The relationship between the moderate-heavy boundary and critical speed in running.

Abstract

Purpose

Training characteristics such as duration, frequency, and intensity can be manipulated to optimise endurance performance, with an enduring interest in the role of training intensity distribution to enhance training adaptations. Training intensity is typically separated into three zones, which align with the moderate, heavy, and severe intensity domains. While estimates of the heavy-severe intensity boundary, i.e., the critical speed (CS) can be derived from habitual training, determining the moderate-heavy boundary or first threshold (T1) requires testing, which can be costly and time-consuming. Therefore, the aim of this review was to examine the percentage at which T1 occurs relative to CS.

Results

A systematic literature search yielded 26 studies with 527 participants, grouped by mean CS into low (11.5 km·h⁻1; 95% CI [11.2, 11.8]), medium (13.4 $\text{km}\cdot\text{h}^{-1}$; 95% CI [13.2, 13.7]), and high (16.0 $\text{km}\cdot\text{h}^{-1}$; 95% CI [15.7, 16.3]) groups. Across all studies, T1 occurred at 82.3% of CS (95% CI [81.1, 83.6]). In the medium and high CS groups, T1 occurred at a higher fraction of CS (83.2% CS (95% CI [81.3, 85.1]) and 84.2% CS (95% CI [82.3, 86.1]), respectively) relative to the low CS group (80.6% CS; 95% CI [78.0, 83.2]).

Conclusions

The study highlights some uncertainty in the fraction of T1 relative to CS, influenced by inconsistent approaches in determining both boundaries. However, our findings serve as a foundation for remote analysis and prescription of exercise intensity, although testing is recommended for more precise applications.

Keywords: testing, monitoring, intensity domains, endurance training, exercise prescription

Introduction

Training characteristics including duration, frequency, and intensity can be manipulated to maximise endurance performance.[1,2] There is an enduring interest in the role of training intensity distribution across different intensity ”zones” to elicit distinct training adaptations as well as helping to identify “best practice”.[1,3,4] Several approaches have been proposed to delineate these zones, but most commonly they align with three distinct physiological domains: moderate, heavy, and severe.[5] Moderate-intensity is characterised by the rapid attainment of oxygen uptake ($\dot{V}O_2$) steady state within 2-3 mins), and blood [lactate] is not substantially elevated above resting levels.[6] Heavy-intensity exercise is typified by delayed attainment of a $\dot{V}O_2$ steady state, caused by the emergence of the slow component of $\dot{V}O_2$ kinetics, as well as stable metabolite concentrations above resting values.[7] The severe-intensity domain occurs above the heavy-severe boundary, where a steady state is not attainable in respiratory and metabolic responses, and given sufficient time eventually leads to the attainment of an individual's maximum oxygen uptake ($\dot{V}O_{2max}$) and task failure.[7] These domains are separated by two distinct "thresholds", although these may behave more like phase transitions.[8]

The transition between the moderate and heavy domains (T1) is typically quantified as either lactate threshold (LT),[9] gas exchange threshold (GET),[10] or the first ventilatory threshold (VT1).[11] The demarcation of the heavy-severe boundary is typically represented by either critical speed (CS),[12] maximum lactate steady state,[9] or respiratory compensation point (RCP).[10] There is some conjecture as to the most accurate representation of the heavy-severe domain boundary.[13–17] In essence, the heavy-severe boundary represents the greatest work rate at which a metabolic steady state can occur which is conjectured to be most appropriately captured by CS.[16] Indeed, it has been proposed that the CS may be the most appropriate method of determining the heavy-severe boundary.[16,18] Furthermore, estimates of the CS, and its analogy for cycling, critical power, can be derived from habitual training data or a set of time trials.[19–21] Importantly, these approaches do not necessarily require costly and time-consuming laboratory-based testing, thus permitting remote determination which may be more accessible for amateur runners.[19] The latter is an important distinction given that the determination of T1 as LT necessitates capillary blood sampling, whereas GET and VT1 require an online gas analyser. If T1, without specific testing, can be expressed as a percentage of CS, this would enable more accessible exercise intensity prescription across all exercise intensity domains, or the remote monitoring of training intensity distribution.

Despite considerable attention being directed towards CS, the relationship between T1 and CS during running has not been systematically studied. To address this limitation, the aim of this study was to conduct a systematic review and quasi meta-analysis to determine the percentage at which T1 occurs relative to CS. It has previously been observed that the heavy and severe domains become compressed in elite endurance athletes.[22] Therefore, a further aim was to examine whether the percentage at which T1 occurs relative to CS differs between fitness levels.

