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Acute Physiological and Perceptual Responses to Interval versus Continuous Threshold Training in Middle-Distance Athletes

Rania Lampou[1*], Sarthak Sengupta[2]

[1] Directorate of Educational Technology and Innovation, Greek Ministry of Education, Religious Affairs and Sports, Athens, Greece;
[2] ADMIRE Center for Advancing Digital Health, Institute of Health Management Research, Bangalore, India;

* **Corresponding author:** rania.lampou@gmail.com.

ABSTRACT: This study compared the acute physiological and perceptual responses to two threshold-based running formats in trained male middle-distance athletes. Twenty male 800-1500 m specialists completed a randomized crossover field protocol consisting of continuous threshold training (CTT; 32 min continuous running at individual second lactate-threshold velocity) and interval threshold training (ITT; 4 × 8 min at the same velocity with 2-min jog recoveries). Heart rate (HR), blood lactate concentration ([BLa]), Borg rating of perceived exertion (RPE), session-RPE (sRPE), affective valence, and 30-min total quality recovery (TQR) were recorded. Paired-samples tests compared session outcomes, repeated-measures ANOVA examined time-course responses, and statistical significance was set at $p < 0.05$. ITT elicited higher mean HR (177.8 ± 6.3 vs. 170.3 ± 5.3 beats·min−1), greater time above 90% HRmax (19.5 ± 6.4 vs. 13.7 ± 3.5 min), higher post-session [BLa] (5.12 ± 1.31 vs. 4.12 ± 1.10 mmol·L−1), higher end-session Borg RPE (16.2 ± 1.3 vs. 15.3 ± 1.3), and greater sRPE (6.6 ± 1.0 vs. 5.8 ± 1.0) than CTT (all $p < 0.05$). The [BLa] and HR time courses showed significant condition × time interactions, indicating progressive divergence between formats during the main work period. When the work duration and intensity thresholds were matched, the interval format produced greater cardiometabolic and perceptual load than continuous-threshold running. Coaches should therefore avoid assuming that interval and continuous threshold sessions are interchangeable merely because they share the same nominal threshold speed and work duration.

Keywords: Lactate Threshold; Interval Training; Endurance Running; Heart Rate; Perceived Exertion; Middle-Distance Running.

I. INTRODUCTION

Middle-distance running occupies a demanding region of the endurance-performance continuum. Competitive 800-m and 1500-m races require the athlete to sustain a high fraction of maximal aerobic power while also tolerating large rates of anaerobic energy release, rapid lactate accumulation, and substantial neuromuscular strain. The physiological profile of a successful middle-distance runner, therefore, differs from that of a pure sprinter or long-distance specialist: aerobic power, lactate-threshold speed, running economy, buffering capacity, and tactical speed reserve all contribute to performance. Earlier work on middle-distance running emphasized that a single variable cannot explain performance because event duration places athletes in a mixed metabolic domain in which aerobic and anaerobic contributions overlap substantially [1]-[5]. This mixed demand is one reason coaches frequently use threshold sessions to develop sustainable speed while reserving very-high-intensity interval training for race-specific phases.

Threshold training is commonly prescribed to improve the speed or power output that can be sustained before blood lactate rises rapidly. In running practice, threshold work may take the form of a continuous tempo run, a cruise-interval session, or repeated blocks near the second lactate threshold. Classic and

contemporary discussions of interval training indicate that small changes in work-bout duration, rest duration, and intensity can alter physiological signals, even when the external workload appears similar [6]-[10]. The scientific challenge is that coaches often treat both continuous tempo runs and interval threshold workouts as a single broad category of training. In reality, a 32-min continuous run at threshold speed and 4 × 8 min at the same speed with short recoveries may not produce the same internal load. The brief recoveries in the interval format may allow athletes to maintain slightly better mechanics and tolerate the prescribed speed. Still, they may also increase average cardiovascular strain during the work bouts and total time at high fractions of HRmax.

The importance of this distinction increases for middle-distance athletes, whose weekly training typically includes low-intensity mileage, threshold development, and race-pace or faster repetitions. Threshold speed is strongly connected to endurance capacity. Still, its interpretation depends on the method used to define it, the stability of lactate kinetics, and the context of the training session [11]-[17]. A fixed lactate value, an individualized lactate threshold, and a maximal lactate steady-state estimate may yield slightly different speeds. Consequently, the acute response to a given threshold prescription should be examined directly rather than assumed from the nominal intensity. The issue is not merely theoretical. A session that produces higher HR, higher [BLa], and greater perceived strain may require a different recovery window, may interact differently with strength or speed sessions, and may be inappropriate during some phases of a competitive microcycle.

Research on training-intensity distribution further supports evaluating internal load rather than relying solely on the label assigned to a session. Descriptive and intervention studies in endurance athletes show that the proportion of low-intensity, threshold, and high-intensity work affects adaptation and fatigue management [18]-[21]. While much of this literature compares blocks of training over weeks or months, the distribution ultimately emerges from single sessions. If two sessions are classified as threshold training but create different acute demands, their cumulative effect across a training block may also differ. Therefore, accurate characterization of threshold-session formats is necessary for both sport scientists and coaches.

Previous studies of interval work-bout duration and recovery have shown that the same total work time can produce different heart-rate, oxygen-uptake, blood-lactate, and perceptual responses [22]-[27]. However, middle-distance runners are underrepresented in acute field studies comparing interval and continuous threshold formats. Most available studies have either involved cyclists, mixed endurance samples, recreational runners, or interventions focused on performance outcomes rather than the immediate physiological and perceptual profile of the session. Perceived exertion is particularly important because RPE and sRPE provide a simple field-compatible representation of internal training load and are widely used to monitor athletes [28]-[31]. For middle-distance athletes, a small increase in perceived strain during threshold work may be meaningful if it occurs near races or during weeks containing speed endurance sessions.

The acute training studies often report only mean responses, leaving coaches uncertain about individual variability. Reliability, effect size estimation, and transparent uncertainty reporting are important in sport-science studies with relatively small trained samples [32]-[36]. A statistically significant difference can still be practically small, while a non-significant result may remain useful if the confidence interval excludes a large detrimental effect. In addition, physiological variables such as running economy and fatigue thresholds influence how athletes respond to a threshold prescription [37], [38]. A well-trained athlete with high economy may complete both formats with little distress. In contrast, another athlete with similar race performance but lower tolerance to metabolic acidosis may experience a larger increase in [BLa] and RPE during the interval format.

The same athlete may respond differently to the two formats depending on the phase of the season. During general preparation, continuous threshold running may be chosen to build aerobic durability and pacing discipline. During pre-competition phases, interval threshold running may be preferred because it permits repeated high-quality blocks at a speed close to a 1500-m rhythm, with less mechanical disruption than faster repetitions. Without direct measurement, however, coaches may underestimate the cost of the interval version. A session that looks moderate in the plan may become a heavier internal-load session in practice, especially when athletes arrive with residual fatigue.

