RESEARCH PAPER

Feasibility of The Aqua-T-Relax Recovery Protocol On Blood Lactate Clearance and Subjective Fatigue in Cricketers.

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ABSTRACT
Objectives: Post-exercise recovery is critical for sustained athletic performance, yet evidence for aquatic relaxation interventions in cricket populations is sparse. This preliminary trial determined the feasibility, safety, and acute effects of the Aqua-T-Relax (ATR) protocol on blood lactate clearance and subjective fatigue in male cricketers compared with passive seated rest.
Methods: Twenty-four male cricketers (18–30 years) were allocated to an ATR group (n = 12) receiving 15 minutes of thermoneutral aquatic immersion (32–34 °C) combined with a structured relaxation sequence, or a passive seated rest control group (n = 12). Fatigue was induced using the Yo-Yo Intermittent Recovery Test Level 1. Blood lactate was measured with a portable analyser at immediate post-fatigue and at 5, 10, and 15 minutes. Subjective fatigue was assessed using the Multidimensional Fatigue Inventory (MFI). Between-group comparisons used Welch's unpaired t-test; effect sizes were reported as Cohen's d.
Results: All 24 participants completed the protocol (100% retention) with no adverse events. No between-group difference was observed for immediate post-fatigue lactate ($p = 0.538$), confirming matched metabolic stress. Significant differences favouring ATR emerged at 5 minutes ($p = 0.045$, $d = -0.76$), 10 minutes ($p = 0.035$, $d = -0.80$), and 15 minutes ($p = 0.041$, $d = -0.76$), all representing medium effect sizes. No significant between-group differences were observed for MFI scores at any time point.
Conclusions: The Aqua-T-Relax protocol is feasible, safe, and produces significantly greater post-exercise blood lactate clearance than passive rest in male cricketers, with medium effect sizes. Subjective fatigue was unaffected, supporting a metabolic–perceptual dissociation. These data justify adequately powered randomised controlled trials comparing ATR with established active recovery modalities..
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INTRODUCTION
Cricket occupies a distinct position among team sports, requiring athletes to maintain performance across match durations ranging from several hours in limited-overs formats to five consecutive days in the Test format. Noakes and Durandt[1] described cricket's physiological demand as an unusual combination of explosive anaerobic power and prolonged aerobic endurance, a profile not replicated by any other major team sport. A GPS-based movement analysis by Petersen et al.[2] confirmed that cricket involves intermittent high-intensity efforts interspersed with lower-intensity repositioning, while subsequent work by the same group[3] demonstrated that movement patterns vary distinctly by playing position and match format, with limited-overs cricket imposing the highest intensity demands. Within cricket, fast bowlers face particular physiological strain: Bray et al.[4] reported significant elevations in creatine kinase and marked decrements in countermovement jump performance following a simulated bowling program, with neuromuscular impairment persisting beyond 24 hours. Collectively, these findings establish that cricket generates a complex, multi-system fatigue burden requiring targeted recovery interventions.

The physiological mechanisms underpinning fatigue are multidimensional, involving peripheral metabolic components and central neural drive impairments.[5] At the cellular level, Allen et al.[6] identified impaired calcium release, metabolic byproduct accumulation, and disrupted excitation–contraction coupling as key contributors to skeletal muscle fatigue. Gandevia[7] established that central fatigue is characterised by decreased motor unit recruitment and firing frequency, which can persist independently of peripheral recovery and has direct implications for recovery strategy design. Blood lactate concentration has long served

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as a practical marker of metabolic stress, although the historical view of lactate as a waste product has been replaced by Brooks' lactate shuttle theory, which establishes lactate as a mobile metabolic fuel and signalling molecule.[8] The accumulation of hydrogen ions produced alongside lactate creates intracellular acidosis that impairs muscle function.[9] Gladden[10] confirmed that lactate clearance depends on the balance between its production and removal, driven by tissue blood flow, oxidative capacity, and monocarboxylate transporter activity. Heck et al.[11] established that the 4 mmol/L blood lactate threshold reflects the intensity at which lactate production exceeds clearance capacity, a value widely accepted as a marker of significant metabolic stress.

