen and the removal of carbon dioxide. The return of breathing rate toward baseline can therefore provide information about respiratory recovery. In addition, blood lactate concentration is an important metabolic indicator of exercise-induced fatigue and recovery (Devlin et al., 2014). High-intensity exercise can result in an increased accumulation of lactate in the blood (Brooks, 1986; Gladden, 1996)., and the subsequent decline in blood lactate can be used to evaluate the effectiveness of different recovery strategies in facilitating post-exercise metabolic recovery.

For swimmers, the comparison of land- and water-based recovery methods is particularly relevant because water provides a unique recovery environment. Water immersion may influence circulation, hydrostatic pressure, buoyancy, and thermal regulation, while water-based activity can allow recovery movements to be performed with reduced impact on the musculoskeletal system (Torres-Ronda & I del Alcázar, 2015; Wilcock et al., 2006). At the same time, active recovery on land may promote continued muscular activity and circulation without the additional environmental effects associated with immersion. Passive recovery, in contrast, may provide a greater reduction in physical activity and allow the athlete to rest without additional muscular demand. However, the relative effectiveness of these modalities

may vary according to the intensity of exercise, the characteristics of the athlete, and the physiological variable being assessed.

Although recovery strategies have received considerable attention in sports science, there is a need to examine their comparative effectiveness specifically among swimmers at the district level. Comparing active land-based, active water-based, passive land-based, and passive water-based recovery modalities under standardized conditions can help determine which method is more effective in promoting physiological recovery after strenuous swimming exercise.

Therefore, the present study, titled "Comparative Efficacy of Land- and Water-Based Active and Passive Recovery Modalities on Post-Exercise Cardiorespiratory and Metabolic Recovery in Male Swimmers," is designed to compare the effects of four recovery modalities on selected physiological and metabolic indicators of recovery. The findings of the study are expected to provide evidence regarding the relative effectiveness of different recovery approaches and may assist swimmers and coaches in selecting appropriate recovery strategies for improved training adaptation, fatigue management, and subsequent performance.

METHODOLOGY

The study was conducted to compare the effectiveness of four recovery modalities among 40 male swimmers (age 25-30) from Rewa District, Madhya Pradesh, who had represented Madhya Pradesh at least once at the state level in swimming. A comparative experimental research design was adopted. The participants were divided into four groups of 10 swimmers each: Active Land-Based Recovery, Active Water-Based Recovery, Passive Land-Based Recovery, and Passive Water-Based Recovery. The independent variables were the four recovery modalities, while heart rate, breathing rate, and blood lactate concentration were considered dependent variables. All participants performed 200-meter continuous swimming at maximum intensity as the prescribed physical activity. The Heart rate, breathing rate, and blood lactate concentration were measured at three stages: before the activity, immediately after completing the 200-meter maximum-intensity swim, and after 20 minutes of the respective recovery modality. Heart rate was recorded in beats per minute, breathing rate in breaths per minute, and blood lactate concentration using a validated blood lactate analyser. The same testing procedures and equipment were used for all participants. The collected data were analysed using SPSS. Descriptive statistics, including mean, standard deviation, were calculated for all variables. A two-way repeated measure ANOVA was applied to examine the effects of recovery modalities and measurement time, along with their interaction, on heart rate, breathing rate, and blood lactate concentration. The level of significance was set at $p < 0.05$. The findings were used to determine the comparatively most effective recovery modality for the swimmers.

RESULT AND DISCUSSION

Table 1. Descriptive Statistics by Recovery Modality and Measurement Time

Variable	Measurement time	ALR, M ± SD	AWR, M ± SD	PLR, M ± SD	PWR, M ± SD
Heart rate (beats·min^{-1})	**Pre-swimming**	61.90 ± 3.60	61.00 ± 3.65	63.10 ± 3.67	62.40 ± 3.95