The present study addressed this applied gap by comparing two common threshold-training formats under matched work-duration and intensity conditions in trained male middle-distance athletes. An

individualized threshold speed was established in a preliminary test; athletes completed both sessions in a randomized crossover order, and outcome measures were chosen because they are routinely accessible to coaches. The central question was whether interval threshold training and continuous threshold training generate comparable acute internal loads when the threshold work is matched, or whether the interval format produces a distinct response profile that should be treated differently in training prescription.

1. AIMS AND HYPOTHESES

The aims of the study were:

- To compare the acute cardiovascular response to interval versus continuous threshold running in trained male middle-distance athletes.
- To compare the blood-lactate response and recovery lactate profile between the two formats.
- To compare perceptual load, affective response, and short-term perceived recovery between formats.
- To examine whether within-athlete differences in physiological strain were associated with differences in perceived exertion and internal training load.

The hypotheses were:

- Interval threshold training would produce a higher mean HR, peak HR, and time above 90% HRmax than continuous threshold training.
- Interval threshold training would result in higher post-session [BLa] than continuous threshold training, despite identical threshold-speed work duration.
- Interval threshold training would be perceived as more strenuous, with higher end-session Borg RPE and sRPE and lower 30-min TQR.
- The condition-related increase in post-session [BLa] would be positively associated with the condition-related increase in sRPE.

II. RELATED WORK

The literature on middle-distance running physiology consistently shows that 800-m and 1500-m performance depends on the interaction of aerobic capacity, anaerobic energy release, and the ability to maintain efficient mechanics at high speed. Brandon described middle-distance performance as a multicomponent phenomenon in which high aerobic power is necessary but not sufficient [1]. Spencer and Gastin quantified the energy-system contribution during events from 200 to 1500 m. They showed that the 1500-m event contains a large aerobic component while still requiring substantial anaerobic contribution during fast starts, surges, and finishing phases [2]. Duffield and colleagues extended this work to track time trials over 1500 and 3000 m, reinforcing the idea that middle-distance events demand a blend of oxidative and glycolytic metabolism [3]. Hill's analysis of energy-system contributions and Lacour's competition-based lactate observations further support the view that high lactate values after 400-m and 800-m racing are not abnormal byproducts but expected outcomes of fast middle-distance running [4], [5]. These findings explain why training programs for middle-distance athletes cannot rely solely on long, easy running or on maximal intervals.

Billat's two-part review described aerobic and anaerobic interval training as a practical system in which the intensity, duration, number of repetitions, and recovery design determine the stimulus [6], [7]. Laursen and Jenkins later emphasized that high-intensity interval training is effective for well-trained endurance athletes because it can expose athletes to high oxygen uptake, high cardiac output, and race-relevant metabolic stress [8]. Buchheit and Laursen expanded this reasoning by showing that the programming puzzle is not solved by choosing an intensity alone; rather, work-bout duration, relief intensity, relief duration, accumulated work, and sport-specific mechanical load all influence the physiological outcome [9], [10]. Although the present study focused on threshold rather than severe-intensity intervals, the same programming logic applies: a continuous and an intermittent session can share the same target speed yet differ in internal load.

Midgley and colleagues discussed the physiological determinants of running performance and highlighted the trainability of variables related to maximal oxygen uptake, lactate threshold, and running economy [11]. Faude and colleagues reviewed lactate-threshold concepts and concluded that thresholds can

be valid performance indicators, provided their methodological limitations are recognized [12]. Beneke and colleagues described blood-lactate diagnostics as a useful but context-dependent tool for exercise testing and training [13]. Billat and colleagues argued that maximal lactate steady state is a relevant intensity boundary, while Heck and colleagues presented the historical justification for the 4 mmol·L−1 criterion [14], [15]. Meyer and colleagues provided a conceptual framework linking submaximal gas-exchange parameters to performance diagnosis and training prescription [16]. These studies collectively show that threshold training is not a single physiological point but a cluster of related intensities that must be interpreted with care.

Jones and Doust demonstrated that a 1% treadmill gradient can better approximate the energetic cost of outdoor running than level treadmill running [17]. Even so, field-based threshold training differs from laboratory testing because athletes experience turns, wind, footwear-surface interactions, and group pacing dynamics. Field studies, therefore, have value when they are conducted with careful standardization and reliable measurement.

Seiler and Kjerland showed that elite endurance athletes often accumulate a large proportion of their total training below the first threshold, with smaller proportions near threshold and above the second threshold [18]. Seiler's review of best practice in endurance training distribution argued that successful athletes typically balance high volumes of low-intensity work with carefully placed high-intensity or threshold sessions [19]. Esteve-Lanao and colleagues found that different intensity distributions affected performance in endurance runners [20]. Stöggl and Sperlich compared polarized, threshold, high-intensity, and high-volume training models and reported that polarized training produced broad improvements in well-trained endurance athletes [21]. This body of work does not imply that threshold training is unimportant. Rather, it suggests that threshold sessions should be used precisely, because spending too much time near the threshold can increase load without consistently producing proportionate adaptation.

Seiler and Sjursen compared different work durations during self-paced intervals and found that work-bout structure influenced physiological and perceived-exertion responses [22]. Seiler and Hetlelid examined how rest duration affects work intensity and RPE during interval training, showing that recovery design can change the achieved session intensity [23]. Seiler and colleagues later reported that accumulated work duration and intensity interact to shape adaptations to aerobic interval training [24]. Smith and colleagues showed that individualized high-intensity interval training based on maximal aerobic speed and time to exhaustion could improve performance variables [25]. Denadai and colleagues compared interval training at 95% and 100% of VO2max velocity in well-trained runners and found effects on physiological indices and performance [26]. Ronnestad and colleagues reported that short intervals can produce strong adaptations in cyclists under effort-matched conditions [27]. Together, these studies make it reasonable to expect that interval threshold training may differ from continuous threshold running even when external work is matched.

Perceptual monitoring is essential because athletes do not adapt to external speed alone; they adapt to the internal strain imposed by the session. Borg established the theoretical basis for perceived exertion and its relation to physiological stress [28]. Foster's work on monitoring training load linked subjective training strain to the risk of overtraining and to practical session management [29]. The session-RPE method was then developed as a simple approach for quantifying internal load across different forms of exercise [30]. Impellizzeri and colleagues provided evidence that RPE-based training load can represent global internal load in team-sport contexts [31]. Although middle-distance running differs from soccer, the logic is transferable: the athlete's perceived strain integrates cardiovascular, respiratory, muscular, thermal, motivational, and contextual information. For this reason, the present study included both end-session Borg RPE and 30-min sRPE.