The importance of structured recovery has gained increasing recognition within sports science. The international consensus statement by Kellmann et al.[12] recommended that practitioners adopt multimodal recovery strategies tailored to individual sport demands, emphasising that recovery is as critical as training itself for sustained performance. Nédélec et al.[13] systematically evaluated recovery protocols in soccer and concluded that modality efficacy varies according to the specific outcome and individual athlete. Monedero and Donne[14] reported that active recovery accelerated lactate clearance compared with passive rest in trained cyclists, but faster clearance did not consistently translate to improved performance, underscoring the complexity of the fatigue–recovery relationship. Despite the growing evidence base, recovery practices in cricket are largely adopted from other sports without cricket-specific validation, while the modern cricket calendar provides limited recovery opportunity between matches.[15]

Aquatic therapy offers a distinct recovery technique by leveraging the unique properties of water. Becker[16] provided the scientific foundation for aquatic therapy applications, establishing that buoyancy reduces gravitational stress on musculoskeletal structures, hydrostatic pressure enhances venous return and cardiac output, and thermal conductivity influences tissue temperature and vascular tone. Mooventhan and Nivethitha[17] systematically examined hydrotherapy and documented cardiovascular benefits including reduced heart rate and blood pressure alongside enhanced parasympathetic nervous system activity. Wilcock et al.[18] reported that water immersion produces measurable cardiovascular and perceptual benefits relevant to post-exercise recovery, while Harrison and Bulstrode[19] quantified buoyancy-related unloading effects at various immersion depths. Versey et al.[20] reviewed water immersion recovery strategies across athletic populations and concluded that thermoneutral immersion produces moderate but consistent recovery benefits, although optimal protocols remain unclear and individual variability is substantial.

Aqua-T-Relax (ATR) is a novel recovery protocol combining thermoneutral aquatic immersion (32–34 °C) with a structured relaxation sequence, integrating the haemodynamic benefits of hydrostatic pressure with muscular relaxation supported by buoyancy and warm water. The protocol rests on three converging mechanisms: first, hydrostatic pressure enhances venous return and cardiac output, accelerating blood flow through metabolically active tissues and facilitating lactate transport to sites of oxidation[16]; second, thermoneutral water temperature reduces muscle spindle sensitivity and peripheral vascular resistance, promoting vasodilation and tissue perfusion without provoking thermoregulatory stress[17]; and third, the buoyancy-supported environment reduces gravitational load and skeletal muscle activation, potentially enabling deeper relaxation than achievable on land.[19] Toledo and Filho[21] showed that relaxation techniques can accelerate lactate clearance compared with passive rest, suggesting that the structured relaxation component of ATR may add benefit beyond the aquatic environment alone.

Before investing in large-scale randomised controlled trials, feasibility data are needed to establish that ATR is tolerable, safe, and capable of producing measurable physiological effects in the target population. The present study aimed to determine the feasibility and acute effects of the ATR protocol on blood lactate clearance and subjective fatigue in male cricketers compared with passive seated rest.

MATERIALS AND METHODS

This preliminary study was conducted at the Department of Physiotherapy, KLE's Dr. Prabhakar Kore Charitable Hospital, Belagavi, India, over six months from recruitment to study commencement. Ethical clearance was obtained from the Institutional Ethics Committee, KAHER (Ref. No. 1015). All participants provided written informed consent before enrolment, and participant anonymity and confidentiality were maintained throughout. The trial was prospectively registered with the Clinical Trials Registry of India (CTRI/2025/08/092631). The study conformed to the 1983 revision of the 1975 Helsinki Declaration. Reporting followed the CONSORT 2010 Extension to Pilot and Feasibility Trials and the TIDieR checklist.

