Title: The training intensity distribution of marathon runners across performance levels

Running title: Training intensity distribution of marathon runners

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Abstract

Background. The training characteristics and training intensity distribution (TID) of elite athletes have been extensively studied, but a comprehensive analysis of the TID across runners from different performance levels is lacking.

Methods. Training sessions from the 16 weeks preceding 151,813 marathons completed by 119,452 runners were analysed. The TID was quantified using a three-zone approach (Z1, Z2, and Z3), where critical speed defined the boundary between Z2 and Z3, and the transition between Z1 and Z2 was assumed to occur at 82.3% of critical speed. Training characteristics and TID were reported based on marathon finish time.

Results. Training volume across all runners was 45.1±26.4 $km \cdot wk^{-1}$, but the fastest runners within the dataset (marathon time 120-150 min) accumulated >3 times more volume than slower runners. The amount of training time completed in Z2 and Z3 running remained relatively stable across performance levels, however, proportion of Z1 was higher in progressively faster groups. The most common TID approach was pyramidal, adopted by >80% of runners with the fastest marathon times. There were strong, negative correlations ($p < 0.01$, $R^2 \geq 0.90$) between marathon time and markers of training volume, and the proportion of training volume completed in Z1. However, the proportion of training completed in Z2 and Z3 were correlated ($p < 0.01$, $R^2 \geq 0.85$) with slower marathon times.

Conclusion. The fastest runners in this dataset featured large training volumes, achieved primarily by increasing training volume in Z1. Marathon runners adopted a pyramidal TID approach, and the prevalence of pyramidal TID increased in the fastest runners.

Key Points

- We analysed the training characteristics and training intensity distribution (TID), which refers to the fraction of training completed within discrete training zones, of 151,813 marathon runners with a wide range of performance levels.
- Training volume was three times higher in the fastest runners (finish times of 120-150 min) compared to slower runners (>240 min) within the dataset. Faster runners accrued larger training volumes almost exclusively by accumulating training at intensities below the lactate threshold (zone 1).
- The majority of runners adopted a pyramidal TID approach, whereby the highest proportion of training volume is completed in zone 1, and progressively less training volume is completed between lactate threshold and critical speed (zone 2) and above critical speed (zone 3). Furthermore, the proportion of runners adopting a pyramidal TID approach increased with performance, reaching ~80% among runners with fastest marathons times.
- These data suggest that a pyramidal approach with a high training volume is a hallmark of successful marathon performance.

Conflicts of interest:

All listed authors declare that they have no conflicting interests.

1. Introduction

Endurance training aims to maximise exercise capacity and endurance performance by manipulating several parameters, such as the type, frequency, intensity, and duration of training. The fraction of training volume completed within discrete training zones, referred to as training intensity distribution (TID), has become one such parameter of interest, due to its potential influence on performance outcomes [1–4]. The TID can be quantified according to a three-zone model [2,3]. The three-zone TID model was initially proposed by Skinner and McLellan [5] based on changes in gas exchange and blood lactate. More recently, three-zone TID models have been aligned with the moderate, heavy, and severe exercise intensity domains, whereby each exercise domain elicits distinct and well-defined physiological responses to exercise [6–8]. Using a three-zone TID framework, zone 1 (Z1) comprises intensities up to the lactate threshold or gas exchange threshold, zone 2 (Z2) consists of intensities above lactate threshold, but below the maximal metabolic steady state (normally determined as critical speed (CS), see reference [9]), and zone 3 (Z3) comprises high-intensity exercise, where the intensity of exercise exceeds CS [10].

Several TID paradigms have been investigated, including pyramidal, polarised, threshold, or high-intensity training (HIT). A pyramidal TID approach is characterised by a decreasing volume from Z1 to Z3 (i.e., Z1 > Z2 > Z3), with a large proportion (typically ~80%) of training occurring in Z1 and the remaining ~20% split, in a decreasing manner, between Z2 and Z3 [11]. Polarised training typically involves high volumes of training performed in Z1 (~80%) and Z3 (~20%), with little- to no-training completed in Z2 (Z1 > Z3 > Z2) [12]. A threshold TID has a higher training volume performed in Z2 compared to other paradigms (>20%), with typically less training performed in Z1 and Z3 (Z2 > Z1 and Z2 > Z3) [13]. Finally, HIT is characterised by a larger proportion the volume being performed in Z3, with lower volume performed in Z1 and Z2 (Z3 > Z1 and Z3 > Z2) [14]. Despite considerable attention to the area, the optimal TID approach remains a disputed subject [15,16].