The interpretation of small-sample sport-science data requires careful statistical reasoning. Hopkins reviewed reliability measures in sports medicine and science, emphasizing that measurement error and within-athlete variability must be considered [32]. Atkinson and Nevill discussed statistical methods for assessing measurement error and warned against overreliance on a single inferential statistic [33]. Cohen's treatment of statistical power remains relevant because many athlete studies are limited by sample availability [34]. Batterham and Hopkins argued for a magnitude-based interpretation of uncertainty, while later work by Hopkins and colleagues presented progressive statistics for sport and exercise science [35],

[36]. Although this study used conventional $p < 0.05$ significance testing as requested, effect sizes and confidence intervals were also reported to help readers judge the practical size of the condition differences.

Barnes and Kilding reviewed running economy as a key determinant of distance-running performance, noting that economical athletes may run at a given speed at a lower oxygen cost [37]. Poole and colleagues framed critical power as an important fatigue threshold separating exercise domains with different physiological stability [38]. Threshold running sits close to these boundaries. When intensity is only slightly above sustainable steady state, lactate, ventilation, and perceived exertion rise progressively; when intensity remains below that boundary, responses stabilize. Interval recoveries may temporarily reduce strain-related symptoms but can also enable the athlete to spend more total time near the upper boundary of the heavy-intensity domain. This is precisely why interval threshold training may feel manageable during early repetitions but produce higher cumulative physiological and perceptual load by the end of the session.

A further issue in threshold training is that athletes rarely run in perfectly stable physiological conditions. Sleep, glycogen availability, heat stress, emotional stress, and preceding training can all change HR, lactate kinetics, and perceived effort on a given day. Because middle-distance runners often complete threshold work in groups, pacing behavior can also alter the intended stimulus. Athletes may run slightly faster when leading or responding to teammates, and small deviations from target speed can matter near the second threshold. For this reason, the present protocol used individualized pacing targets and recorded adherence to the prescribed speed.

Continuous and intermittent threshold running may also differ in neuromuscular rhythm. Continuous running requires stable pace regulation and progressive tolerance of discomfort. Interval threshold work introduces repeated starts, re-establishment of rhythm after each jog recovery, and a subtle psychological reset at the beginning of each repetition. These features may make the interval format more attractive to athletes, yet the repeated changes in rhythm can increase cardiovascular and metabolic instability. The perceptual response is therefore not obvious in advance: athletes may report higher exertion because the session is physiologically heavier, or they may tolerate the load better because the work is mentally segmented.

HR describes cardiovascular load, [BLa] describes the balance between lactate appearance and removal, RPE describes immediate whole-body strain, sRPE provides a session-level load estimate, affective valence indicates whether the session feels positive or negative, and TQR offers a short-term recovery signal. None of these variables is perfect on its own. Together, however, they provide a practical, multidimensional profile of a training session, which is exactly what coaches need when deciding where the session fits within a microcycle.

Despite this extensive background, direct comparisons between interval and continuous threshold training in male middle-distance runners remain limited. Coaches often rely on tradition, athlete preference, or calendar constraints when deciding whether to prescribe a tempo run or cruise intervals. The assumption that equal threshold work produces equal internal load is attractive because it simplifies planning, but it may be misleading. A rigorous field comparison can clarify whether these formats are interchangeable or whether they should occupy distinct places in the training week. The present study, therefore, combined heart-rate monitoring, capillary blood lactate, RPE, sRPE, affective valence, and perceived recovery to provide a detailed acute profile of both formats.

III. MATERIAL AND METHOD

1. STUDY DESIGN

A randomized, counterbalanced crossover design was used to compare two threshold-running formats in the same athletes. Each athlete completed one CTT session and one ITT session separated by 72-96 h. The order of conditions was randomized using blocks of four, so that half of the sample completed CTT first and the other half completed ITT first. Athletes were instructed to avoid strenuous training, alcohol, and unusual nutritional practices for 24 h before each experimental session and to replicate their pre-session meal and caffeine intake across conditions. Both protocols were performed on the same track, at the same time of day for each athlete, with the same warm-up, footwear instructions, and recovery controls.

The study design was selected because within-athlete comparisons reduce between-athlete variation in trained samples. The two training formats were matched for target threshold speed and accumulated threshold work duration. The only intentional difference was the organization of the work: continuous running for CTT and four threshold repetitions separated by short jog recoveries for ITT. This design allowed the research question to focus on the influence of session format rather than training intensity.

2. PARTICIPANTS

Twenty trained male middle-distance athletes volunteered for the study. Inclusion criteria were: age 18-28 years, current specialization in 800-m or 1500-m running, at least two years of structured middle-distance training, weekly running volume greater than 45 km·week−1, and no lower-limb injury in the previous eight weeks. Exclusion criteria were cardiovascular, metabolic, or respiratory disease; current medication affecting HR or metabolism; and failure to complete both experimental conditions. Participant characteristics are summarized in Table 1. Before testing, all athletes received written and verbal explanations of the procedures, risks, and benefits. Written informed consent was obtained from each participant. The relevant institutional ethics committee approved the protocol.

Table 1. Participant characteristics (n = 20 male middle-distance athletes).

Variable	Unit	Mean ± SD
Age	years	21.5 ± 2.1
Stature	cm	176.8 ± 5.7
Body mass	kg	68.5 ± 4.7
Middle-distance training history	years	5.7 ± 2.0
Weekly running volume	km·week^{-1}	61.4 ± 9.8
Maximal heart rate	beats·min^{-1}	194 ± 5
Velocity at VO2max	km·h^{-1}	19.1 ± 0.8
Velocity at second lactate threshold	km·h^{-1}	16.4 ± 0.6

Values are mean ± SD. vVO2max = velocity at maximal oxygen uptake; vLT2 = velocity at the second lactate threshold.

3. PRELIMINARY TESTING AND THRESHOLD DETERMINATION

Athletes completed a preliminary graded running test 5-7 days before the first experimental session. The test began at 12 km·h−1 and increased by 1 km·h−1 every 3 min until volitional exhaustion. A 30-second break between stages allowed capillary blood sampling from the fingertip. HR was recorded continuously using a chest-strap telemetry system. The second lactate threshold was identified as the running velocity associated with a clear, sustained rise in [BLa] above the preceding stages, supported by the modified Dmax method and visual confirmation by two investigators. If the threshold fell between stages, linear interpolation was used. The resulting vLT2 was used as the target speed for both experimental sessions.

