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Acute recovery responses across three fixed-sequence contrast water therapy protocols in world-class speed climbers: an exploratory repeated-measures study

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Abstract

Contrast water therapy (CWT) is widely used after intense training, yet acute responses in world-class speed climbers remain poorly characterized. Eight Tier 5 athletes from the Chinese National Climbing Team (5 men, 3 women) completed 7.5-, 12.5-, and 17.5-min CWT protocols in fixed order across three weekly visits after high-intensity training. Perceived fatigue, blood lactate concentration (BLa), bilateral choice reaction time (CRT), and heart rate variability (HRV) were assessed before and after each protocol, with analyses adjusted for weekly training load. Weekly load differed across visits (Friedman $p = 0.030$). After multiplicity correction, pre-to-post changes did not clearly differ among the three protocol–visit conditions (all $q \geq 0.107$). Fatigue was 1–2 points lower and BLa 39–49% lower after each visit (Holm-adjusted $p = 0.047$), whereas bilateral CRT showed no clear change. Mean R–R interval lengthened descriptively, but no within-visit HRV comparison remained significant after Holm adjustment. Because protocol duration was confounded with visit order and elapsed recovery and no time-matched control was included, neither a CWT effect nor an independent duration effect can be isolated. These estimates provide physiological benchmarks for randomized, time-aligned trials using 15-m climbing performance as the primary endpoint.

Introduction

Recovery interventions are used to preserve training quality when high-intensity sessions are closely spaced, but perceptual, metabolic, autonomic, and performance outcomes do not recover on the same time course [1,2]. Contrast water therapy (CWT), which alternates warm- and cold-water immersion, is common in high-performance sport. Hydrostatic pressure and temperature transitions can alter cardiovascular regulation, thermal sensation, pain, and peripheral blood flow, although the proposed ‘vascular pump’ has not been established as a single causal mechanism [3–5].

CWT effects depend on the exercise task, immersion temperatures, work-to-rest ratio, total exposure, and assessment time. Meta-analyses suggest more consistent changes in soreness and perceptual recovery than in subsequent performance, with substantial protocol heterogeneity [6,7]. Direct duration comparisons have not shown a reproducible monotonic response: 6-, 12-, and 18-min CWT produced outcome-specific results after cycling, and running data likewise did not identify a generally optimal duration [8,9]. Recent evidence remains cautious. Water-immersion methods did not accelerate inflammatory or muscle-damage biomarker recovery after sprinting and jumping [10], and repeated cold-water immersion did not improve performance or perceptual outcomes relative to thermoneutral immersion or passive recovery in competitive swimmers [11]. A 2026 network meta-analysis of cold-water immersion further found that protocol rankings varied by exercise mode and were often based on low-certainty or indirect evidence [12].

Speed climbing is a maximal event lasting only a few seconds. Performance depends on rapid force production, coordinated upper- and lower-limb movement, precise start execution, and high anaerobic

demand [13–15]. Evidence from recreationally active participants may not transfer directly to world-class climbers, whose training exposure, autonomic profile, technical consistency, and performance margins differ. McKay et al. [16] distinguish Tier 4 (elite/international) from Tier 5 (world class) and recommend that each athlete be classified with sport-specific performance and competition criteria rather than an unqualified 'elite' label.

This study describes acute pre-to-post changes observed after three fixed-sequence CWT protocol–visit conditions in world-class speed climbers. Outcomes were perceived fatigue, blood lactate concentration (BLa), bilateral choice reaction time (CRT), and heart rate variability (HRV). The study also examines whether within-athlete change varied across conditions after adjustment for visit-specific weekly training load. The condition-period term represents the joint contribution of protocol duration, visit order, and elapsed postexercise recovery, which were inseparable in this design. With no passive or thermoneutral comparison, the study was designed to map response patterns and improve planning of a controlled trial.

Results

Participant flow and training load

Eight world-class speed climbers finished the three study visits and contributed 24 athlete-visit observations (Fig. 1). HRV outcomes were available for all 24 athlete-visits after the stated five-minute segment-selection procedure. Weekly training load differed among visits (exact Friedman Q = 7.00, p = 0.030, Kendall W = 0.438). Mean ± standard deviation (SD) load was 4724 ± 1608 AU before the 7.5-min visit, 5662 ± 1070 AU before the 12.5-min visit, and 4568 ± 971 AU before the 17.5-min visit.