Variable	Measurement time	ALR, M ± SD	AWR, M ± SD	PLR, M ± SD	PWR, M ± SD
	Post-swimming	183.50 ± 5.02	181.90 ± 5.17	183.60 ± 5.93	182.40 ± 6.08
	After recovery	104.80 ± 4.54	99.50 ± 4.38	120.40 ± 6.74	113.00 ± 6.50
Breathing rate (breaths·min⁻¹)	**Pre-swimming**	15.30 ± 1.16	15.30 ± 1.16	15.70 ± 1.34	15.70 ± 1.34
	Post-swimming	48.50 ± 2.72	47.40 ± 2.63	48.60 ± 3.20	47.70 ± 3.27
	After recovery	24.00 ± 1.63	22.30 ± 1.42	27.80 ± 1.93	25.80 ± 1.93
Blood lactate concentration	**Pre-swimming**	1.42 ± 0.15	1.39 ± 0.15	1.45 ± 0.16	1.42 ± 0.18
	Post-swimming	10.70 ± 0.84	10.48 ± 0.82	10.60 ± 0.82	10.41 ± 0.88
	After recovery	4.63 ± 0.42	4.11 ± 0.39	6.17 ± 0.55	5.42 ± 0.57

Note: $n = 10$ per group; total $N = 40$. ALR = active land-based recovery; AWR = active water-based recovery; PLR = passive land-based recovery; PWR = passive water-based recovery; M = mean; SD = standard deviation.

Table 2. Assumption Tests for the Repeated-Measures Analysis

Variable	Mauchly's W	Approx. χ^2	df	p	Greenhouse–Geisser ε	Levene's $p$range
Heart rate	0.681	13.456	2	.001	0.758	.220–.929
Breathing rate	0.220	52.964	2	<.001	0.562	.556–.915
Blood lactate concentration	0.074	91.337	2	<.001	0.519	.445–.991

Note: Levene's tests were conducted separately at each measurement time. The reported ranges represent the minimum and maximum p-values across the three measurement occasions.

Table 3. Mixed Repeated-Measures ANOVA for breathing rate, heart rate and Blood lactate concentration

	Effect	*F*	Df	*p*	Partial η^2
Breathing Rate	**Time**	12,406.233	1.124, 40.454	<.001	.997
	Time × recovery modality	17.056	3.371, 40.454	<.001	.587
	Recovery modality	2.506	3, 36	.075	.173
Heart Rate	**Time**	84,125.424	1.516, 54.580	<.001	1.000
	Time × recovery modality	138.301	4.548, 54.580	<.001	.920
	Recovery modality	5.079	3, 36	.005	.297
Blood Lactate Concentration	**Time**	7,007.981	1.038, 37.375	<.001	.995
	Time × recovery modality	22.380	3.115, 37.375	<.001	.651
	Recovery modality	4.011	3, 36	.015	.251

Note: *Greenhouse–Geisser-corrected degrees of freedom are reported for within-subjects' effects. The between-subjects effect uses uncorrected degrees of freedom.*

The mixed repeated-measures ANOVA revealed a significant main effect of time for all three physiological variables, indicating that heart rate, breathing rate, and blood lactate concentration each changed substantially across the three measurement occasions (pre-swim, post-swim, and post-recovery). More critically, a significant time × recovery-modality interaction was observed for heart rate, $F(4.548, 54.580) = 138.301$, $p < .001$, $\eta_p^2 = .920$; breathing rate, $F(3.371, 40.454) = 17.056$, $p < .001$, $\eta_p^2 = .587$; and blood lactate concentration, $F(3.115, 37.375) = 22.380$, $p < .001$, $\eta_p^2 = .651$. These interactions demonstrate that the trajectory of physiological recovery over time differed meaningfully according to the recovery modality employed. The magnitude of these interaction effects was large for all outcomes, with partial eta-squared values ranging from .587 to .920. In contrast, the between-subjects main effect of recovery modality was significant for heart rate, $F(3, 36) = 5.079$, $p = .005$, $\eta_p^2 = .297$, and blood lactate concentration, $F(3, 36) = 4.011$, $p = .015$, $\eta_p^2 = .251$, but not for breathing rate, $F(3, 36) = 2.506$, $p = .075$, $\eta_p^2 = .173$. This pattern indicates that, when averaged across all measurement occasions, the recovery modalities produced statistically distinguishable overall responses for heart rate and blood lactate concentration, but not for breathing rate.