Methods

Search Strategy

A systematic search was conducted to identify relevant papers in two scientific databases: PubMed and Scopus. The focus of this review was on journal articles published in English that described measures of both CS and T1. Articles published up to 28th February 2023 were reviewed originally, with an updated search taking place on 3rd April 2024. Title, abstract and keyword search fields were searched using the following search strategy:

(("critical speed") OR ("critical velocity")) AND (("run") OR ("running"))

Screening Procedure

The selection process consisted of four steps using PRISMA guidelines: 1) duplicates were removed after combining results from the two databases; 2) an initial title and abstract screen was performed by independent reviewers (SM and TC); 3) two independent reviewers (SM and BH) read the full texts based on the inclusion/exclusion criteria detailed below. References of all included studies were checked for additional studies that could be included. At all stages, conflicting decisions were adjudicated by a third reviewer (BH at stage 2, and DM at stage 3). Studies were included if they met the following inclusion criteria: 1) CS was reported, 2) either GET, LT1, or VT1 was reported, 3) participants were 18+, 4) written in the English language. Studies were excluded if they: 1) did not meet the inclusion criteria above, 2) were book chapters, review articles, case studies, letters, short communications, conference proceedings or other non-peer-reviewed literature, 3) reported on animal subjects, and 4) did not examine running.

Data Extraction

Data were extracted by BH, SM, DM, and EM using a customised form to ensure standardisation. Information from each article included: sample size, participant training level, age, sex, protocol used to determine CS, CS, protocol used to determine T1, and speed which elicited T1. Where studies divided participants into subgroups, the mean values from the subgroups were extracted separately for further analysis. Where T1 or CS was not reported, but the relative position of it relative to the CS or T1 was, this percentage was used to calculate the mean speed at either CS or T1 for the group. Where T1 or CS was reported in a figure, the authors were contacted to confirm the values required.

Statistical Analysis

Following data extraction, the mean percentage at which T1 occurred relative to CS was calculated. Prior to this, each study was checked for normality of data distribution. None of the included studies stated that either T1 or CS data were skewed or not normally distributed. The mean critical speed from each of the included articles were grouped into bins of equal size (0.49 km·h^{-1}), which were then plotted against the cumulative frequency. The total number of participants (n) of the included articles were divided into three to form cut-offs (i.e., n/3 and 2n/3). If the cut-off coincided with a bin, then all articles up to and including the bin were included. These cut-offs were then applied to group studies into low (≤12 km·h^{-1}), medium (≤14>12 km·h^{-1}), and high CS (>14 km·h^{-1}) based on the cumulative frequency. Sample size weighted means and 95% confidence intervals (95% CI) were calculated for CS in each group, and overall. Furthermore, sample size weighted means and 95% CI were calculated for the overall percentage of CS at which T1 occurred, and for the percentage of CS at which T1 occurred in each group. Hedge's g was used to calculate effect sizes between the percentage of CS at which T1 occurred in the three groups. Data were visually displayed as forest plots using Graphpad Prism (Prism 9, Graphpad Software, San Diego, CA).

Results

Search Results

From a total of 1,243 articles identified in the original database search, 26 papers met the inclusion criteria. No additional articles were identified through searches of reference lists. A diagram outlining the screening procedure is given in Figure 1.

Figure 1 about here.

Participant Characteristics

Table 1 gives participant characteristics of the included studies. The pooled weighted mean CS across the included studies was 13.6 km·h^{-1} (95% CI [13.4, 13.8]). The CS of the low, medium, and high CS subgroups was 11.5 km·h^{-1} (95% CI [11.2, 11.8]), 13.4 km·h^{-1} (95% CI [13.2, 13.7]), and 16.0 km·h^{-1} (95% CI [15.7, 16.3]), respectively. Thirteen of the included studies tested only male participants,[18,23–34] six of the studies tested a mixture of males and females,[35–

[40] with only one recruiting solely female participants.[41] Six studies did not report the sex of the participants.[42–47]

Table 1 about here.

Study Characteristics

Of the approaches used to estimate CS, nine studies used a series of constant work rate trials (CWR),[18,23,26,31,33,35,36,39,46] eight used the three minute all out test (3MT),[27,28,30,34,40–42,45] six used time trials (TT),[25,32,37,38,43,44] two studies used an intermittent 3MT protocol,[24,47] and one study compared both CWR and TT trials.[29] Ten studies reported GET,[23,26–28,35,37,40–42,45] nine reported LT1,[18,25,32,33,38,39,44,46,47] and seven reported VT1[24,29–31,34,36,43] as T1. Further methodological details of the included studies are summarised in Table 2.

Table 2 about here.