Protocol–visit condition comparisons

No outcome in the protocol–visit condition analyses remained significant after family-level multiplicity adjustment (Tables 5). Adjusted q values were at least 0.749 for fatigue and BLa and at least 0.181 for CRT. Across the 13 HRV outcomes, q values ranged from 0.107 to 0.693. Seven outcomes (Mean RR, SDNN, RMSSD, TINN, TP, SD1, and SD2) had q = 0.107 after rounding; none met q < 0.05. Among these seven, Mean RR, SDNN, TINN, TP, and SD2 had raw omnibus p values from 0.010 to 0.050. Pairwise protocol–visit contrasts were therefore not interpreted. Individual profiles showed substantial heterogeneity (Fig. 2).

Pre-to-post changes at each study visit

Perceived fatigue was lower at post-assessment at all three visits. Median changes were −2.0 [−2.0, −1.0], −2.0 [−2.0, −1.0], and −1.0 [−2.2, −1.0] CR-10 units at the 7.5-, 12.5-, and 17.5-min visits, respectively. Median BLa changes were −39.1% [−43.9, −30.9], −49.3% [−53.9, −40.0], and −42.0% [−49.9, −29.7]. All six recovery-marker comparisons had family-adjusted p = 0.047. Neither left- nor right-hand CRT changed between pre- and post-assessment at any visit (adjusted $p \geq 0.938$; Table 2 and Fig. 2).

Mean RR increased descriptively by medians of 13.9%, 16.5%, and 23.0% at the 7.5-, 12.5-, and 17.5-min visits. At the 12.5-min visit, median RMSSD increased by 60.3%, pNN50 by 13.12 percentage points, HF by 136.5%, and SD1 by 60.2%, while LF/HF decreased by 59.5% and SD2/SD1 by 26.1%. None of the 39 within-visit HRV tests remained below 0.05 after familywise Holm adjustment (smallest adjusted p = 0.305; Tables 3 and 4; Fig. 2). These HRV findings are descriptive protocol–visit patterns.

Discussion

Across 24 athlete-visits, fatigue and BLa declined at each visit, bilateral CRT remained stable, and HRV responses varied markedly among athletes. No protocol–visit condition effect survived multiplicity correction across the 17 outcomes. These athlete-level estimates provide a rare description of acute recovery markers in Tier 5 speed climbers under routines used in national-team practice. Because protocol duration was locked to visit order and post-assessment timing, the condition estimates represent the three joint protocol–visit settings rather than an isolated duration response.

The repeated pre-to-post reductions in fatigue and BLa resemble earlier CWT reports after short, intense exercise [17,18]. BLa also falls during passive recovery and is affected by redistribution, oxidation, prior exercise, and sampling time [19,20]. Perceived recovery can respond to treatment expectation: cold-water immersion has not consistently outperformed a credible placebo, and competitive swimmers may prefer water immersion even when performance and perceptual outcomes do not differ from comparison conditions [11,21]. The present values are therefore useful benchmarks for the recovery pattern observed in team practice; a time-matched passive or thermoneutral comparator would be needed to isolate the thermal contribution.

The HRV data could reflect ordinary time-dependent autonomic recovery, a response to the protocol, or both. Mean RR increased at all three visits, and the 12.5-min visit showed concurrent changes in RMSSD, pNN50, HF, and SD1. CWT and cold-water immersion can modify post-exercise vagal-related HRV, but the direction and timing depend on whether HRV is measured during the cold stimulus or after exercise and water exit [22–26]. Hagner-Derengowska et al. [27] reported lower RMSSD and SDNN during 5°C unilateral forearm immersion. That acute cold-stress setting differs materially from post-exercise whole-body CWT ending in 15°C water, so the two protocols should not be expected to produce the same autonomic response.

Interpretation of the HRV data is constrained by fixed order, unequal post-test timing, and spontaneous breathing. The 7.5-min routine always occurred in Week 1 and the 17.5-min routine in Week 3, and baseline HRV values varied across visits. On nominal immersion time alone, post-assessment began 5 min later after the 12.5-min protocol and 10 min later after the 17.5-min protocol. HRV came last in the assessment sequence, so its elapsed time from training differed by at least these amounts. Breathing was neither paced nor recorded. RMSSD and HF are defensible short-term vagal-related measures, but LF has mixed determinants, LF/HF is not a direct measure of sympathovagal balance, and VLF from a 5-

min segment has limited physiological specificity [28–30]. These features argue against interpreting a single HRV metric or an unadjusted p value in isolation.