Participants and Allocation

Male cricketers aged 18–30 years from clubs in Belagavi were screened for eligibility. Inclusion criteria required participants to be professional cricketers with a minimum of 5 years of playing experience, to have played a professional match within the preceding month, and to achieve a post-exercise blood lactate concentration exceeding 4 mmol/L following the fatigue induction protocol. Exclusion criteria included musculoskeletal injuries affecting performance, neurological impairments, having played a match or undergone training on the day of the intervention, and hydrophobia. Forty-two cricketers were screened, of whom 24 met all inclusion criteria and were enrolled. The sample size was calculated using 85% power and a 5% significance level, informed by previous pilot trial designs.[22,23] Participants were allocated to the ATR group (n = 12) or the passive rest control group (n = 12) using opaque envelope randomisation.

Outcome Measures and Apparatus

Blood lactate concentration was measured using the LactoSpark portable lactate analyser (ICC = 0.85). The fingertip site was cleaned and aseptic precautions were observed before puncture. A lancing device with a new lancet was used at each measurement, and blood was collected onto test strips for immediate analysis. Measurements were obtained at four time points: immediately post-fatigue, and at 5, 10, and 15 minutes following intervention commencement. Subjective fatigue was assessed using the Multidimensional Fatigue Inventory (MFI; ICC = 0.70),[24] which evaluates five dimensions: general fatigue, physical fatigue, reduced motivation, reduced activity, and mental fatigue. Higher scores indicate greater fatigue. The MFI was administered at pre-exercise baseline and post-intervention.

Fatigue Induction Protocol

Following a standardised 10-minute warm-up of dynamic stretching and light jogging, fatigue was induced using the Yo-Yo Intermittent Recovery Test Level 1.[25] This validated protocol requires participants to perform repeated 2 × 20 m shuttle runs at progressively increasing speeds, interspersed with 10-second active recovery periods. The test was terminated when participants were unable to maintain the required pace on two consecutive shuttles. Blood lactate was measured immediately on cessation to confirm values exceeded the 4 mmol/L threshold.

Intervention: Aqua-T-Relax Protocol

The ATR intervention was administered in a therapeutic pool (4 × 3 m; depth 1.2 m) maintained at thermoneutral temperature (32–34 °C), monitored using a calibrated pool thermometer at the start and midpoint of each session. Participants were immersed to shoulder level and guided through a structured 15-minute relaxation sequence by a qualified physiotherapist present throughout. The protocol comprised four phases: (a) 3 minutes of controlled diaphragmatic breathing with eyes closed to promote parasympathetic activation; (b) 5 minutes of systematic muscle group relaxation progressing from the lower to the upper extremities with verbal therapist cues; (c) 4 minutes of gentle passive limb mobilisation performed by the therapist using buoyancy support to achieve low-resistance range of motion; and (d) 3 minutes of quiet floating in a supine position with continued breathing focus.

Control Group: Passive Rest

Control group participants rested in a seated position on a standard chair in a temperature-controlled room (24–26 °C) for 15 minutes. Participants remained seated and still, with no physical activity, no conversation about the study, and no use of electronic devices.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 28 (IBM Corp., Armonk, NY, USA). Continuous data are presented as mean ± standard deviation. The Shapiro–Wilk test was used to assess normality of distribution for all outcome variables. Between-group comparisons employed Welch's unpaired t-test, which does not assume equal variances. Statistical significance was set at $p < 0.05$. Effect sizes were calculated as Cohen's d and interpreted as small (0.20), medium (0.50), and large (0.80).[26] Ninety-five percent confidence intervals are reported for all between-group mean differences.