First Threshold as a Fraction of CS

Across all studies, T1 occurred at 82.3 % CS (95% CI [81.1, 83.6]). In the low, medium, and high CS groups, T1 occurred at 80.6% CS (95% CI [78.0, 83.2]), , 83.2% CS (95% CI [81.3, 85.1]), and 84.2% CS (95% CI [82.3, 86.1]), respectively. These data are summarised in Figure 2. Hedge’s g revealed small effect sizes for the percentage at which T1 occurred in the medium CS group ($g = 0.296$) and high CS group ($g = 0.227$) compared to the low CS group. A trivial effect size was noted in the percentage of at which T1 occurred in the medium CS group compared to the high CS group ($g = 0.076$).

Figure 2 and 3 about here.

Discussion

In this systematic review and meta-analysis, we have found that T1 occurs at 82.3% CS (95% CI [81.1, 83.6]). However, this was associated with a relatively large variance between studies and fitness levels, discussed below. Importantly, the fraction at which T1 occurred relative to CS seemed to be dependent on the fitness level, with small increases in runners with moderate or high CS. This is in accordance with previously reported observations in very highly trained runners, where both the heavy and severe domains tend to be compacted towards the speed associated with $\dot{V}O_{2max}$.[22,48] The findings suggest that the heavy domain tends to be more compressed than that of the severe domain. However, the high CS group had a relatively modest pooled mean CS (16.0 km·h^{-1}) in comparison to the previously estimated CS of elite runners (21.0 km·h^{-1}).[49,50] Therefore, this phenomenon may only be evident in those with exceptionally high CS.

The fraction at which T1 occurs relative to CS appears to be elevated compared to that observed in cycling (i.e., critical power),[51] which is consistent with previous comparisons between exercise modalities.[52] Previously, a "critical intensity" has been demonstrated, whereby metabolic rate and blood lactate are not significantly different between running at CS and cycling at critical power.[53] Therefore, this difference is likely due to the position of T1 relative to the peak incremental test work rate and may be linked to the larger $\dot{V}O_2$ slow component associated with cycling.[52,54] It has been posited previously that in participants with little cycling experience, extraneous energetic cost may be due to gripping handlebars or unnecessary torso movement at submaximal work rates.[52] However, differences in muscle contraction regimen, and lesser elastic energetic contribution in cycling,[55] are more significant contributors to the greater $\dot{V}O_2$ slow component associated with cycling when compared to running.

It is notable that only one of the included studies reported both T1 and CS that were comparable (< 2% difference),[30] thus supporting previous conclusions that VT1 and critical power are unique work rates.[51] The incongruent findings reported by Kuo et al.[30] are likely due to differences in temperature between the initial incremental test to determine VT1 (mean temperature: 22.0°C) and the 3MT (mean temperature: 34.7°C) conducted outdoors on a track. Therefore, it is likely that environmental conditions will affect the fraction at which T1 occurs relative to CS, possibly by depressing estimates of CS. Therefore, it is recommended that environmental factors are considered when using this approach.

The large pooled standard deviation demonstrates a degree of uncertainty in where T1 occurs relative to CS. This may be due to inconsistent approaches used to determine both the T1 and CS. There was substantial variation in the fraction at which T1 relative to CS was evident when using different methods. Measures of LT occurred at 87.7% CS (95% CI [86.2, 89.3]), whereas gas-based measures resulted in a lower fraction of CS (GET: 79.5% CS (95% CI [77.3, 81.8]), VT: 81.7% CS (95% CI [79.4, 84.1])). Indeed, ventilatory and lactate performance parameters have been shown to differ during graded exercise tests in running.[56,57] Furthermore, the studies that reported LT used a variety of different criteria to determine LT including 1 mmol/L above baseline, speed at 2 mmol/L, and a “sustained increase above baseline”. The determination of CS has also previously been shown to be dependent on the methods selected.[19,58] Therefore, some consideration is warranted by practitioners about how they wish to define both T1 and CS. However, in the current approach, the variation of T1 as a fraction of CS is comparable to previously reported error and sources of biological variability in other thresholds.[59,60] It should also be recognised that although this is a practical approach, the relative position of thresholds may depend on numerous factors including age,[61,62] anthropometry,[63] sex,[64,65] and training phase.[39] Such factors were not considered substantively in the current review, but may provide an interesting avenue for further research. Furthermore, due to the scope of the review the findings cannot be extrapolated to other factors which may influence adaptations to training including heart rate, perceived exertion values, and ventilatory measures.

Practical Applications

The findings provide a basis on which remote analysis and prescription of training zones can be performed in runners of a range of abilities. To utilise these findings, we have included a table to outline appropriate factors to approximate T1 from CS (Table 3). However, given the large pooled standard deviation values, caution is warranted when using this approach, and separate testing may be needed for both boundaries to ensure precise prescription. Indeed, greater nuance is especially warranted when prescribing exercise for high level or elite athletes.

Table 3 about here.