McKay et al. [16] distinguish Tier 5 (world class) from the broader Tier 4 (elite/international) category. Applying that framework athlete by athlete, using documented 15-m performance and international competition credentials, places every analyzed athlete at Tier 5. The cohort therefore offers unusual ecological relevance for world-class speed-climbing practice. Its narrow composition also defines the inference: eight athletes from one national team do not represent every world-class climber, and sex-specific or individual-response moderators were not estimable. The unchanged CRT findings pertain only to a generic hand-response task. Recovery should ultimately be judged with 15-m climbing time, start and split times, or repeated-climb performance rather than CRT alone [13,14,31].

For practitioners, the 7.5-min routine was accompanied by fatigue and BLa changes of similar order to those at the longer visits while requiring less immersion time. This descriptive pattern does not establish equivalence. In practice, logistics, athlete preference, tolerance, and the goal of the surrounding training block remain reasonable selection criteria. The shorter routine is a practical candidate for a randomized, time-matched noninferiority comparison.

The cohort of eight world-class athletes was small, and the resulting estimates are imprecise. Nonsignificant condition-period tests do not establish similarity, equivalence, or absence of a meaningful difference. Seventeen outcomes were examined without a prospectively designated primary endpoint; multiplicity control reduced selective false-positive interpretation but also limited sensitivity. The main design constraints were fixed treatment order, no passive-rest or thermoneutral comparison, and confounding of duration with visit week and elapsed recovery. Weekly-load adjustment addressed measured variation, not unmeasured visit effects or the counterfactual response under randomized order. Respiration and menstrual-cycle phase were not incorporated, HRV followed the other post-exit assessments, and no subsequent climbing performance was recorded.

Individual trajectories are shown, but athletes were not classified as responders or nonresponders. Measurement-specific reliability and typical error were not established in this cohort, and one observation per protocol cannot distinguish a stable individual response from day-to-day variation. A future responder analysis should include repeated baseline measurements and define a smallest worthwhile change before classifying individual responses.

A confirmatory crossover should randomize or counterbalance protocol order, align every outcome by elapsed time from training, and include a time-matched passive-rest or thermoneutral comparison. The primary endpoint should be 15-m climbing time, with start and split times as secondary process measures. Its smallest worthwhile change and typical error should be estimated from repeated baseline runs in the target population before recruitment. Ln-transformed RMSSD can remain a secondary autonomic outcome. Repeated measurements across training blocks or collaboration between national teams would improve precision while retaining the ecological value of a world-class sample.

In these Tier 5 speed climbers, the observed pre-to-post pattern was compatible with time-dependent recovery after high-intensity training. Short-term changes in perceptual or lactate measures should not be interpreted as evidence that CWT accelerated recovery or restored climbing readiness. Because duration was confounded with visit order and elapsed recovery and no time-matched control was included, neither a CWT effect nor an independent duration effect could be isolated. These athlete-level estimates provide descriptive physiological benchmarks for randomized, time-aligned trials using 15-m climbing performance as the primary endpoint.

Methods

Participants and ethics

Ten speed climbers from the Chinese National Climbing Team entered the study. Eight athletes (5 men and 3 women) finished all three visits and formed the repeated-measures cohort, contributing 24 athlete-visit observations; two women did not finish one scheduled visit and were not included in the three-visit analysis (Fig. 1). All eight analyzed athletes were full-time members of the Chinese National Climbing Team and specialized in speed climbing. McKay et al. [16] reserve Tier 5 for world-class performers and recommend sport-specific classification from performance and competition metrics. Each analyzed athlete was therefore classified individually from documented 15-m personal-best performance and verified international competition credentials; every athlete met Tier 5 criteria. Membership of the Chinese National Climbing Team alone was not used to assign the classification. Individual rankings are not shown because they would make athletes in this small cohort readily identifiable. Group characteristics are reported in Table 1. Because world-class speed climbers constitute a small accessible population, all eligible athletes available during the study period were invited. No a priori sample-size calculation was performed, and the study was treated as exploratory.

The study was approved by Ethics Committee of the China Institute of Sport Science (project code: CISSLA20260212), was conducted in accordance with the Declaration of Helsinki and relevant institutional guidelines and regulations, and was completed after written informed consent was obtained from all athletes.

Experimental design and CWT protocols

This was a nonrandomized, single-sequence, three-visit within-athlete study. All athletes received 7.5-, 12.5-, and 17.5-min CWT in that order over three consecutive weekly visits. Each visit followed the scheduled high-intensity training session of the athlete group. No passive-rest or thermoneutral-immersion control condition was included.