Descriptive studies have reported the TID of elite athletes (for reviews, see [2,13,17]). These studies, however, may be limited in scope, influenced by the training philosophies of the coaches and athletes under investigation, and rely on relatively small samples of highly successful athletes. Elite athletes benefit from full-time dedication to their training which may enable them to accumulate high training loads (e.g. 160–220 km in elite distance runners [18]). Conversely, there is a scarcity of data regarding the TID practices of recreational athletes [19,20]. These studies have demonstrated that TID can be manipulated and affect endurance performance in non-professional endurance athletes, although which TID approach is most effective remains to be elucidated [19,20]. Further, recreational athletes may have limited time available for training and thus may not be able to accumulate very large training volumes, as typically seen in elite athletes. Moreover, existing evidence on what may be considered 'best' practice by elite athletes includes a substantial focus on male athletes [13,18]. For example, in a systematic review conducted by Casado and colleagues [13] to observe training practice of 142 elite distance runners, only 11 (~8%) were female. Similarly, when considering results-proven practice of 59 world-leading athletes, only 17 (~29%) athletes were female [18]. Observational studies using large databases have previously been used to identify determinants of marathon success [21–23], but an analysis of TID in a large sample of marathon runners with heterogeneous levels of performance is lacking.

The overall aim of this study was, therefore, to analyse the training characteristics of a large sample of marathon runners with different levels of performance. We specifically investigated the TID of a large heterogenous group of marathon runners based on their marathon finish time, and as training progressed towards race day. We further analysed the association between marathon performance and TID approaches, as well as other training characteristics. We hypothesised that, among a large sample of marathon runners, a wide of range TID approaches would be evident, but the fastest runners within the dataset would accumulate large training volumes, and therefore pyramidal TID would be most popular. We further hypothesised that training characteristics linked to training volume would exhibit strong correlations with marathon performance.

2. Methods

2.1 Participants

This is a retrospective analysis of an existing dataset containing 119,452 anonymised marathon runners, who completed 151,813 marathons between 2014 and 2017. The dataset contained all running activities recorded on a training platform (Strava®), during 16 weeks prior to a marathon. Marathons were identified as runs covering 42.2 km, happening at a date, time, and location known to coincide with major marathons. Due to retrospective analysis of this dataset, ethical approval was not deemed necessary by the ethics committees of the authors' institutions.

2.2 Training intensity zones and training intensity distribution

The dataset contains distance, time, and elevation data, sampled at 100-m intervals. Raw training data were analysed, as previously described by Minetti et al. [24], to account for differences in metabolic stress required to run on flat, uphill, or downhill terrain, where the grade adjustment (g) is calculated as:

$$Adjusted(g) = 1 + \frac{\left(g \cdot \left(19.5 + g \cdot \left(-43.3 + g \cdot (-30.4 + g \cdot 155.4)\right)\right)\right)}{3.6}$$

The grade-adjusted pace for a given pace (p) is therefore given by:

$$Grade\ adjusted\ pace(p, g) = \frac{p}{Adjusted(g)}$$

A three-zone model was used to characterise TID, whereby training zones were intended to represent the moderate, heavy, and severe intensity domains [10,11,13]. We used CS to identify the transition from heavy to severe exercise domains, and thus the boundary between Z2 and Z3, as it has been shown that CS represents the highest intensity at which a metabolic steady state may be achieved [9,25]. Critical speed was estimated for each runner using raw training data, as previously described [21,22]. In brief, the best performances recorded for each runner over a range of distances (400 – 5,000 m) were used to construct the distance–time relationship, where the slope estimates CS [21,22]. The boundary between the moderate and heavy domains, thus demarcating the boundary between Z1 and Z2 in the present study, is normally determined as the lactate threshold or gas exchange threshold [26,27], and therefore cannot be derived directly from the dataset used in the current study. Accordingly, the boundary between Z1 and Z2 was assumed to be at 82.3% of CS, as determined from a recent meta-analysis [28]. TID was then quantified for each week, and every training session. For the purpose of this study, TID was subsequently described as polarised when time spent in Z1>Z2 and Z3>Z2; pyramidal if Z1>Z2 and Z2>Z3; threshold TID if Z2>Z1 and Z2>Z3; and high-intensity interval (HIT) TID if Z3>Z1 and Z3>Z2 [4,11,13,14]. No further criteria were used when charectersing TID approaches, and therefore, for instance, polarised or pyramidal TIDs were defined if Z1>Z2 and Z3>Z2 and Z1>Z2 and Z2>Z3, respectively, irrespective of the proportion of training completed in each zone.

2.3 Data analyses

The training volume, training frequency, TID (fraction of training time completed in Z1, Z2, and Z3), and TID approach (polarised, pyramidal, threshold, or HIT) was determined for the entire dataset. Training characteristics and TID were then compared between athletes with different performance levels, and as training progressed before the marathon race.