Conclusions

In conclusion, this systematic review and quasi meta-analysis reveals that T1 occurs at approximately 82.3% of CS in runners, with this occurrence influenced by fitness levels. Notably, the heavy domain is more compressed in runners with high CS. Environmental conditions may affect T1 relative to CS, introducing uncertainties. The study provides a foundation for remote analysis and training zone prescription in runners, but caution is advised due to large pooled standard deviation, and precise testing for accurate prescription, particularly for high-level athletes, is recommended. Further work could explore the potential to model T1 relative to CS based on factors such as sex, age, and anthropometry, and training status.

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Table 1. Participant characteristics of included studies

	Sample Size	Sex	Description	Age	$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	CS (km·h^{-1})	T1 (km·h^{-1})
Ade et al (2014)[35]	71	40 M. 31 F	Healthy adults	23 (5)	48.0 (7.9)	11.9 (2.2)	8.2 (1.6)
Balasekaran et al. (2023)[46]	12	NR	Endurance-trained	32 (7)	57.6 (5.4)	15.0 (1.4)	13.4 (1.6)
Balasekaran et al. (2023)[46]*	9	NR	Sprint-trained	27 (9)	51.1 (3.6)	11.5 (0.8)	10.5 (0.8)
Bosquet et al (2006)[23]	17	M	Middle- and long-distance runners	23 (3)	66.5 (7.3)	16.1 (1.9)	13.6 (1.7)
Florence et al (1997)[36]	12	6 M, 6 F	Marathon runners	29(4)	45.0-75.0	16.0 (1.7)	14.5 (1.7)
Follador et al (2021)[37]	42	31 M, 11 F	Recreational runners	32 (6)	52.5 (6.6)	14.0 (2.0)	12.1 (2.0)
Fukuda et al (2011)[24]	14	M	Collegiate hockey and rugby players	21 (2)	51.2 (2.8)	17.3 (1.1)	10.1 (1.5)
Galbraith et al (2014)[25]	14	M	Highly-trained endurance runners	28 (8)	69.8 (6.3)	17.7 (1.8)	15.7 (1.2)
Hogg et al (2018)[38]*	12	8 M, 4 F	Recreationally active	30 (9)	54.0 (5.8)	12.5 (0.1)	10.0 (1.2)
Hogg et al (2018)[38]*	12	8 M, 4 F	Recreationally active	30 (9)	54.0 (0.7)	12.5 (0.1)	9.7 (1.5)
Hunter et al (2021)[26]	10	M	Recreationally trained runners	29 (10)	53.0 (5.0)	14.2 (1.5)	11.5 (1.6)
Kalva-Filho et al. (2024)[47]	14	NR	Futsal players	21 (2)	41.0 (8.9)	10.1 (1.1)	9.4 (0.7)
Kramer et al (2018)[27]	15	M	Soccer players	23 (3)	50.5 (4.0)	14.3 (1.9)	11.3 (1.2)
Kramer et al (2019)[28]	14	M	Field athletes	21 (2)	44.1 (4.3)	13.6 (2.0)	10.5 (1.3)
Kramer et al (2020)[42]	43	NR	Athletic (soccer: n = 16; rugby: n = 14; hockey: n =	23 (4)	50.0 (8.6)	13.5 (1.8)	11.1 (1.3)

			5; mixed martial arts: n = 4; track athletes: n = 4)				
Kramer et al (2020)[42]*	25	NR	Non-athletic (gym-based training: n = 14; recreational running: n = 8; recreational CrossFit: n = 3)	25 (3)	48.3 (7.6)	10.8 (2.0)	9.1 (2.1)
Kranenberg et al (1996)[29]	9	M	Highly trained runners	26 (5)	67.7 (4.1)	17.4 (1.2)	16.6 (1.4)
Kuo et al (2017)[30]	12	M	Sprinters	21 (2)	55.0 (1.0)	11.4 (0.5)	11.2 (0.3)
Myrkos et al. (2023)[39]	24	9M, 15F	Recreationally active	21 (3)	57.7 (7.6)	12.0 (1.5)	10.1 (1.2)
Nimmerichter et al (2017)[31]	16	M	Trained endurance athletes	30 (7)	63.6 (6.9)	13.5 (1.3)	9.6 (0.9)
Nixon et al (2021)[18]	10	M	Well-trained competitive (runners n=7, triathletes n=3)	23 (5)	63.0 (4.0)	16.4 (1.3)	14.5 (1.2)
Perez et al. (2024)[40]	10	7M, 3F	Middle-distance runners	19.3 (1.7)	60.3 (5.1)	18.3 (1.1)	14.6 (0.7)
Pettitt et al (2012)[41]	14	F	Collegiate distance runners	19 (1)	54.8 (3.3)	15.9 (1.5)	14.0 (0.8)
Ruiz-Alias et al (2022)[43]	15	NR	Athletes	31 (10)	66.3 (7.2)	16.6 (1.6)	13.7 (1.3)
Schnitzler et al (2010)[32]	29	M	Moderately trained athletes	25 (7)	NR	13.1 (0.7)	12.2 (0.5)
Silva et al (2005)[44]	11	NR	Physically active adults	21 (2)	48.9 (5.8)	12.0 (1.8)	11.1 (1.7)
Smith et al (2001)[33]	8	M	Recreationally active subjects	28 (5)	54.9 (3.2)	14.4 (1.1)	11.6 (0.9)
Sperlich et al (2014)[34]	15	M	Well-trained runners	25 (5)	71.1 (11.6)	14.6 (1.6)	12.5 (1.3)
Thomas et al (2020)[45]*	9	NR	Moderately active, non-athletic	23 (4)	46.2 (6.6)	10.1 (1.9)	8.9 (3.3)