CWT began approximately 30 min after training. One cycle comprised 90 s in warm water (38 ± 1 °C) followed by 60 s in cold water (15 ± 1 °C); transfers of approximately 5 s were excluded from nominal immersion time. Athletes remained seated and were immersed to the neck. The 7.5-, 12.5-, and 17.5-min

routines comprised 3, 5, and 7 cycles, respectively. Every routine began in warm water and ended in cold water.

At each visit, assessments were performed in the same order immediately before immersion and immediately after water exit: perceived fatigue, BLa, left/right CRT, and HRV. On nominal immersion time alone, the 12.5- and 17.5-min protocols shifted the start of post-assessment by 5 and 10 min, respectively, relative to the 7.5-min protocol; brief inter-bath transfers increased these offsets slightly. HRV was measured last, after fatigue, BLa, and CRT, so the protocol-length offsets carried forward to HRV acquisition. These timing differences formed part of each protocol–visit condition rather than a separately estimable factor. Athletes were familiarized with all procedures before data collection (Fig. 1).

Training-load monitoring

Training load was quantified by the session rating of perceived exertion (sRPE) method [32]. Athletes rated each session on the Borg category-ratio 10 (CR-10) scale. Session load was calculated as session duration in minutes multiplied by the session rating and expressed in arbitrary units (AU); weekly load was the sum of all sessions in that week. Weekly load was entered in the model as a visit-specific covariate.

Perceived fatigue and blood lactate

Current whole-body fatigue was rated on the Borg CR-10 scale, anchored by 0 (‘no fatigue’) and 10 (‘extreme fatigue’) [33]. This immediate fatigue rating was distinct from sRPE. Capillary BLa was measured from an earlobe sample with a portable analyzer (EKF Diagnostics, Germany) and expressed in $mmol \cdot L^{-1}$.

Choice reaction time

Left- and right-hand CRT were measured with an electronic reaction-time device (FYS-1, Shanghai Kangfu Medical Instrument Co., China). After familiarization, athletes completed three valid trials per hand and the fastest trial was retained. Lower values indicated faster responses. CRT was treated as a general psychomotor measure, not as a surrogate for start or on-wall performance.

Heart rate variability

HRV assessment took place in the same quiet room at every visit. Athletes rested supine for 1 min, after which R–R intervals were recorded for more than 5 min with the Polar Team Pro system (Polar Electro, Finland). Recordings were imported into Kubios HRV Scientific (Kubios Oy, Finland), visually quality-checked, and a stable continuous 5-min segment was selected. Athletes remained still and breathed spontaneously; respiratory frequency and tidal volume were not recorded. Outcomes were mean R–R interval (Mean RR); standard deviation of normal-to-normal intervals (SDNN); root mean square of successive differences between normal-to-normal intervals (RMSSD); percentage of successive normal-to-normal intervals differing by more than 50 ms (pNN50); triangular interpolation of the normal-to-

normal interval histogram (TINN); very-low-frequency power (VLF), low-frequency power (LF; 0.04–0.15 Hz), high-frequency power (HF; 0.15–0.40 Hz), and total power (TP); the LF/HF ratio; Poincaré plot standard deviations perpendicular (SD1) and parallel (SD2) to the line of identity; and the SD2/SD1 ratio [28,34].

Statistical analysis

All analyses were exploratory; no primary endpoint or directional hypothesis was prospectively designated. Seventeen outcomes were evaluated: perceived fatigue, BLa, two CRT outcomes, and 13 HRV outcomes. Analyses used within-athlete pre-to-post change. Perceived fatigue, left/right CRT, and pNN50 were expressed as post minus pre. BLa and all other HRV outcomes were analyzed as the natural logarithm of the post-to-pre ratio [ln(post/pre)] to reduce right skew; percentage changes were obtained by back-transformation. For each outcome, an ordinary least-squares model included athlete fixed effects, standardized weekly training load, and a three-level condition-period term. This two-degree-of-freedom term represents the joint protocol–visit condition rather than an isolated duration effect because each duration occurred at only one ordered visit. Model-adjusted changes are reported at mean weekly load with 95% confidence intervals (CIs), together with F tests and partial η^2.