4. EXPERIMENTAL SESSIONS

Both sessions began with a standardized 15-min warm-up consisting of 10 minutes of easy running, mobility drills, and four progressive 80-m strides. The CTT session consisted of 32 minutes of continuous running at 100% of the individual vLT2. The ITT session consisted of 4 × 8 min at 100% of individual vLT2, separated by 2 min of jogging at approximately 60% vLT2. Both sessions ended with a 10-min easy jog cool-down. The threshold work duration was identical across conditions (32 min). The slightly longer elapsed time in ITT was accepted because the recovery jogs are part of the interval prescription and reflect normal coaching practice. Table 2 summarizes the protocols, and Fig. 1 illustrates the session structure.

Table 2. Experimental training protocols.

Condition	Threshold-work structure	Target speed	Recovery structure	Warm-up/cool-down	Purpose
Continuous threshold training (CTT)	32 min continuous	100% individual vLT2	No planned recovery	5-min jog and drills; 10-min easy jog cool-down	Controlled steady threshold exposure
Interval threshold training (ITT)	4 × 8 min	100% individual vLT2	2 min jog at ~60% vLT2 between repetitions	Same warm-up and cool-down	Same threshold work duration with brief relief intervals

CTT = continuous threshold training; ITT = interval threshold training; vLT2 = velocity at the second lactate threshold.

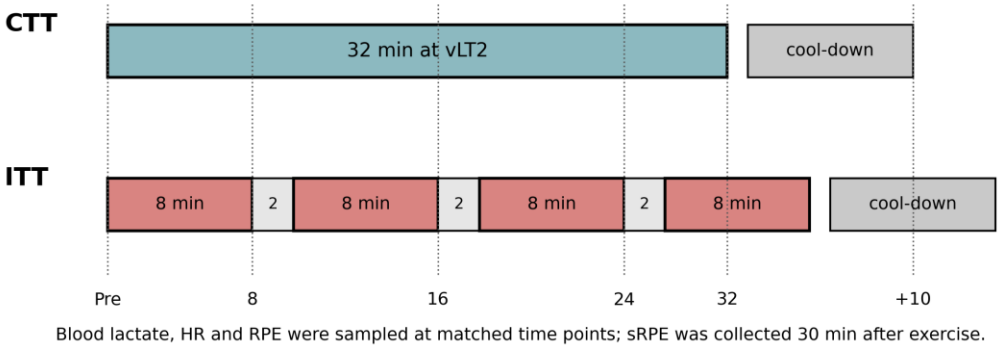


FIGURE 1. Experimental protocol schematic for continuous and interval threshold training. Vertical dotted lines indicate matched measurement points for HR and blood lactate; sRPE was collected 30 min after the session.

5. OUTCOME MEASURES

HR was recorded continuously and later exported as 1-s data. Mean HR, peak HR, mean percentage of individual HRmax, and accumulated time above 90% HRmax were calculated for the threshold-work period. HR-based training impulse (TRIMP) was calculated using session duration and HR reserve weighting. Capillary [BLa] was sampled before exercise, at 8, 16, 24, and 32 min of threshold work, and 10 min after completion. The Borg 6-20 RPE scale was recorded immediately after the threshold-work period. Session RPE was collected 30 min after exercise using a CR-10 scale and multiplied by session duration for descriptive internal-load interpretation. Affective valence was measured using a -5 to +5 feeling scale immediately after the work period, and total quality recovery (TQR) was collected 30 min after exercise.

6. QUALITY CONTROL AND FIELD STANDARDIZATION

The same investigator operated the timing system and blood-lactate analyzer during all sessions. The lactate analyzer was calibrated according to the manufacturer's instructions before each testing block, and duplicate samples were taken when a value was inconsistent with the athlete's preceding stage response or when sampling quality was visible. Athletes wore the same model of racing flat or lightweight trainer across both experimental sessions, and they were asked to use the same lane distribution to minimize distance error. Split times were called every 200 m to help athletes stay close to the target speed without creating a competitive atmosphere.

Environmental conditions were recorded because heat, humidity, and wind can alter HR drift and perceived exertion during threshold work. Sessions were rescheduled if heavy rain, strong winds, or

temperatures above 28 °C occurred. The two trials for each athlete were scheduled at the same time of day whenever possible. These procedures do not eliminate field variability, but they reduce avoidable noise and make the results more applicable.

7. STATISTICAL ANALYSIS

Data were inspected using histograms, Q-Q plots, and Shapiro-Wilk tests. Normally distributed paired outcomes were compared using paired-samples t-tests. Non-normal scale data were checked with Wilcoxon signed-rank tests; parametric results are presented for consistency alongside effect sizes. Time-course HR and [BLa] responses were analyzed using two-way repeated-measures ANOVA with condition (CTT, ITT) and time (Pre, 8, 16, 24, 32, +10 min) as within-athlete factors. When a significant interaction was present, paired comparisons at each time point were interpreted with Bonferroni adjustment. Cohen's dz was calculated for paired comparisons as the mean difference divided by the standard deviation of the difference. Ninety-five percent confidence intervals (95% CI) were calculated for mean differences. Pearson correlations examined associations between within-athlete condition differences. Statistical significance was set at $p < 0.05$.

IV. RESULTS

All 20 athletes completed both sessions without injury or protocol failure. No athlete was excluded from the analysis. Mean environmental temperature during testing was 20.8 ± 1.9 °C for CTT and 21.1 ± 2.1 °C for ITT, with no meaningful difference between conditions. Athletes completed the prescribed threshold work at 99.1 ± 1.3% of target speed in CTT and 99.4 ± 1.2% in ITT, indicating good adherence to the individualized prescription. Protocol adherence and environmental characteristics are shown in Table 3. The main condition comparisons are shown in Table 4.

Table 3. Protocol adherence and environmental conditions.

Variable	Unit	CTT	ITT
Target vLT2	km·h^{-1}	16.4 ± 0.7	16.4 ± 0.7
Actual threshold-work speed	km·h^{-1}	16.2 ± 0.7	16.3 ± 0.7
Speed adherence	% of target	99.1 ± 1.3	99.4 ± 1.2
Accumulated threshold-work duration	min	32.0 ± 0.0	32.0 ± 0.0
Accumulated threshold-work distance	km	8.64 ± 0.37	8.69 ± 0.38
Recovery-jog distance	km	0.00 ± 0.00	1.19 ± 0.14
Total elapsed session time	min	57.0 ± 0.0	63.0 ± 0.0
Ambient temperature	°C	20.8 ± 1.9	21.1 ± 2.1
Relative humidity	%	48 ± 7	50 ± 8

Values are mean ± SD. CTT = continuous threshold training; ITT = interval threshold training; vLT2 = velocity at the second lactate threshold.

Table 3 confirms that the two threshold sessions were implemented as intended. The athletes ran very close to the same target threshold speed in both conditions, and the accumulated threshold-work duration was identical. The ITT session necessarily included additional jog-recovery distance and a longer elapsed session time. Environmental conditions were mild and similar between sessions, reducing the likelihood that temperature or humidity explained the physiological differences.