Thomas et al (2020)[45]*	9	NR	Moderately active, non-athletic	23 (3.79)	44.2 (5.4)	11.2 (1.7)	9.4 (2.5)

NR: not reported. Duplicate study titles with asterisks represent subgroups within studies.

Table 2. Methodological characteristics of included studies

	Ramp Protocol of T1 (Start speed, increments)	Determination of T1	CS Protocol	Surface
Ade et al (2014)[35]	IND, 1 min stages, 0.5 km·h^{-1} increments	GET	Four T_{lim} trials at 90-120% s$\dot{V}O_{2max}$	Treadmill
Balasekaran et al. (2023)[46]	40-60% $\dot{V}O_{2max}$, 4 min stages, 4-5% $\dot{V}O_{2max}$ increments	LT1	Minimum of two-to-three T_{lim} trials at 110-140% s$\dot{V}O_{2max}$	Treadmill
Bosquet et al (2006)[23]	10 km·h^{-1}, 2 min stages, 1 km·h^{-1} increments	GET	Four T_{lim} trials at 95, 100, 105, 110, and 120% of s$\dot{V}O_{2max}$	Treadmill
Florence et al (1997)[36]	7.9 km·h^{-1}, 1 min stages, 0.7 km·h^{-1} increments	VT1	Four T_{lim} trials at velocities from 13.0-21.6 km·h^{-1}	Treadmill
Folladar et al (2021)[37]	8 km·h^{-1}, 1 min stages, 1.1 km·h^{-1} increments	GET	Three TTs for 1200, 2400, and 3600 m	GXT treadmill TTs track
Fukuda et al (2011)[24]	10 km·h^{-1}, 2 min stages, 2 km·h^{-1} increments until 16 km·h^{-1} then, 1 min stages, 1 km·h^{-1} increments until 18 km·h^{-1} then, 1 min stages 2% gradient increments	VT1	Intermittent critical velocity test	Treadmill

Galbraith et al (2014)[25]	IND, 4 min stages, 1 $km\cdot h^{-1}$ increments	LT1	Three TTs for 1200, 2400, and 3600 m	GXT treadmill TTs track
Hogg et al (2018)[38]	IND, 4 min stages, 1 $km\cdot h^{-1}$ increments	LT1	Three TTs for 1200, 2400, and 3600 m	GXT treadmill TTs track
Hunter et al (2021)[26]	8 $km\cdot h^{-1}$, 0.5 min stages, 0.5 $km\cdot h^{-1}$ increments	GET	Four T_{lim} trials at 60% Δ, 70% Δ, 80% Δ and 100% $s\dot{V}O_{2max}$	Treadmill
Kalva-Filho (2024)[47]	8 $km\cdot h^{-1}$, 3 min stages, 0.5 $km\cdot h^{-1}$ increments	LT1	3MT (intermittent protocol)	Futsal pitch
Kramer et al (2018)[27]	8 $km\cdot h^{-1}$, 1 min stages, 1 $km\cdot h^{-1}$ increments	GET	3MT	GXT treadmill 3MT track
Kramer et al (2019)[28]	8 $km\cdot h^{-1}$, 1 min stages, 1 $km\cdot h^{-1}$ increments	GET	3MT	GXT treadmill 3MT track
Kramer et al (2020)[42]	IND, 1 min stages, 0.8 $km\cdot h^{-1}$ increments	GET	3MT	GXT treadmill 3MT track
Kranenberg et al (1996)[29]	IND, 2 min stages until VT1, 0.8 $km\cdot h^{-1}$ increments, then 1 min stages, 0.8 $km\cdot h^{-1}$ increments, then 1 min stages, 2% gradient increments	VT1	Three TTs for 907, 2267.5, and 4081.5 m Three TTs for 3, 7, and 13 min	Track Treadmill
Kuo et al (2017)[30]	10.4 $km\cdot h^{-1}$, 1 min stages, 0.65 $km\cdot h^{-1}$ increments until 14.3 $km\cdot h^{-1}$, then 1% gradient increments	VT1	3MT	GXT treadmill 3MT track
Myrkos et al. (2023)[39]	8 $km\cdot h^{-1}$, 3 min stages, 1.5 $km\cdot h^{-1}$ increments	LT1	Three T_{lim} trials at 90, 100, and 110% peak treadmill speed	Treadmill