Table 6. Bonferroni-Adjusted Pairwise Comparisons of Recovery Modalities

Dependent variable	Significant comparison	Mean difference	SE	Adjusted *p*	95% CI
Heart rate	AWR – PLR	−8.233	2.209	.004	[−14.400, −2.067]
Blood lactate concentration	AWR – PLR	−0.747	0.221	.011	[−1.364, −0.130]

Note. Pairwise comparisons are based on estimated marginal means averaged across the three measurement occasions. SE = standard error; CI = confidence interval. Only statistically significant comparisons are shown.

Bonferroni-adjusted comparisons showed that AWR differed significantly from PLR for heart rate and blood lactate concentration. The AWR group had lower estimated marginal means than the PLR group:

- Heart rate difference: 8.233 beats·min^{-1}.
- Blood lactate difference: 0.747 concentration units.

No, pairwise comparison for breathing rate was statistically significant after Bonferroni adjustment. Although the descriptive means at 20 minutes favored AWR, the overall adjusted breathing-rate comparison did not meet the significance criterion.

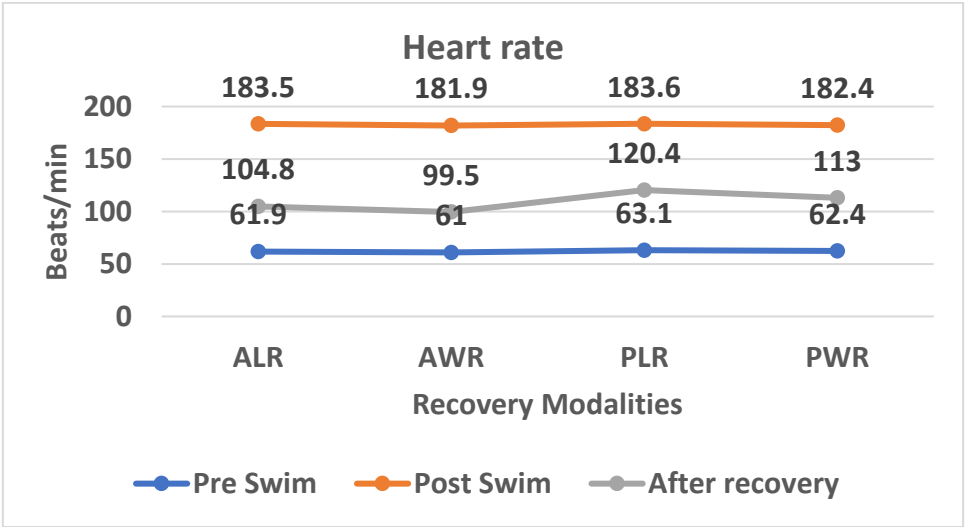

Figure 1: Graphical representation of Heart rate post different recovery modalities

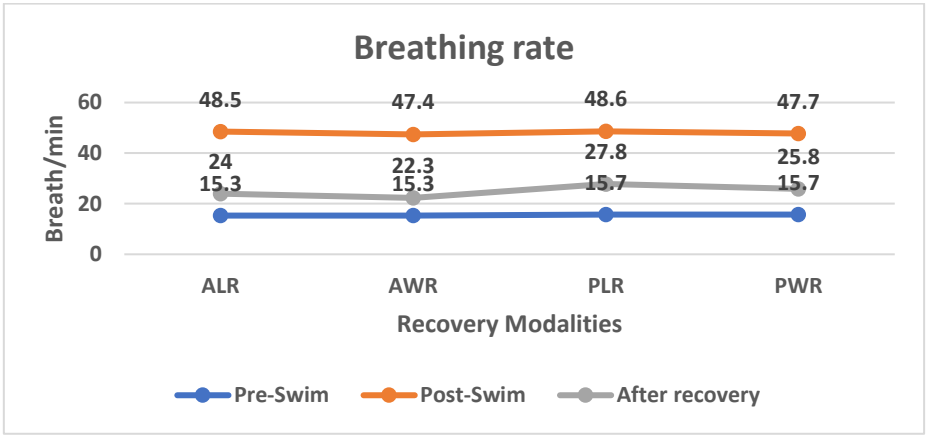

Figure 2: Graphical representation of Breathing rate post different recovery modalities