Table 4. Acute physiological and perceptual responses to continuous and interval threshold training.

Outcome	Unit	CTT	ITT	ITT-CTT	95% CI	t	p	dz
Mean heart rate	bpm	170.3 ± 5.3	177.8 ± 6.3	7.52	5.00 to 10.04	6.24	<0.001	1.40
Peak heart rate	bpm	183.8 ± 7.1	188.1 ± 6.9	4.22	2.24 to 6.21	4.46	<0.001	1.00
Mean HRmax	%	87.7 ± 3.1	90.7 ± 3.5	2.96	1.98 to 3.94	6.35	<0.001	1.42

Time >90% HRmax	min	13.7 ± 3.5	19.5 ± 6.4	5.79	3.37 to 8.21	5.01	<0.001	1.12
HR-based TRIMP	AU	71 ± 12	80 ± 13	9.00	6.56 to 11.45	7.72	<0.001	1.73
Post-session blood lactate	mmol·L⁻¹	4.12 ± 1.10	5.12 ± 1.31	1.00	0.73 to 1.27	7.68	<0.001	1.72
10-min blood lactate	mmol·L⁻¹	2.93 ± 0.71	3.27 ± 0.86	0.34	0.16 to 0.52	3.94	<0.001	0.88
End-session Borg RPE	6-20	15.3 ± 1.3	16.2 ± 1.3	0.93	0.57 to 1.29	5.45	<0.001	1.22
Session RPE	CR-10	5.8 ± 1.0	6.6 ± 1.0	0.76	0.56 to 0.97	7.68	<0.001	1.72
Affective valence	-5 to +5	1.4 ± 1.1	0.7 ± 1.3	-0.72	-1.30 to -0.15	-2.65	0.016	-0.59
Total quality recovery, 30 min	6-20	14.5 ± 1.2	13.7 ± 1.3	-0.84	-1.12 to -0.55	-6.16	<0.001	-1.38

Values are mean ± SD. Positive differences indicate higher values in ITT. HRmax = maximal heart rate; TRIMP = training impulse; BLa = blood lactate concentration; RPE = rating of perceived exertion; sRPE = session rating of perceived exertion; TQR = total quality recovery; dz = paired standardized effect size. Statistical significance was set at $p < 0.05$.

ITT produced a higher cardiovascular load than CTT. Mean HR was higher by approximately six beats·min−1, mean %HRmax was higher by about three percentage points, and time above 90% HRmax increased by nearly six minutes. The magnitude of the HR difference was moderate. In contrast, the difference in time above 90% HRmax was practically meaningful, representing a sizeable increase in high-cardiovascular-strain exposure within a session with the same target threshold speed.

The lactate response also differed between formats. Post-session [BLa] was higher after ITT, and [BLa] remained modestly higher 10 min after exercise. These values were not excessive for trained middle-distance athletes but indicated that the interval format led to a greater glycolytic contribution and reduced lactate clearance relative to continuous running. RPE and sRPE were higher after ITT, while affective valence and TQR were lower, indicating that athletes perceived ITT as more demanding despite the inclusion of jog recoveries.

Table 5. Repeated-measures ANOVA for heart-rate and blood-lactate time-course responses.

Variable	Effect	F	df	p
Heart rate (%HRmax)	Condition	159.27	1, 19	<0.001
Heart rate (%HRmax)	Time	1542.86	5, 95	<0.001
Heart rate (%HRmax)	Condition × Time	5.23	5, 95	<0.001
Blood lactate	Condition	67.24	1, 19	<0.001
Blood lactate	Time	385.95	5, 95	<0.001
Blood lactate	Condition × Time	8.55	5, 95	<0.001

Condition = CTT vs ITT; Time = Pre, 8, 16, 24, 32, and +10 min. Significant condition × time effects indicate that the difference between formats changed during the session.

Table 5. shows significant condition, time, and condition × time effects for HR and [BLa]. The significant time effect confirmed that both variables increased during the threshold-work period and declined after exercise. The significant condition × time interaction indicated that ITT and CTT did not differ uniformly across the session; rather, the formats separated progressively during the work period. Fig. 2 shows that HR was similar before exercise but rose more rapidly and remained higher during the later stages of ITT. Fig. 3 shows a similar pattern for [BLa], with the largest between-condition difference at the end of threshold work.

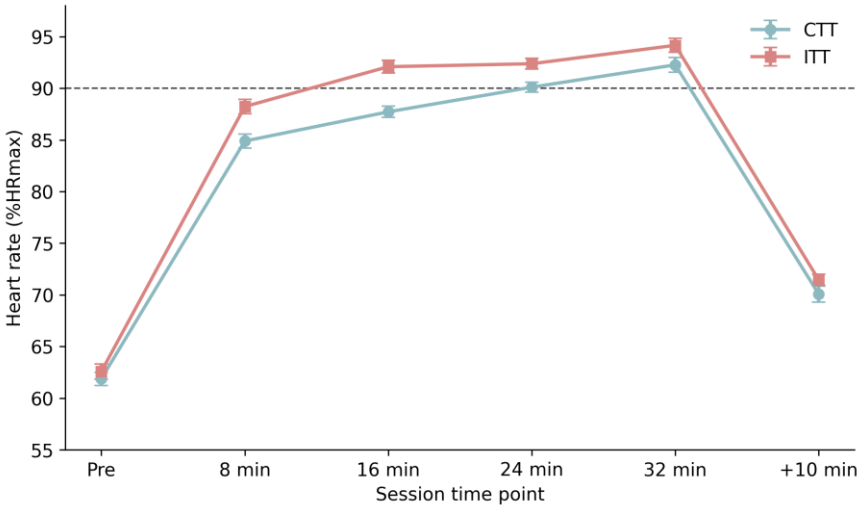


FIGURE 2. Heart-rate time course during continuous threshold training and interval threshold training. Values are mean ± SEM. The dashed line represents 90% HRmax.