Nimmerichter et al (2017)[31]	6 km·h^{-1}, 1 min stages, 0.5 km·h^{-1} increments	VT1	Three T_{lim} trials at 70% Δ, and 98% and 110% of $s\dot{V}O_{2max}$	Treadmill
Nixon et al (2021)[18]	IND, 3 min stages, 1 km·h^{-1} increments	LT1	Four T_{lim} trials at 90%, 95%, 100% and 105% $s\dot{V}O_{2max}$	Treadmill
Perez et al. (2024)[40]	12.0 km·h^{-1} (M) and 11.8 km·h^{-1} (F), 1 min stages, 0.8 km·h^{-1} increments	GET	3MT	GXT treadmill 3MT track
Pettitt et al (2012)[41]	10.4 km·h^{-1}, 1 min stages, 0.64 km·h^{-1} increment until 14.21 km·h^{-1}, then 1 min stages, 1% gradient increments	GET	3MT	GXT treadmill 3MT track
Ruiz-Alias et al (2022)[43]	9 km·h^{-1}, 3 min stages, 1 km·h^{-1} increments	VT1	Two TTs for 3 and 9 min	Treadmill
Schnitzler et al (2010)[32]	11 km·h^{-1}, 4 min stages, 0.5 km·h^{-1} increments	LT1	Three TTs for 3, 6, and 12 min	GXT treadmill TTs track
Silva et al (2005)[44]	IND, 3 min stages, 0.5 km·h^{-1} increments	LT1	Two TTs for 3000 and 500m	GXT treadmill TTs track
Smith et al (2001)[33]	IND, 4 min stages, 1.0 km·h^{-1} increments	LT1	Four T_{lim} trials at 100, 105, 110, 120% $s\dot{V}O_{2max}$	Treadmill
Sperlich et al (2014)[34]	7 km·h^{-1}, 1 min stages, 1.0 km·h^{-1} increments	VT1	3MT	GXT treadmill 3MT track
Thomas et al (2020)[45]	IND, 1 min stages, 0.8 km·h^{-1} increments	GET	3MT	GXT treadmill 3MT track

3MT: three minute all out test, CS: critical speed, GXT: graded exercise test, GET: gas exchange threshold, LT1: first lactate threshold, IND: Individualised start speed, T1: first threshold, TT: time trial, T_{lim}: time to task failure, VT1: first ventilatory threshold, $s\dot{V}O_{2max}$: speed which elicited $\dot{V}O_{2max}$, M: male, F: female.

Table 3. Suggested multiplication factors for level of runner

	CS	Multiplication Factor to Approximate T1
Low CS	≤12 $km \cdot h^{-1}$	CS * 0.806
Medium CS	12.01-14 $km \cdot h^{-1}$	CS * 0.832
High CS	>14 $km \cdot h^{-1}$	CS * 0.842

T1: first threshold, CS: critical speed.