RESULTS

Descriptive Statistics and Group Equivalence

All 24 participants completed the study protocol without dropouts or adverse events, yielding a 100% completion rate and supporting the feasibility of both protocols. The ATR group comprised 12 male cricketers (mean age 24.22 ± 2.58 years; BMI 23.10 ± 0.28 kg/m²) and the control group comprised 12 male cricketers (mean age 23.83 ± 2.44 years; BMI 23.07 ± 0.47 kg/m²). No significant between-group differences were observed for any demographic or anthropometric variable (Table 1),

Table 1. Comparison of demographic and anthropometric characteristics between ATR and Control groups.

Variable	ATR Mean	ATR SD	Control Mean	Control SD	t	df	p	d
Age (years)	24.22	2.58	23.83	2.44	0.42	24.6	0.682	0.15
Height (cm)	172.37	2.69	172.33	1.84	0.05	28.0	0.957	0.02
Weight (kg)	68.68	2.78	68.50	1.61	0.22	27.6	0.824	0.08
BMI (kg/m²)	23.10	0.28	23.07	0.47	0.22	16.3	0.831	0.08

Data are presented as mean ± SD. n = 12 per group. Between-group comparisons used Welch's unpaired t-test. None significant at p < 0.05. ATR: Aqua-T-Relax; BMI: body mass index; SD: standard deviation

confirming that the groups were well matched at baseline. All outcome variables were normally distributed according to the Shapiro–Wilk test (all $p > 0.05$), supporting the use of parametric tests.

Between-Group Comparison of Blood Lactate Concentrations

Between-group comparisons of blood lactate concentrations at each measurement time point are presented in Table 2.

Table 2. Between-group comparison of blood lactate concentrations (mmol/L) at each time point.

Time Point	ATR Mean	ATR SD	Control Mean	Control SD	Mean Diff.	t	df	p	d
Immediate post-fatigue	6.16	0.31	6.09	0.30	0.07	0.62	24.3	0.538	0.23
5 min	5.25	0.27	5.43	0.20	−0.18	−2.09	27.6	0.045*	−0.76
10 min	4.75	0.27	4.94	0.20	−0.19	−2.21	27.6	0.035*	−0.80
15 min (removal)	1.41	0.11	1.48	0.07	−0.07	−2.14	27.9	0.041*	−0.76

Data are presented as mean ± SD. n = 12 per group. Negative mean difference indicates ATR group lower than Control.

*Welch's unpaired t-test. *p < 0.05. d = Cohen's d effect size. ATR: Aqua-T-Relax; SD: standard deviation*

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At the immediate post-fatigue time point, no significant difference was observed between the ATR group (6.16 ± 0.31 mmol/L) and the control group (6.09 ± 0.30 mmol/L; $t = 0.62$; $p = 0.538$; $d = 0.23$), confirming that both groups experienced comparable metabolic stress following the Yo-Yo test. A statistically significant between-group difference first emerged at 5 minutes, where the ATR group demonstrated lower lactate concentrations (5.25 ± 0.27 mmol/L) than the control group (5.43 ± 0.20 mmol/L; $t = -2.09$; $p = 0.045$; $d = -0.76$). This difference became more pronounced at 10 minutes, where ATR lactate (4.75 ± 0.27 mmol/L) was significantly lower than the control value (4.94 ± 0.20 mmol/L; $t = -2.21$; $p = 0.035$; $d = -0.80$). The between-group difference remained significant at the 15-minute removal time point, with the ATR group achieving 1.41 ± 0.11 mmol/L compared with 1.48 ± 0.07 mmol/L in the control group ($t = -2.14$; $p = 0.041$; $d = -0.76$). All three significant comparisons yielded medium effect sizes ($|d| = 0.76$–0.80).

Between-Group Comparison of Subjective Fatigue (MFI)

Between-group comparisons of MFI scores revealed no significant differences at any time point (Table 3).

Table 3. Between-group comparison of Multidimensional Fatigue Inventory (MFI) scores at pre-test and post-test.

