Lactate threshold speed and fractional utilisation as key correlates of HYROX© performance in trained males

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Headline

Few studies address the determinants of HYROX© performance. The only one reported VO_2max as the strongest correlate in recreational athletes. Endurance research suggests that within a well-trained group of similar VO_2max, the ceiling becomes a prerequisite rather than a discriminator, and threshold indices the better predictors. In eight trained male HYROX© competitors, threshold speed (LT2) and fractional utilisation (VO_2 at LT2 as a percentage of VO_2max) showed large-to-very-large associations with running, functional-station and total-race time. VO_2max range was too narrow to resolve.

Aim of the paper

HYROX© is a hybrid endurance race pairing eight 1 km runs with eight functional strength-endurance stations (sled push/pull, burpee broad jumps, rowing, farmers carry, lunges, wall balls). Among the few physiological studies to date, Brandt and colleagues (1) found VO_2max to be the strongest determinant of HYROX© performance (Spearman ρ = -0.71) in a recreational cohort (n = 11, mixed sex; VO_2max spanning 46.6–72 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$). Across such a wide aerobic range, VO_2max readily discriminates fast from slow athletes; notably, in that study participant characteristics correlated with running time but not with exercise-station time, leaving the determinants of station performance unresolved. The broader endurance literature, however, indicates that once athletes are well trained and homogeneous in VO_2max, the maximal ceiling becomes a prerequisite rather than a discriminator. Conversely, threshold velocity, and the fraction of VO_2max that is sustainable (fractional utilisation), become the superior predictors of performance (2-4).

It is anticipated that this is especially true for HYROX©, as unlike continuous, steady-state events, competitors must repeatedly surpass their maximal metabolic steady state (MMSS) to complete the stations. Consistent with this, both blood lactate and heart rate are higher during stations than runs (∼8.5 vs 7.7 $mmol{\cdot}L^{-1}$; 185 vs 180 bpm) (1). Work above the MMSS accrues a fatigue cost that is only repaid at intensities below it (5-7), so runs are ideally paced at or below LT2 (Figure 1). Accordingly, we aimed to evaluate the ability of LT2 and fractional utilisation to predict HYROX© performance in a cohort of trained males homogeneous in VO_2max.

Methods

Design: cross-sectional observational study. The study was conducted in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to testing.

Eight male HYROX© solo competitors (Pro and Open divisions; trained sub-elite to elite; mean ± SD age 29.6 ± 5.8 yr, body mass 91.0 ± 6.7 kg) completed laboratory testing and had a matched competition result (HYROX© finishing time: 69.7 ± 6.3 min). During a single visit, participants completed a combined incremental treadmill test determining the first and second lactate thresholds (LT1, LT2) and maximal oxygen uptake (VO_2max). After standardised pre-test instructions (no strenuous exercise for 24 h; light carbohydrate meal 2–3 h prior), they ran on a motorised treadmill (COSMED T150LC) at a 1% gradient to reflect the energetic cost of outdoor running (8), starting at ∼70% of recent race pace (10km to Marathon distance) and increasing 1 $km{\cdot}h^{-1}$ every 4 min to volitional exhaustion (9).

Pulmonary gas exchange was measured breath-by-breath (ParvoMedics TrueOne 2400; 15-s averages) and heart rate via chest strap (Polar H10). After each 4-min stage, a 1-min rest permitted a capillary fingertip blood-lactate sample (Arkray Lactate Pro 2), with a resting sample taken before testing to construct the lactate–velocity curve. Participants then completed a constant-load verification bout at ∼100–105% of the final stage speed to exhaustion; VO_2max was taken as the highest 30-s rolling average and accepted when incremental and verification values agreed within 3% alongside secondary criteria (peak Respiratory Exchange Ratio (RER) ≥ 1.10, HR within 10 bpm of age-predicted maximum). LT2 was quantified as the individualised modified Dmax (mDmax) speed (primary), with the fixed 4 $mmol{\cdot}L^{-1}$ Onset of Blood Lactate Accumulation (OBLA) speed as a standardised cross-check. Fractional utilisation was calculated as the VO_2 at LT2 expressed as a percentage of VO_2max; VO_2 at the LT2 speed was obtained from the breath-by-breath data as the steady-state VO_2 (final ∼60 s) of each 4-min stage, interpolated to the individualised mDmax LT2 speed. Running economy was calculated as the O_2 cost of running (steady-state $VO_2 \times 60 \div$ speed; $ml{\cdot}kg^{-1}{\cdot}km^{-1}$), averaged across the 12 and 14 $km{\cdot}h^{-1}$ stages completed sub-maximally by all athletes.