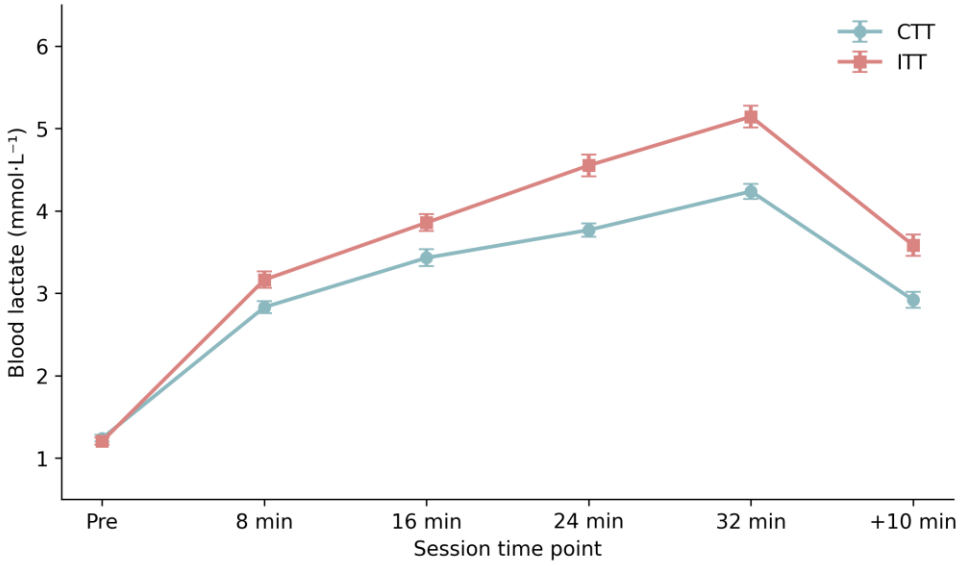


FIGURE 3. Blood-lactate time course during continuous threshold training and interval threshold training. Values are mean ± SEM.

Perceptual outcomes are displayed in Fig. 4. End-session Borg RPE and sRPE were higher after ITT, while affective valence and TQR were lower. The direction of these changes was consistent with the physiological findings, suggesting that athletes experienced the interval format as a heavier internal-load session. The differences were not extreme, but they were large enough to influence training-week planning when threshold work is placed near speed endurance, strength training, or competition.

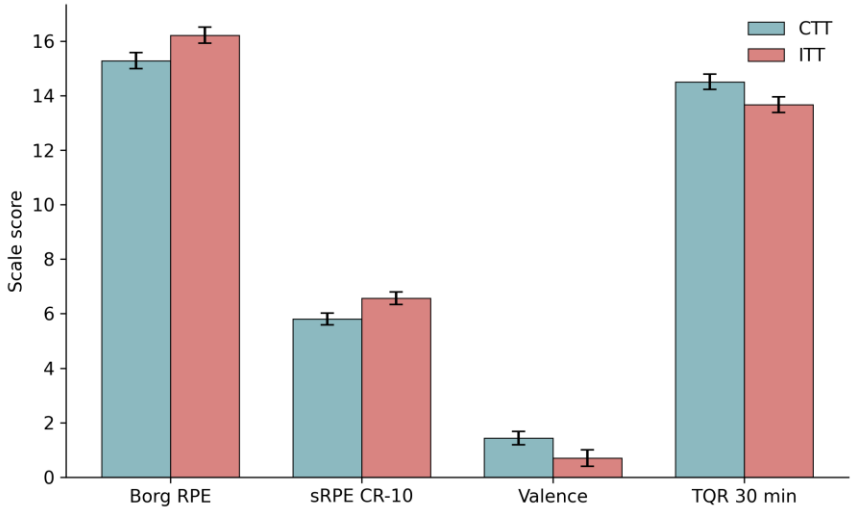


FIGURE 4. Perceptual responses after continuous and interval threshold training. Values are mean ± SEM. Higher Borg RPE and sRPE indicate greater perceived exertion; higher valence and TQR indicate a more positive affective state and better perceived recovery.

Individual responses are shown in Figs. 5 and 6. Most athletes demonstrated higher mean %HRmax and higher post-session [BLa] after ITT than after CTT, although the size of the difference varied. This variation is important because it shows that the interval format did not affect every athlete equally. Some runners showed only a small increase in HR or [BLa], whereas others showed larger increases that may require additional recovery or a lower subsequent training load.

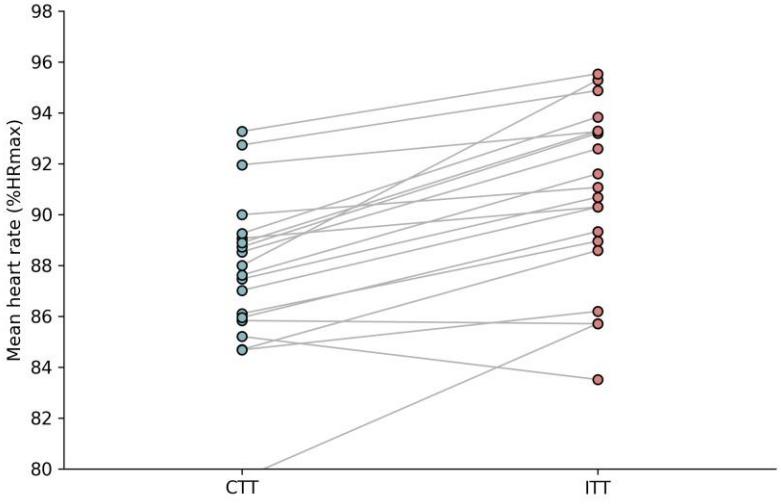


FIGURE 5. Individual paired mean heart-rate responses during continuous and interval threshold training. Each grey line represents one athlete.

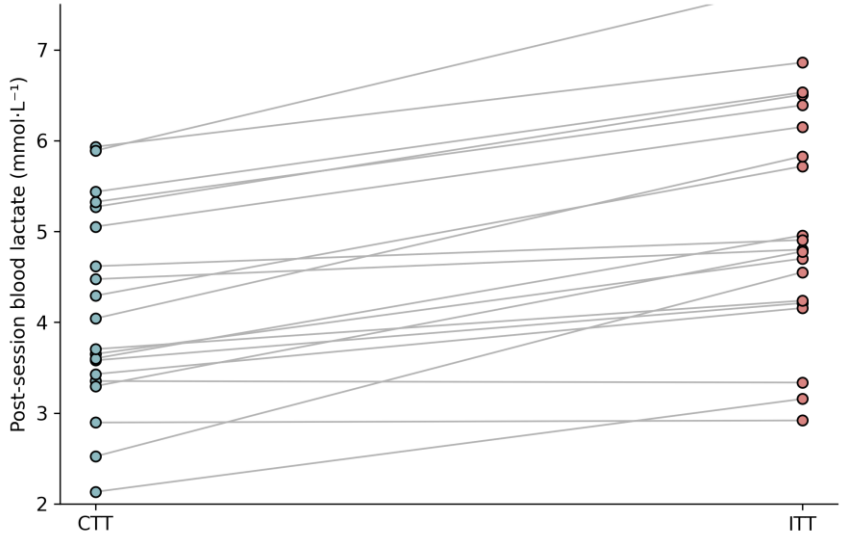


FIGURE 6. Individual paired post-session blood-lactate responses during continuous and interval threshold training. Each grey line represents one athlete.