Time Point	ATR Mean	ATR SD	Control Mean	Control SD	Mean Diff.	t	df	p	d
Pre-test	52.67	2.20	52.50	2.40	0.17	0.19	22.5	0.853	0.07
Post-test	55.39	4.88	55.50	4.20	−0.11	−0.06	26.2	0.949	−0.02
Change (pre–post)	2.72	4.60	3.00	3.80	−0.28	−0.18	26.6	0.860	−0.07

Data are presented as mean ± SD. n = 12 per group. Higher MFI scores indicate greater subjective fatigue. Welch's unpaired t-test. None significant at p < 0.05. d = Cohen's d effect size. ATR: Aqua-T-Relax; MFI: Multidimensional Fatigue Inventory; SD: standard deviation.

Pre-test scores were comparable between the ATR group (52.67 ± 2.20) and the control group (52.50 ± 2.40; $p = 0.853$; $d = 0.07$), confirming equivalent baseline subjective fatigue. Post-test scores were also comparable (ATR: 55.39 ± 4.88; Control: 55.50 ± 4.20; $p = 0.949$; $d = -0.02$). Pre-to-post change scores showed no significant between-group difference (ATR change: 2.72 ± 4.60; Control change: 3.00 ± 3.80; $p = 0.860$; $d = -0.07$), confirming that the magnitude of subjective fatigue change was virtually identical across both groups.

Feasibility Outcomes

All 24 enrolled participants completed the full study protocol without discontinuation, yielding a retention rate of 100%. No adverse events, discomfort, or safety concerns were reported in either group. All ATR participants tolerated thermoneutral water immersion without thermal discomfort, dizziness, or skin reactions. The ATR protocol required one qualified physiotherapist and a standard therapeutic pool with no specialised equipment, supporting its practical feasibility and safety for cricket populations.

DISCUSSION

This preliminary study demonstrates that the Aqua-T-Relax protocol is feasible, safe, and produces significantly greater blood lactate clearance than passive seated rest in male cricketers following exhaustive intermittent exercise. Between-group differences emerged as early as 5 minutes post-intervention and were sustained throughout the 15-minute observation period, with consistent medium effect sizes ($d = -0.76$ to -0.80) representing practically meaningful differences.

The accelerated lactate clearance observed in the ATR group is consistent with the known physiological properties of aquatic immersion. Becker[16] reported that hydrostatic pressure increases venous return and cardiac output, mechanisms expected to accelerate blood flow through metabolically active tissues and enhance lactate transport to sites of oxidation and gluconeogenesis. Mooventhan and Nivethitha[17] reported that hydrotherapy promotes parasympathetic nervous system activity and reduces peripheral vascular resistance, creating conditions that favour oxidative metabolism of accumulated lactate. The thermoneutral water temperature (32–34 °C) was selected following recommendations by Versey et al.[20] to reduce muscle spindle sensitivity and promote vasodilation without provoking thermoregulatory stress. Brooks' lactate shuttle theory provides important context: lactate functions as a mobile metabolic fuel transported between tissues for oxidation, and its clearance depends on blood flow, tissue oxidative capacity, and monocarboxylate transporter activity.[8,10] The ATR protocol appears to favour this clearance process through hydrostatic-pressure-mediated haemodynamic enhancement combined with buoyancy-mediated muscular unloading, reducing ongoing lactate production while enhancing removal through improved tissue perfusion.

The absence of significant between-group differences in subjective fatigue despite differential lactate clearance represents an important finding. This metabolic–perceptual dissociation is consistent with the multifactorial fatigue framework advanced by Enoka and Duchateau,[5] who noted that peripheral and central fatigue mechanisms do not necessarily recover in parallel. Gandevia[7] demonstrated that central fatigue, characterised by reduced neural drive, can persist after peripheral metabolic perturbations have been corrected. The psychobiological model proposed by Marcora et al.[27] suggests that subjective effort perception is influenced by cognitive processes that operate independently of peripheral physiological states. The MFI captures dimensions including mental fatigue and decreased motivation that would not be expected to respond to a short physical intervention even when metabolic homeostasis has been restored. Bestwick-Stevenson et al.[28] argued that different fatigue dimensions respond to different interventions at varying rates, and the current finding supports their recommendation for an integrated, multidimensional assessment approach.