Each participant's most recent official HYROX© result (retrieved from the official HYROX© results website and raced within six weeks of laboratory testing) provided total time, segment splits (running, functional-station and roxzone time), and overall and age-group rankings (percentile; lower = better).

Magnitude-based inferences are reported rather than null-hypothesis tests: associations are Pearson correlations with 90% confidence intervals (CI; Fisher z), interpreted by magnitude (trivial < 0.1, small 0.1–0.3, moderate 0.3–0.5, large 0.5–0.7, very large 0.7–0.9, nearly perfect ≥ 0.9) (10). Exploratory linear regression was limited to single predictors. Findings are exploratory and hypothesis-generating. Where a confidence interval spanned substantially different magnitudes, the inference is reported as unclear. Spearman rank correlations and leave-one-out re-estimation of r are provided in the accompanying dataset as sensitivity analyses.

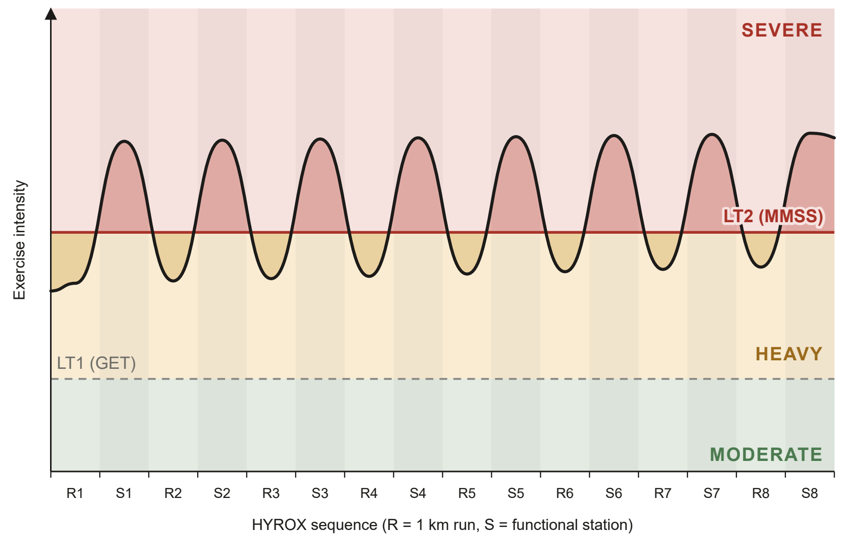

Fig. 1. Proposed pacing framework for HYROX relative to the three exercise-intensity domains. The second lactate threshold (LT2) marks the maximal metabolic steady state (MMSS) and the heavy–severe boundary; LT1 (gas-exchange threshold, GET) marks the moderate–heavy boundary. Stations push intensity into the severe domain, consistent with the higher lactate and heart rate reported at stations than runs (1).

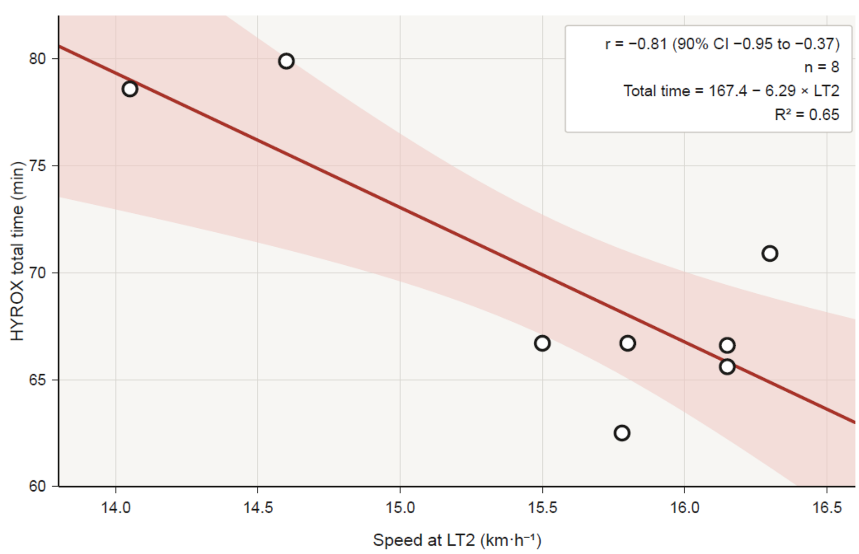

Fig. 2. Threshold running speed (LT2, mDmax) versus total HYROX© time (n = 8).