Given the small cohort (n = 8), exact non-parametric procedures were used for weekly-load and within-visit comparisons. Weekly load was compared with an exact Friedman test and Kendall W, and changes within each visit were assessed using exact two-sided Wilcoxon signed-rank tests. All hypothesis tests were two-sided and used an alpha level of 0.05. To limit multiplicity, outcomes were grouped into recovery markers (fatigue and BLa), CRT (left and right), and HRV (13 outcomes). Omnibus condition-period p values were adjusted within each family using the Benjamini–Hochberg false discovery rate (FDR) procedure and are reported as q values. Within-visit Wilcoxon p values were Holm-adjusted across all condition-by-outcome tests in the relevant family (6 recovery-marker tests, 6 CRT tests, and 39 HRV tests). Pairwise protocol–visit contrasts were to be interpreted only if the corresponding family-adjusted omnibus q was below 0.05; no outcome met this criterion. Residual and influence diagnostics were inspected and no observations were removed. Inference emphasized adjusted estimates, 95% CIs, corrected p values, and individual response profiles.

Declarations

Data availability

The datasets generated and analysed during the current study are not publicly available because the small cohort comprises readily identifiable national-team athletes and public release could compromise participant confidentiality. De-identified data that can be shared without breaching confidentiality are available from the corresponding author (Jiexiu Zhao; zhaojiexiu@ciss.cn) on reasonable request, subject to institutional ethics and data-governance approval.

Competing interests

The authors declare no competing interests.

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Author contributions

G.Y.: conceptualization, methodology, investigation, data curation, visualization, funding acquisition, writing—original draft, and writing—review and editing. W.L.: conceptualization, writing—original draft, and writing—review and editing. B.Y.: resources and investigation. S.L.: data curation, investigation, methodology, funding acquisition, and visualization. G.L.: data curation and investigation. P.C.: writing—review and editing. C.W.: resources, methodology, and visualization. D.W.: writing—review and editing. J.Z.: conceptualization, resources, supervision, and writing—review and editing. All authors read and approved the final manuscript.

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Tables

Table 1 Participant characteristics of the analyzed world-class cohort

Sex	n	Age (years)	Height (cm)	Body mass (kg)	15-m personal best (s)
Men	5	20.4 ± 0.9	170.8 ± 4.6	67.7 ± 6.6	5.06 ± 0.09
Women	3	22.0 ± 1.0	162.0 ± 1.7	56.5 ± 3.0	6.88 ± 0.35

Values are mean ± standard deviation (SD). Tier 5 (world class) classification was applied athlete by athlete from documented 15-m performance and international competition credentials under McKay et al. [16].

Table 2 Perceived fatigue, blood lactate concentration, and choice reaction time before and after each fixed-sequence CWT protocol–visit condition

Outcome	CWT	n	Pre mean ± SD	Post mean ± SD	Median change [IQR]	Adjusted *p*
Perceived fatigue	7.5 min	8	5.50 ± 1.20	3.88 ± 1.13	-2.0 [-2.0, -1.0] units	0.047
CR-10	12.5 min	8	4.75 ± 1.58	3.00 ± 1.07	-2.0 [-2.0, -1.0] units	0.047
	17.5 min	8	5.38 ± 1.69	3.88 ± 1.46	-1.0 [-2.2, -1.0] units	0.047
Blood lactate	7.5 min	8	2.55 ± 0.56	1.60 ± 0.35	-39.1% [-43.9, -30.9]	0.047
	12.5 min	8	2.45 ± 1.10	1.24 ± 0.44	-49.3% [-53.9, -40.0]	0.047
	17.5 min	8	2.41 ± 1.14	1.40 ± 0.45	-42.0% [-49.9, -29.7]	0.047
Left CRT	7.5 min	8	309.5 ± 17.2	318.5 ± 25.3	+8.5 [-8.2, +21.5] ms	0.938
	12.5 min	8	323.0 ± 17.9	322.4 ± 16.1	+8.0 [-10.0, +13.0] ms	1.000
	17.5 min	8	313.9 ± 17.6	313.8 ± 26.3	+4.5 [-18.0, +19.2] ms	1.000
Right CRT	7.5 min	8	320.1 ± 33.8	306.8 ± 17.5	-10.0 [-15.5, -2.2] ms	0.938
	12.5 min	8	314.8 ± 22.1	319.5 ± 31.5	-8.5 [-12.5, +23.2] ms	1.000
	17.5 min	8	301.6 ± 18.5	313.0 ± 16.6	+13.5 [+2.5, +23.5] ms	0.938