Although the absolute between-group lactate differences at individual time points were modest (0.07–0.19 mmol/L), consistent medium effect sizes across three successive measurements indicate a genuine physiological advantage for ATR over passive rest. In a multi-day Test match, where recovery windows are typically short, even modest improvements in early metabolic recovery could contribute cumulatively to better recovery quality across the match duration.[13] Fast bowlers, who experience the greatest metabolic demands during cricket,[4] may benefit most from accelerated lactate clearance between bowling spells. However, Monedero and Donne[14] cautioned that faster lactate clearance does not consistently translate to improved subsequent performance, an important caveat that must be acknowledged. The effect-size estimates generated by this feasibility study ($d = 0.76$–0.80) provide the data needed for a priori power calculations to design adequately powered trials.

The practical implementation of ATR in cricket settings requires consideration of resource requirements and logistical constraints. The protocol requires access to a temperature-controlled pool, which is standard equipment in most physiotherapy departments and sports medicine centres but may not be available at all cricket grounds. Portable heated recovery pools, increasingly available commercially and transportable to training venues, represent a feasible alternative. The protocol requires only one qualified physiotherapist for a 15-minute session, compatible with staffing levels available at most organised cricket programmes. The 100% completion rate and absence of adverse events suggest that ATR is well tolerated

and acceptable to cricketers, an essential prerequisite for sustained adoption. The Kellmann et al.[12] consensus statement emphasised that recovery strategies must be practically implementable and athlete-acceptable to be effective in real-world training environments, and the present feasibility data support ATR on both counts.

Limitations

The sample comprised only male cricketers aged 18–30 years from a single city, limiting generalisability to female athletes, older cricketers, and populations with different training backgrounds. Only acute single-session effects were assessed; whether the observed differences would be maintained, amplified, or diminished with repeated ATR exposure over training blocks remains unknown. The Yo-Yo Intermittent Recovery Test, though well validated, does not perfectly replicate the specific physiological demands of a cricket match. Single blinding was employed, with participants necessarily aware of their group allocation, introducing the possibility of expectancy effects. Additional recovery markers—including creatine kinase, heart rate variability, countermovement jump performance, and inflammatory cytokines—were not measured and would provide a more comprehensive recovery profile.

Future Research

The medium effect sizes reported here ($d = 0.76$–0.80) can inform a priori sample-size calculations for larger randomised controlled trials. Future studies should compare ATR with established active recovery modalities such as cold water immersion, contrast water therapy, or progressive muscle relaxation, rather than passive rest alone. Inclusion of female cricketers, broader age ranges, and multiple competitive levels would strengthen external validity. Longitudinal designs examining repeated ATR exposure over 4–12-week training blocks would clarify whether chronic adaptations develop with regular use. Expanding the outcome battery to include neuromuscular function, autonomic markers, and cricket-specific performance tests would address the multidimensional nature of fatigue more comprehensively.

CONCLUSIONS

This preliminary study demonstrates that the Aqua-T-Relax recovery protocol is feasible, safe, and produces significantly greater blood lactate clearance than passive rest in male cricketers following exhaustive intermittent exercise. Medium effect sizes ($d = 0.76$–0.80) at the 5-, 10-, and 15-minute time points indicate a genuine physiological advantage for ATR that warrants further investigation. The persistence of equivalent subjective fatigue across both groups underscores the multidimensional nature of exercise-induced fatigue and suggests that comprehensive recovery strategies targeting both metabolic and psychological dimensions are needed. These effect-size estimates support the design of adequately powered randomised controlled trials comparing ATR with established active recovery modalities in cricket and other intermittent sports.

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