Results

Descriptive characteristics are shown in Table 1 and all associations in Table 2. Threshold running speed (LT2, mDmax) was the strongest correlate of total race time (r = -0.81, 90% CI [-0.95, -0.37]); a single-predictor model — total time (min) = 167.4 - 6.29 × LT2 ($km \cdot h^{-1}$) — explained ~65% of the variance (R^2 = 0.65), or ~6.3 min per +1 $km \cdot h^{-1}$ of threshold speed. Fractional utilisation was a consistent correlate across total time, functional-station time and overall ranking (r = -0.63 to -0.71; the related VO_2 at LT2 was the strongest correlate of station time, r = -0.84 [-0.96, -0.45]). By contrast, relative VO_2max and running economy were unclear against total time (r = +0.06 and +0.03), the cohort's narrow VO_2max range (50.4–57.0 $ml \cdot kg^{-1} \cdot min^{-1}$) precluding resolution.

Table 1. Descriptive characteristics of the pilot cohort (n = 8).

Variable	Mean ± SD	Range
Age (yr)	29.6 ± 5.8	24–41
Body mass (kg)	91.0 ± 6.7	83.5–100.1
VO_2max (ml·kg^{-1}·min^{-1})	53.1 ± 1.9	50.4–57.0
vVO_2max (km·h^{-1})	17.6 ± 1.2	16.0–19.5
LT1 speed (km·h^{-1})	13.0 ± 1.3	11.5–15.0
LT2 speed, mDmax (km·h^{-1})	15.6 ± 0.8	14.1–16.3
LT2 by OBLA, 4 mmol·L^{-1} (km·h^{-1})	15.1 ± 1.4	12.9–16.6
Fractional utilisation (LT2 %VO_2max)	89.6 ± 4.7	83.1–96.8
VO_2 at LT2 (ml·kg^{-1}·min^{-1})	47.5 ± 1.9	43.9–49.8
Running economy (ml·kg^{-1}·km^{-1})	191 ± 10	178–206
Total race time (min)	69.7 ± 6.3	62.5–79.9
Running time (min)	31.8 ± 2.3	28.9–34.7
Functional-station time (min)	31.7 ± 3.9	27.5–39.2
Roxzone time (min)	6.3 ± 1.0	5.0–8.2

SD, standard deviation; VO_2max, maximal oxygen uptake; vVO_2max, velocity at VO_2max; LT1, first lactate threshold (gas-exchange threshold); LT2, second lactate threshold; mDmax, modified Dmax method; OBLA, onset of blood lactate accumulation (fixed 4 mmol·L^{-1}); VO_2 at LT2, oxygen uptake at the LT2 speed.

Table 2. Associations (Pearson r [90% CI], magnitude) of aerobic/threshold variables with HYROX© performance (n = 8). Negative r = higher value linked to faster time/better rank.

Predictor	Outcome	r [90% CI]	Magnitude
LT2 speed (mDmax)	Total time	-0.81 [-0.95, -0.37]	Very large
LT2 by OBLA	Total time	-0.75 [-0.94, -0.23]	Very large
Fractional utilisation	Total time	-0.63 [-0.90, -0.01]	Large
VO_2 at LT2	Total time	-0.74 [-0.93, -0.21]	Very large
LT1 speed	Total time	-0.49 [-0.85, +0.20]	Unclear
Running economy	Total time	+0.03 [-0.61, +0.64]	Unclear
VO_2max (relative)	Total time	+0.06 [-0.59, +0.66]	Unclear
LT2 by OBLA speed	Running time	-0.73 [-0.93, -0.19]	Very large
LT2 speed (mDmax)	Running time	-0.69 [-0.92, -0.11]	Large
LT1 speed	Running time	-0.55 [-0.87, +0.12]	Unclear
Running economy	Running time	+0.15 [-0.53, +0.71]	Unclear
Fractional utilisation	Station time	-0.70 [-0.92, -0.13]	Very large
VO_2 at LT2	Station time	-0.84 [-0.96, -0.45]	Very large
LT2 speed (mDmax)	Station time	-0.77 [-0.94, -0.28]	Very large
Fractional utilisation	Overall rank	-0.71 [-0.93, -0.15]	Very large
VO_2 at LT2	Overall rank	-0.74 [-0.93, -0.21]	Very large

r, Pearson correlation coefficient; CI, confidence interval; Negative r = higher predictor value linked to a faster time / better (lower) rank.