To compare the training characteristics and TID of athletes with different performance levels, runners were grouped by marathon finish time in 30-min bins, starting from the fastest marathons recorded within the dataset (marathon times 120-150 min), and then progressively slower marathons, until those with marathon between 360-390 min. Similarly, training characteristics were determined for each week, starting 16 weeks prior to the marathon and up to the week prior to the marathon. However, data are presented in four 4-week blocks for ease of reading, and to approximate mesocycles prior to the marathon.

The polarisation index was calculated to assess the level of polarisation, as described by Treff et al. [11]:

$$Polarisation\ index = \log_{10}\left(\frac{Z1}{Z2 \times Z3}\right)$$

where Z1, Z2, and Z3 represent the proportion of training completed in zones 1, 2 and 3, respectively. A polarisation index greater than 2.0 (a.U.) denotes a polarised TID, whereas values <2.0 denote non-polarised TIDs [11]. Similarly, the Gini coefficient was determined as a measure of how consistently runners adhered to a particular TID approach, by means of determining the ratio of the area between the perfect equality line and the Lorenz curve, divided by the total area under the perfect equality line [29]. In brief, the Gini coefficient is a value between 0.25 and 1.0, where a value of 0.25 means all TID approaches were equally popular (i.e., 25% runners follow a polarised TID, 25% pyramidal, etc.), and a value of 1.0 indicates all runners adopted the same TID approach (e.g., 100% runners followed a pyramidal TID).

2.4 Statistical Analysis

To examine the relationship between finishing time and training, Pearson correlation coefficients were calculated for marathon times and key training characteristics: total training distance, total training time, number of 'long runs' and total distance covered in 'long-runs', where a long-run is herein defined as training sessions where distance exceeds 20 km, the fraction of training completed in Z1, Z2 and Z3, and the polarisation index. Ordinary least squares (OLS) regressions were performed to build a predictive model of the marathon finishing time as a function of training factors including total training volume (km), total training time (min), active days, defined as days when a running activity was recorded, total number of long runs, total distance covered in long runs (km), the polarisation index (a.U.), and sex. Due to collinearity between the fraction of training completed in Z1, Z2, and Z3, three separate OLS models were built to predict marathon finishing time, using the percent of time spent in each zone. Data are presented as mean ± SD, and separately for male and female runners, and for younger and older runners (herein defined as runners aged ≤40 and >40 yrs, respectively, as a value that approximate the median age).

3. Results

3.1 Training characteristics and marathon performance

Runners within this dataset completed ~56 training sessions during the 16 weeks prior to the marathon (3.6 ± 1.7 training sessions per week), which enabled them to accumulate a training volume of ~45 km per week, which included a 'long run' of ~20 km per week (Table 1). The average marathon time of the entire dataset was ~3 h and 50 min (230.2 ± 41.9 min).

Training volume for athletes within each performance group, and each of the four training phases investigated is presented in Figure 1. Runners with the fastest marathon time of 120-150 min accumulated the highest training volume (~107 km·week^{-1}, n = 620), a three-fold difference compared to those with slower marathon times (e.g. ~35 km·week^{-1} for athletes with a marathon time of 270-300 min, n = 8,798).

Table 1. Training characteristics and overall performance of the athletes within the dataset analysed.

	F	M	>40	≤40	All
Number of runners*	28,118	91,334	65,781	55,120	119,452
Number of marathons	34,451	117,362	83,287	68,526	151,813
Number of marathons/Runner	1.23	1.28	1.27	1.24	1.27
Age (yrs)	37.9 ± 26.2	39.9 ± 28.6	48.0 ± 41.5	33.3 ± 4.8	39.5 ± 28.1
Finish-time (mins)	253.0 ± 41.4	223.5 ± 39.7	233.9 ± 42.0	225.6 ± 41.4	230.2 ± 41.9
Marathon speed (km·h^{-1})	10.3 ± 1.6	11.7 ± 2.0	11.2 ± 1.9	11.6 ± 2.0	11.4 ± 2.0
Critical speed (km·h^{-1})	10.7 ± 1.5	12.0 ± 1.7	11.5 ± 1.7	11.9 ± 1.8	11.7 ± 1.8
Critical pace (mins·km^{-1})	5.7 ± 0.8	5.1 ± 0.8	5.3 ± 0.8	5.2 ± 0.8	5.3 ± 0.8
Number of active days (days·wk^{-1})	3.4 ± 1.4	3.4 ± 1.5	3.4 ± 1.4	3.4 ± 1.5	3.4 ± 1.5
Training frequency (sessions·wk^{-1})	3.5 ± 1.6	3.6 ± 1.7	3.6 ± 1.6	3.6 ± 1.7	3.6 ± 1.7
Training volume (km·wk^{-1})	41.8 ± 23.8	46.1 ± 27.1	45.4 ± 25.9	44.8 ± 27.1	45.1 ± 26.4
Average weekly long run distance (km)	19.1 ± 9.5	19.7 ± 9.7	19.8 ± 9.7	19.3 ± 9.5	19.6 ± 9.6

F: female runners, M: male runners, >40: runners over 40 yrs, ≤40: runners equal to or under 40 yrs, All: all runners within the dataset. * Over the course of the years some runners change age grouping, so a runner that was ≤40 appears later as >40. Of note, the sum of ≤40 and >40 is 120,901, because some runners completed more than one marathon, one of which was completed when they were ≤40 yrs, and another one at >40 yrs, and therefore are counted twice. See text for further details.