CR-10: category-ratio 10 scale; *CRT*: choice reaction time; *CWT*: contrast water therapy; *IQR*: interquartile range; ln, natural logarithm; *SD*: standard deviation. Blood lactate concentration is expressed in $mmol \cdot L^{-1}$, and CRT values are in milliseconds. Change is post minus pre for fatigue and CRT and percentage change from ln(post/pre) for blood lactate. Exact Wilcoxon signed-rank *p* values were Holm-adjusted across all six condition-by-outcome tests in the recovery-marker family or CRT family

Table 3 HRV time-domain and Poincaré outcomes

Outcome	CWT	n	Pre mean ± SD	Post mean ± SD	Median change [IQR]	Adjusted *p*
Mean RR	7.5 min	8	726.0 ± 67.0	815.1 ± 43.2	+13.9% [+11.8, +16.0]	0.484
	12.5 min	8	845.2 ± 153.9	996.4 ± 154.9	+16.5% [+13.9, +19.3]	0.305
	17.5 min	8	807.6 ± 119.9	1021.4 ± 152.1	+23.0% [+20.8, +29.7]	0.305
SDNN	7.5 min	8	28.1 ± 22.6	49.3 ± 16.4	+103.2% [+44.1, +275.2]	1.000
	12.5 min	8	46.0 ± 27.5	51.0 ± 22.1	+15.7% [+11.2, +40.1]	1.000
	17.5 min	8	70.3 ± 37.1	67.5 ± 51.7	-9.2% [-46.3, +17.4]	1.000
RMSSD	7.5 min	8	27.1 ± 24.2	47.1 ± 16.3	+116.8% [+74.6, +200.3]	1.000
	12.5 min	8	45.4 ± 33.3	66.7 ± 34.7	+60.3% [+35.1, +68.8]	0.305
	17.5 min	8	76.1 ± 53.8	73.5 ± 36.1	+9.1% [-7.4, +49.4]	1.000
pNN50	7.5 min	8	5.8 ± 8.6	21.1 ± 17.1	+16.78 [+4.09, +24.13] pp	1.000
	12.5 min	8	24.9 ± 24.3	41.8 ± 27.2	+13.12 [+9.14, +27.65] pp	0.484
	17.5 min	8	38.3 ± 29.4	41.0 ± 24.3	+12.18 [-0.91, +21.15] pp	1.000
TINN	7.5 min	8	174.8 ± 136.5	325.4 ± 125.8	+138.5% [+40.7, +198.1]	0.305
	12.5 min	8	239.0 ± 162.9	260.2 ± 94.8	+28.0% [+14.2, +47.8]	1.000
	17.5 min	8	330.2 ± 158.6	352.1 ± 242.3	-8.6% [-28.0, +12.0]	1.000
SD1	7.5 min	8	19.2 ± 17.1	33.3 ± 11.5	+116.5% [+73.8, +198.5]	1.000
	12.5 min	8	32.1 ± 23.6	47.2 ± 24.6	+60.2% [+34.9, +69.1]	0.305
	17.5 min	8	53.9 ± 38.1	52.1 ± 25.7	+9.2% [-7.6, +49.7]	1.000
SD2	7.5 min	8	34.5 ± 26.9	60.4 ± 21.0	+107.4% [+26.1, +279.6]	1.000

Outcome	CWT	n	Pre mean ± SD	Post mean ± SD	Median change [IQR]	Adjusted *p*
	12.5 min	8	54.6 ± 34.7	53.5 ± 21.1	+10.3% [+0.1, +30.3]	1.000
	17.5 min	8	77.3 ± 49.2	77.3 ± 72.3	-14.7% [-44.6, +11.4]	1.000
SD2/SD1	7.5 min	8	1.94 ± 0.43	1.83 ± 0.40	+1.0% [-29.2, +18.5]	1.000
	12.5 min	8	2.03 ± 1.01	1.25 ± 0.41	-26.1% [-37.1, -19.4]	0.305
	17.5 min	8	1.78 ± 0.81	1.42 ± 0.66	-20.4% [-47.9, +16.9]	1.000