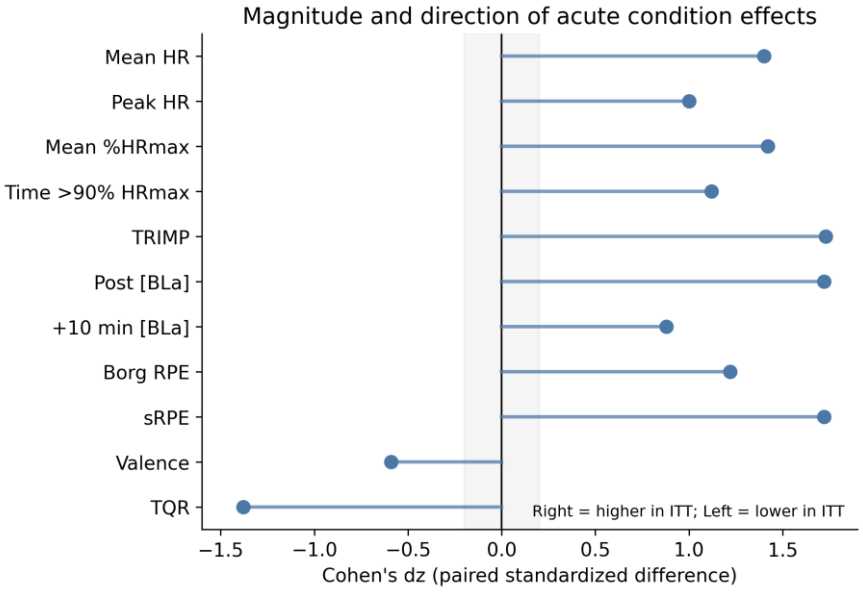


FIGURE 7. Standardized paired effect sizes for the main physiological and perceptual outcomes. Positive values indicate higher responses in interval-threshold training; negative values indicate lower responses.

Fig. 7 provides a compact view of the magnitude and direction of the acute effects. The largest positive effects were observed for HR-based TRIMP, post-session blood lactate, session RPE, and mean %HRmax, confirming that the interval format increased both physiological and perceptual load. Negative effects for affective valence and TQR indicate that the heavier internal load was accompanied by a less positive immediate affective response and lower short-term perceived recovery. This pattern supports the interpretation that ITT is a stronger threshold stimulus, not simply a more fragmented version of the same continuous run.

Table 6. Associations between within-athlete condition differences.

Association	r	p
Δ blood lactate vs Δ session RPE	0.69	<0.001
Δ time >90% HRmax vs Δ TRIMP	0.88	<0.001
Δ mean HRmax vs Δ blood lactate	0.16	0.501

Δ values were calculated as ITT minus CTT. Positive r values indicate that athletes with larger physiological increases also tended to show larger perceptual or internal-load increases.

The exploratory association analysis in Table 6 showed that athletes with larger increases in post-session [BLa] tended to report larger increases in sRPE. The increase in time above 90% HRmax was also associated with the increase in HR-based TRIMP. These findings support the internal consistency of the physiological and perceptual measures and suggest that the greater perceived difficulty of ITT was not merely a psychological response to the interval structure; it was linked to measurable differences in internal load.

V. DISCUSSION

The main finding was that interval-threshold training produced greater acute physiological and perceptual strain than continuous-threshold training when threshold-work duration and target speed were matched. ITT increased mean HR, time above 90% HRmax, HR-based TRIMP, post-session [BLa], Borg RPE, and sRPE, while reducing affective valence and perceived recovery. The differences were moderate rather than extreme. ITT should not be viewed as a maximal interval session, but it should also not be treated as identical to a continuous tempo run. The data support the view that session format is an independent programming variable.

The higher cardiovascular response during ITT is consistent with previous interval-training work showing that work-bout and recovery structure influence internal load [22]-[24]. The brief jog recoveries likely allowed athletes to sustain the target threshold speed with less continuous local discomfort, but repeated accelerations and incomplete recovery may have increased cardiovascular drift across repetitions. This interpretation aligns with the broader HIIT programming literature, which emphasizes that rest intervals do not merely reduce load; they can alter the distribution of physiological stress across the session [8]-[10]. In the present data, HR during ITT rose above the 90% HRmax line earlier and remained higher during the later work period. For coaches, this means that cruise intervals at threshold speed can be used when the goal is to accumulate more high-HR exposure without prescribing faster-than-threshold running.

Continuous threshold running produced a gradual increase in [BLa] to approximately 4 mmol·L−1, which is consistent with a controlled second-threshold stimulus. ITT produced a higher end-of-session [BLa], but the mean remained within a realistic range for trained middle-distance athletes. This supports the idea that the interval format increased glycolytic contribution without turning the session into a race-pace lactate-tolerance workout. Faude and colleagues cautioned that threshold concepts are valid only when methodological context is respected [12], and Beneke and colleagues noted that blood lactate is sensitive to both intensity and duration [13]. The present findings add that format can alter [BLa] even when nominal intensity and work duration are matched.

The perceptual results are important because they show that athletes recognized the greater physiological demand. Borg RPE and sRPE were higher after ITT, and TQR was lower 30 min later. These findings are consistent with the RPE literature, in which perceived exertion integrates multiple signals, including respiratory effort, muscle discomfort, cardiovascular strain, and psychological tolerance [28]-[31]. The higher sRPE after ITT suggests that, in a training log, the interval session would produce a greater internal-load score than CTT. This has implications for weekly load management. If a coach replaces a 32-min continuous threshold run with 4 × 8-minute runs at the same speed, the athlete may receive a stronger stimulus but also greater short-term fatigue.

Seiler and colleagues emphasized that endurance athletes usually manage intensity carefully, and that excessive emphasis on the threshold can accumulate fatigue [18], [19]. Esteve-Lanao et al. and Stöggl and Sperlich showed that the distribution of training intensity affects adaptation over time [20], [21]. The present findings suggest that the classification of a session as threshold training should take into account both

external intensity and format. A week with two interval threshold workouts may impose more internal load than a week with two continuous threshold runs, even if the total threshold work duration is identical. This distinction may help explain why athletes sometimes respond differently to training plans that appear similar on paper.

Seiler and Sjursen found that work duration affects physiological and RPE responses during self-paced intervals [22]. Seiler and Hetlelid reported that changes in rest duration affect work intensity and perceived exertion [23]. Smith et al. and Denadai et al. showed that interval training at intensities related to maximal aerobic speed can alter endurance performance markers [25], [26]. Although the present sessions were performed at threshold rather than vVO2max, the direction of evidence is similar: interval details matter. The present study extends this principle to a training zone often considered controlled and steady.