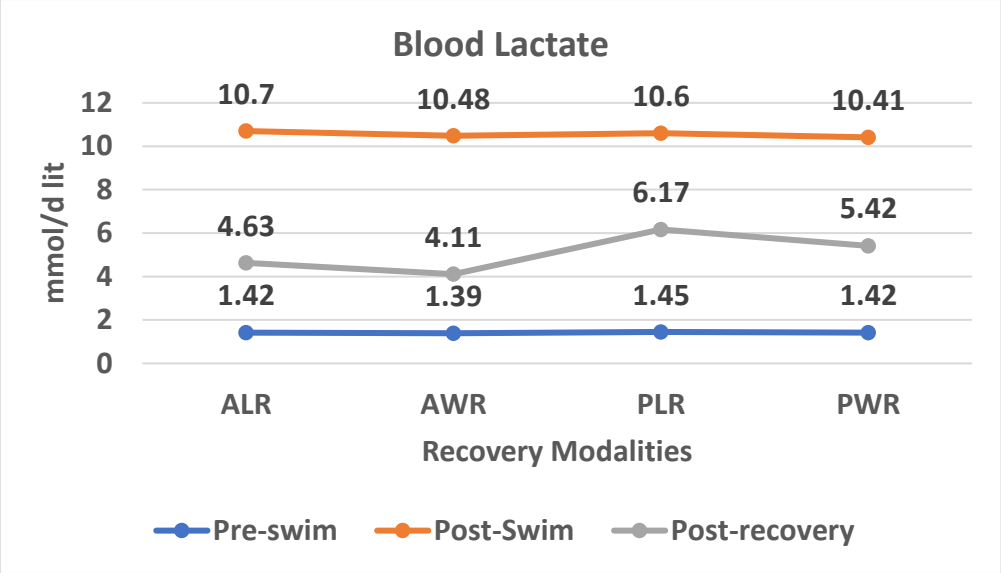

Figure 3: Graphical representation of Blood Lactate Concentration post different recovery modalities

Results of the research shows that active water-based recovery shows the strongest evidence for accelerating Cardiorespiratory and Metabolic Recovery, particularly blood lactate clearance after high-intensity exercise, especially in swimmers and other aquatic athletes (Coffey & Leveritt, 2013). Active water-based recovery accelerates blood lactate clearance primarily because it combines active muscle contraction (which drives lactate oxidation and transport) with hydrostatic pressure and buoyancy (which enhance venous return and central blood volume), creating a uniquely efficient "systemic lactate clearance" environment, especially advantageous for swimmers and aquatic athletes who recover in the same medium they train in.

During low-intensity swimming or water-based active recovery, slow-twitch (Type I) muscle fibres remain active and continue to take up lactate from the blood via monocarboxylate transporters, oxidizing it in mitochondria for energy. (Juel, & Halestrap, 1998). This oxidative clearance is substantially faster during active recovery than passive rest, studies report 60–70% faster lactate removal with active versus passive recovery (García-Pinillos et al., 2013). Water exerts hydrostatic pressure on immersed limbs, compressing superficial veins and promoting venous return toward the heart (Caggiati et al., 2021). In the horizontal swimming position, this effect is amplified because blood does not have to fight gravity to return from the lower body. When water is cooler than core temperature, peripheral vasoconstriction occurs, further centralizing circulation. Alternating thermal stimuli (e.g., contrast water therapy) produce repeated vasoconstriction–vasodilation cycles that act like a vascular pump, enhancing peripheral blood flow and intramuscular circulation, thereby facilitating lactate shuttling and clearance (Halson et al., 2022). Buoyancy unloads joints and muscles, allowing athletes to maintain continuous, low-intensity movement without additional eccentric damage. This permits prolonged activation of oxidative metabolism without imposing new fatigue (Colado et al., 2010).

CONCLUSION

In light of the study's result, active water-based recovery appears to be the most effective method for accelerating physiological recovery.

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