Figures

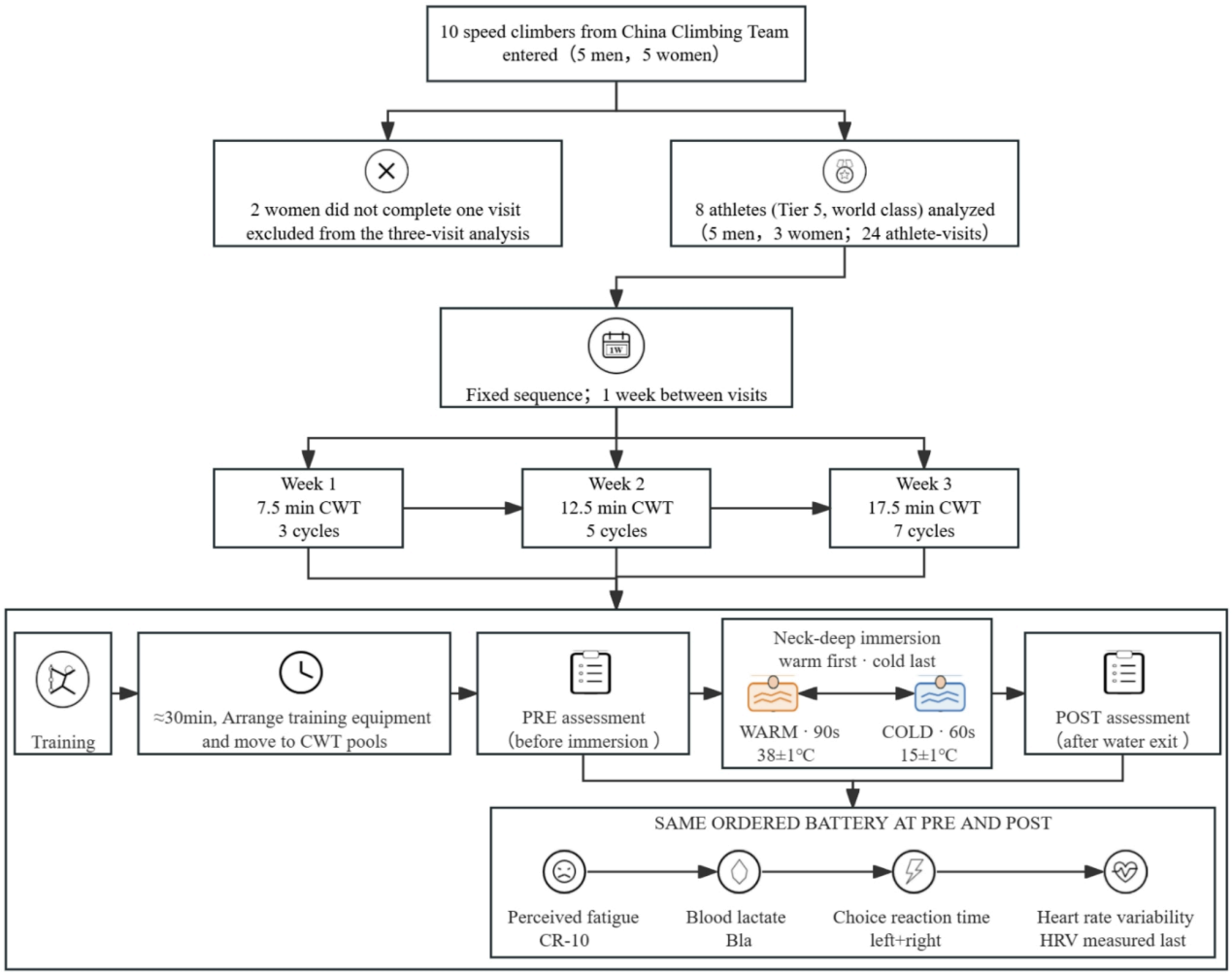


Figure 1

Experimental design. *BLa*: blood lactate concentration; *CRT*: choice reaction time; *CWT*: contrast water therapy; *HRV*: heart rate variability.