Discussion

Threshold running speed was the leading correlate not only of running time but also of functional station time – the outcome that superficially appears to be dictated by neuromuscular strength. This fits the threshold mechanism: stations are completed under accumulated fatigue, so the athlete who is least metabolically stressed by the sub-threshold running (a high LT2 and high fractional utilisation) arrives at each station with more anaerobic reserve and replenishes it faster between efforts. Fatigue resistance, an aerobic quality, therefore, appears to also contribute to station performance alongside neuromuscular strength or skill requirements. Consistent with this, the absolute VO_2 sustained at LT2 was the strongest correlate of station time in this cohort, although it partly reflects VO_2max and is not independent of aerobic capacity.

The absence of a resolvable VO_2max association is best read as a restricted-range effect rather than evidence that aerobic capacity is unimportant. Our cohort spanned only 50–57 ml·kg^{-1}·min^{-1}, so the maximal ceiling was effectively constant and could not discriminate performance; what separated athletes was the fraction of that ceiling they could sustain, captured by LT2 and fractional utilisation. This reconciles our null with Brandt and colleagues' [1] positive VO_2max association: their recreational, mixed-ability cohort spanned a wider aerobic range (46.6–72 ml·kg^{-1}·min^{-1}), in which VO_2max necessarily discriminates. It also extends their work: in that cohort, participant characteristics predicted running but not station time, whereas here fractional utilisation was also a strong correlate of station performance. This suggests that aerobic fatigue resistance partly contributes to station performance, rather than solely strength, power or strength-endurance qualities. This mirrors the wider endurance literature, where threshold and fractional-utilisation indices routinely outperform VO_2max within trained groups. A larger, adequately powered study could test these relationships directly, incorporating additional measures of neuromuscular strength, power and muscular-endurance qualities profiled alongside the running parameters, since these also contribute to HYROX© performance. One caveat on interpretation: fractional utilisation and the absolute VO_2 at LT2 both derive from the VO_2 measured at the LT2 speed, and VO_2 at LT2 additionally embeds VO_2max, so these variables are collinear by construction and should not be read as independent determinants.

Practical applications

These follow from a cross-sectional pilot (n = 8) and are offered as working hypotheses consistent with the proposed mechanism, not as demonstrated cause and effect.

- Profile athletes with a threshold test. LT2 (mDmax as the primary index, OBLA for cross-lab comparability) offers a low-cost, high-information marker of HYROX© potential; VO_2max is worth measuring chiefly to derive fractional utilisation.
- Train to raise threshold speed. Prioritise threshold-oriented running to lift sustainable pace and widen the zone that can be held below LT2; protect easy-day volume below LT1 to broaden the aerobic base.
- Pace runs at or just below LT2. Encourage athletes to hold run segments marginally under threshold. This follows from the intensity-domain framework rather than from the present data, which did not measure pacing.
- Determine LT2 individually. The runs are the only opportunity to recover before the next station, so knowing an athlete's actual threshold speed rather than estimating it appears necessary for sensible pacing and prescription.
- Rehearse stations under fatigue. Use run–station couplets so station work is trained in the metabolically stressed state that it is raced, targeting the fatigue-resistance quality the data implicate.

Limitations

This is a small, exploratory pilot (n = 8) in trained males only; confidence intervals are wide and no causal claims are made. LT2 is a laboratory threshold marker rather than a direct measure of the maximal metabolic steady state (no maximal-lactate-steady-state verification or time-trial protocol was performed), and running economy was estimated from incremental-stage VO_2 rather than a dedicated constant-speed protocol. Some athletes competed in different categories, and events/venues, so total time is only partially standardised (rankings mitigate this). Findings should be confirmed in a larger, more heterogeneous cohort that includes women and a wider ability range, alongside additional assessments of neuromuscular qualities (e.g., strength, power, muscular endurance etc.).

AI use statement

Language and editing: Claude was used to correct grammar and shorten aspects of the manuscript. Figures and tables: Both figures were generated by Claude from the author's sketch (Figure 1) and the collected data (Figure 2).

Accompanying dataset

The anonymised pilot dataset (n = 8) underlying these findings is available from the corresponding author on reasonable request.

Conflicts of interest

PL is co-founder of Athletica AI., a training-prescription platform, and HIIT Science, an education platform. DJP is the founder of ENDUROX Training and ENDURE IQ, a commercial endurance coaching provider. Both entities deliver services informed by threshold-based training prescription of the kind discussed here. CJD declares no competing interests. No external funding was received for this work.

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