Middle-distance athletes may respond differently to interval threshold running than long-distance athletes because they possess a relatively high speed reserve and are accustomed to intermittent work. This may explain why the observed [BLa] values were moderately elevated but not excessive. The athletes could maintain target speed without large lactate accumulation, likely because their event training had developed both oxidative capacity and tolerance of intermittent metabolic stress. This agrees with early work showing that middle-distance performance relies on both aerobic and anaerobic capacities [1]-[5]. For 800-m runners, ITT may be a useful bridge between continuous threshold work and race-specific repetitions. For 1500-m runners, it may provide a way to increase cardiovascular load while preserving mechanics at threshold speed.

Figs. 5 and 6 showed that almost all athletes had higher HR and [BLa] after ITT, but the size of the increase varied. This variation may reflect differences in running economy, lactate kinetics, muscle-fiber composition, threshold determination, or recent training fatigue. Barnes and Kilding highlighted that running economy varies between athletes and can influence the cost of a given speed [37]. Poole and colleagues emphasized that physiological thresholds separate exercise domains with different stability [38]. An athlete operating close to the upper boundary of the sustainable threshold intensity may show a greater response to the interval format than an athlete whose prescribed speed is comfortably below that boundary. Coaches should therefore monitor individual responses rather than applying a single recovery rule to an entire group.

The correlation analysis provides additional support for the interpretation that athletes did not simply rate ITT as harder because it appeared more complex. The athlete-level increase in post-session [BLa] was associated with increases in sRPE, and the increase in time above 90% HRmax was strongly associated with increases in HR-based TRIMP. These relationships are not proof of causation, but they show coherence between metabolic, cardiovascular, and perceptual markers. In applied monitoring, such an agreement is useful because it increases confidence that a single unusual value is not driving the interpretation.

Affective valence was lower after ITT, but the mean value remained positive. This suggests that athletes did not find ITT unpleasant in absolute terms; rather, they found it less comfortable than CTT. Similarly, TQR declined after ITT but remained within a moderate recovery range. For trained athletes, this type of response may be desirable when the goal is to create a meaningful threshold stimulus without excessive disruption. The risk arises when coaches schedule ITT under the assumption that it is a low-cost substitute for continuous threshold running.

The findings should be interpreted with limitations. First, the values represent a controlled field comparison in a sample of trained male middle-distance athletes; they should not be generalized directly to female athletes, adolescents, recreational runners, or elite international finalists without additional data. Second, oxygen uptake and running mechanics were not measured during the field sessions, so the mechanisms behind the higher HR and lactate responses cannot be fully separated. Third, the interval session had a longer elapsed duration because jog recoveries were included. Fourth, the study measured only acute responses. Whether repeated use of ITT produces superior adaptation or greater fatigue than CTT would require a longitudinal training study.

Despite these limitations, the study provides useful evidence for applied programming. Continuous threshold training appears to deliver a steadier, slightly lower internal-load stimulus, suitable for weeks when athletes need aerobic support without excessive fatigue. Interval threshold training creates a stronger cardiometabolic and perceptual stimulus while preserving the same work duration at the same threshold. It may therefore be useful when the training goal is to accumulate high-quality threshold work over a longer

period at higher HR. However, because ITT also increases perceived strain and lowers short-term recovery, it should be placed thoughtfully within the microcycle.

A strength of the design is that the two threshold sessions were matched for individualized target speed and accumulated threshold-work duration. This allowed the comparison to focus on session organization rather than a simple difference in prescribed intensity. The randomized crossover structure also reduced between-athlete variability, because each runner served as their own control. The field setting is another strength because it preserved normal running mechanics, group familiarity, and the surface conditions under which middle-distance athletes usually complete threshold work. At the same time, field studies cannot control every source of variation. Wind, pacing micro-variation, footwear comfort, recent muscle soreness, and motivational state can all influence physiological and perceptual responses. These sources of noise were reduced through familiarization, standardized warm-up procedures, similar environmental conditions, and repeated measurements, but they cannot be completely removed.

A stronger internal load during ITT does not automatically mean that ITT is superior for improving performance; it means that ITT is not the same stimulus as CTT when inserted into a training week. Longitudinal studies are needed to test whether the greater cardiovascular and perceptual load observed here translates into better middle-distance performance, greater fatigue, or no additional benefit compared with continuous threshold work. Future studies should also include female athletes, adolescent runners, and highly trained international competitors, as the balance between aerobic capacity, anaerobic contribution, and running economy may affect the response to threshold intervals. Adding portable gas exchange, muscle oxygenation, or biomechanical monitoring would help explain whether the higher HR and [BLa] in ITT arise mainly from altered oxygen demand, cardiovascular drift, neuromuscular cost, or incomplete recovery between work bouts.

VI. CONCLUSION

This study showed that interval and continuous threshold formats are not interchangeable for trained male middle-distance athletes, even when the same individualized threshold speed and accumulated threshold-work duration are used. The interval format, organized as 4 × 8 min at vLT2 with 2-min jog recoveries, produced higher mean HR, greater time above 90% HRmax, higher HR-based TRIMP, greater post-session blood lactate concentration, higher Borg RPE, and higher session RPE than a 32-min continuous run at the same speed. At the same time, affective valence and short-term perceived recovery were lower after the interval format. These differences were moderate and physiologically realistic, but they are large enough to matter in the day-to-day planning of middle-distance training. The key message is that threshold speed alone does not fully define the training stimulus. The way threshold work is organized changes the internal load experienced by the athlete.

For coaches and sport scientists, continuous threshold training may be the steadier option when the goal is to develop aerobic capacity through controlled metabolic stress. Interval threshold training may be considered a stronger stimulus, allowing athletes to accumulate threshold-speed running while spending more time at high percentages of HRmax. This may be valuable during phases in which athletes need robust aerobic development without moving into full race-pace or suprathreshold interval work. However, the higher sRPE and lower TQR suggest that ITT should be scheduled with attention to recovery, especially when combined with speed endurance sessions, resistance training, or competitions. The findings also support the routine use of simple monitoring tools such as HR, capillary [BLa] when available, Borg RPE, sRPE, and short-term recovery ratings. These measures help identify whether a prescribed threshold session is functioning as intended for each athlete.

The study reinforces a broader principle in endurance training: equal external work does not always produce equal internal load. Athletes may complete the same distance or duration at the same target speed but experience different cardiovascular, metabolic, and perceptual stress depending on session structure. Future studies should examine whether these acute differences translate into different longitudinal adaptations in middle-distance runners, and whether sex, training age, event specialization, and baseline running economy modify the response. Until such data are available, coaches should treat interval threshold training as a distinct session type rather than a simple substitute for continuous tempo running.

Author Contributions

The author conducted the conceptualization, methodology, data analysis, investigation, writing, review, editing, and final approval of the manuscript.

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Data Availability

The dataset will be available from the author upon reasonable request.

Conflicts of Interest

The author declares no conflict of interest.

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