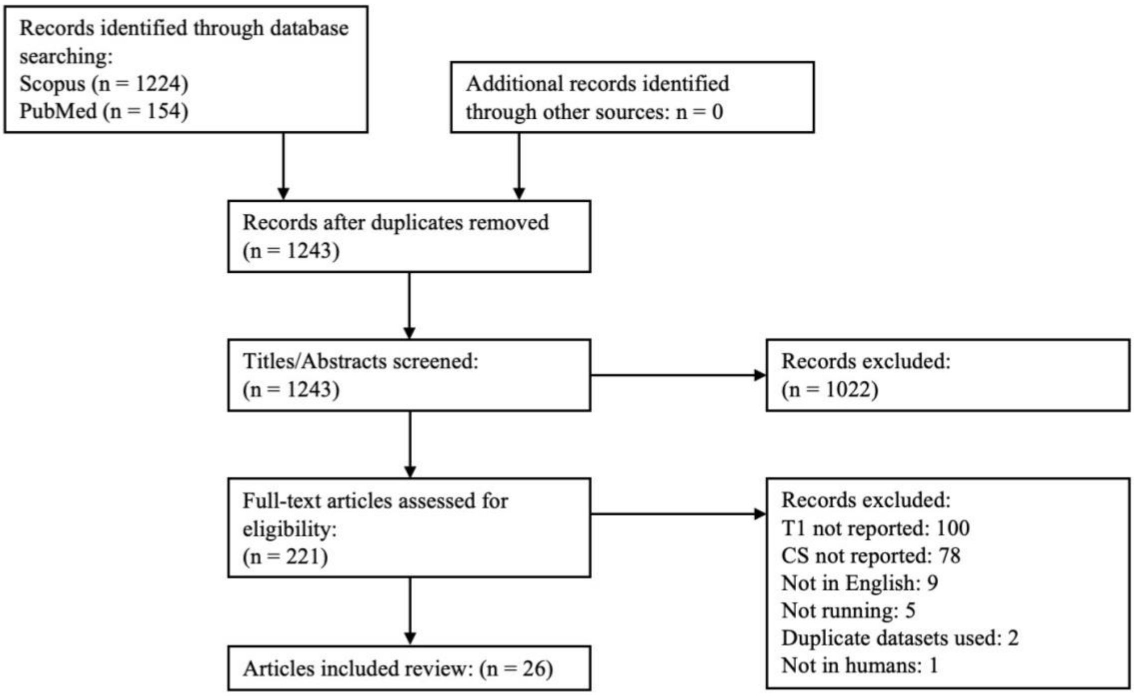

Figure 1. Flow diagram of the search strategy.

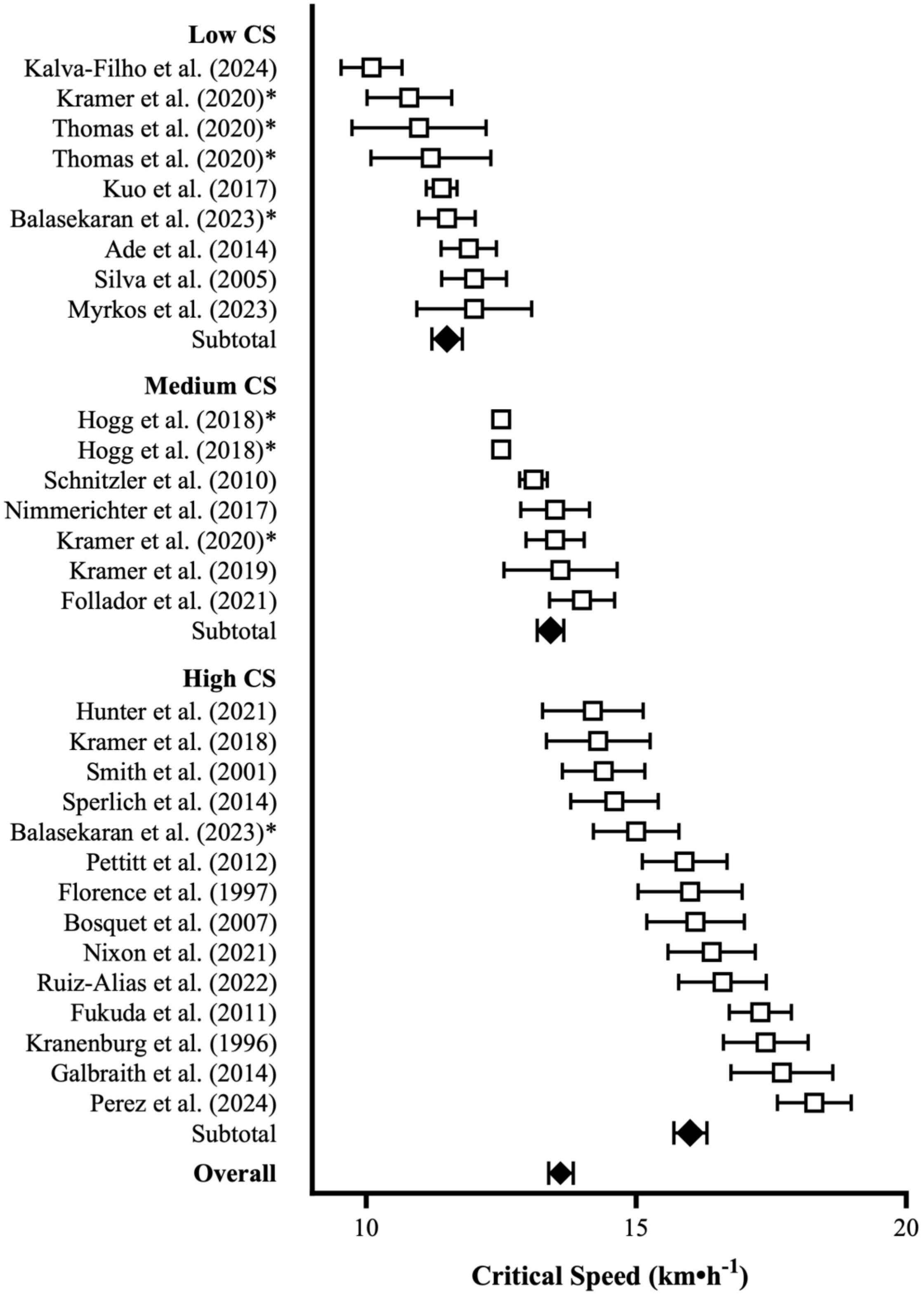

Figure 2. Forest plot of the included studies for critical speed (CS). The white squares and error bars represent the mean and 95% CI of the study. The black diamonds and error bars represent the pooled mean CS and 95% CI for either the subgroups or overall. Duplicate study titles with asterisks represent subgroups within studies.