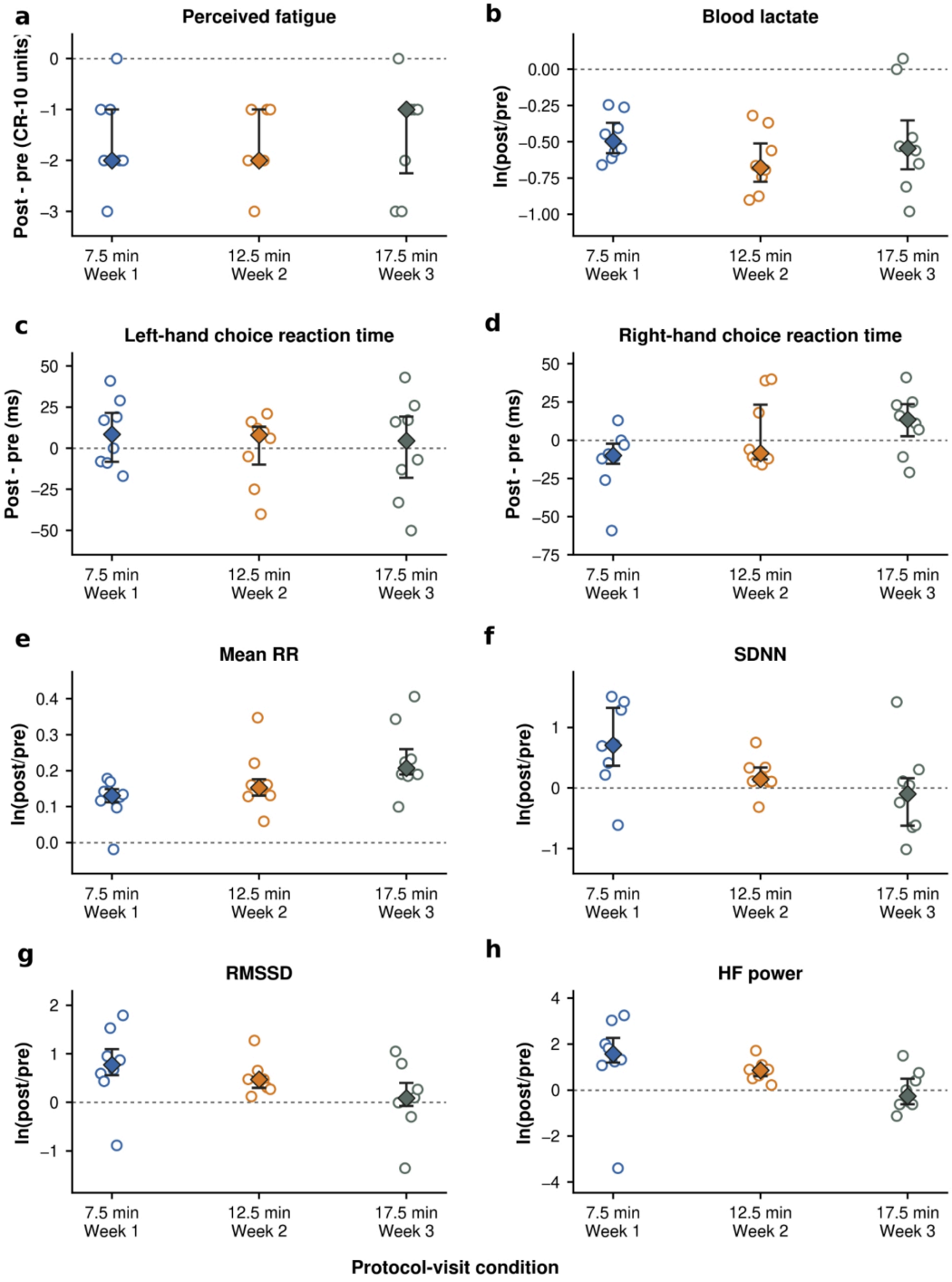


Figure 2

Individual changes in (a) perceived fatigue, (b) blood lactate concentration, (c) left-hand choice reaction time, (d) right-hand choice reaction time, (e) mean R–R interval (Mean RR), (f) standard deviation of normal-to-normal intervals (SDNN), (g) root mean square of successive differences between normal-to-normal intervals (RMSSD), and (h) high-frequency power (HF) across the three fixed-sequence CWT protocol–visit conditions. Open circles show individual athlete-visit observations; diamonds and error bars show medians and interquartile ranges. When a median equals a quartile, the corresponding error-bar arm has zero length. Fatigue and choice reaction time are shown as post minus pre; blood lactate and HRV outcomes are shown as ln(post/pre). The horizontal dashed line denotes no change. No HRV protocol–visit condition effect remained after false-discovery-rate adjustment. *BLa*: blood lactate concentration; *CR-10*: category-ratio 10 scale; *CRT*: choice reaction time; *CWT*: contrast water therapy; *HF*: high-frequency power; *HRV*: heart rate variability; *IQR*: interquartile range; *ln*, natural logarithm; *Mean RR*: mean R–R interval; *RMSSD*: root mean square of successive differences between normal-to-normal intervals; *SDNN*: standard deviation of normal-to-normal intervals