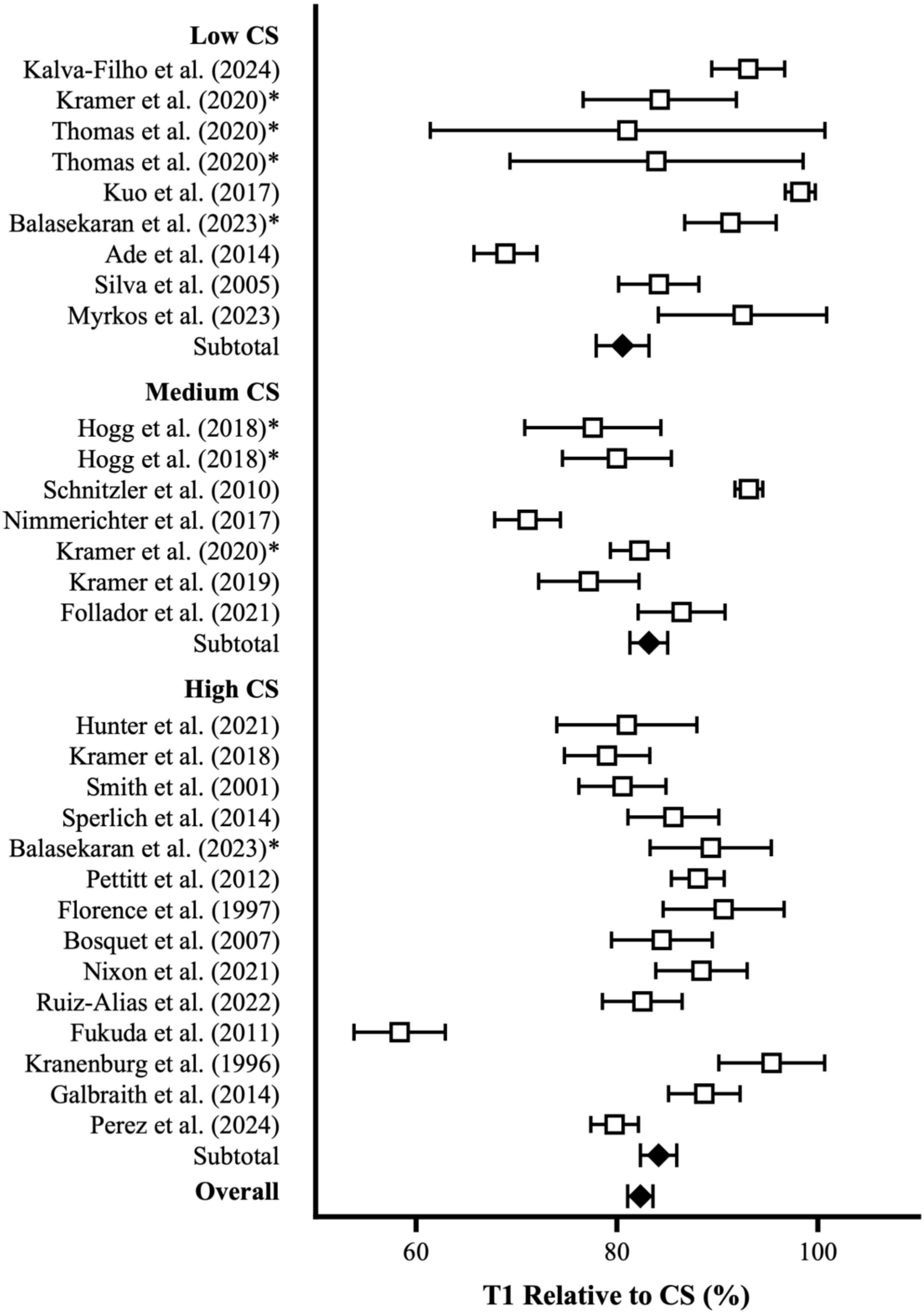

Figure 3. Forest plot of the included studies for the percentage at which T1 occurred relative to CS. The white squares and error bars represent the mean and 95% CI of the study. The black diamonds and error bars represent the pooled mean percentage at which T1 occurred relative to CS and 95% CI for either the subgroups or overall. Duplicate study titles with asterisks represent subgroups within studies.