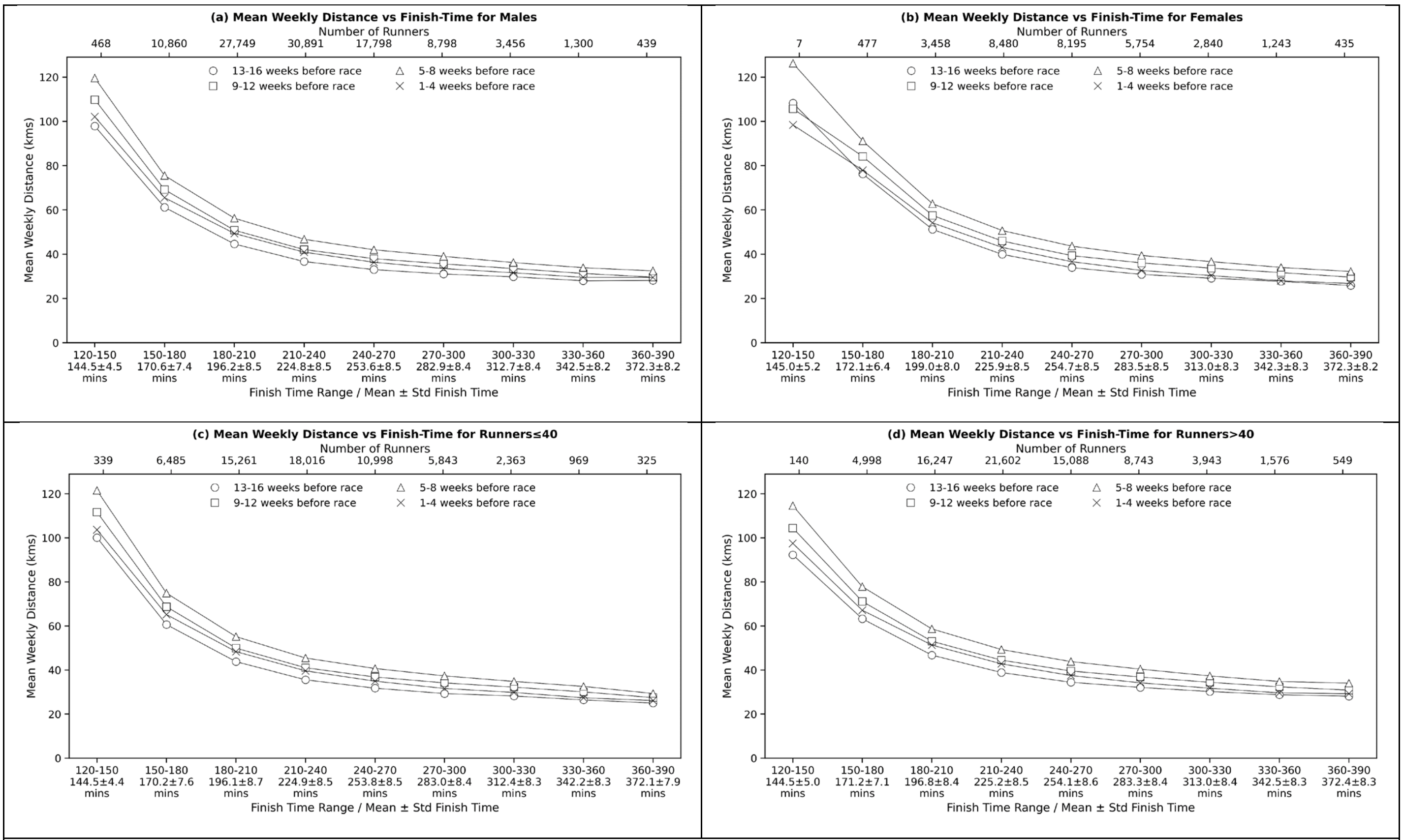


Figure 1. Training volume, expressed as mean weekly distance (km), for athletes with different marathon finishing times, and reported for each 4-week block. Top panels represent male (panel a) and female (b) marathon runners; and panels c and d at the bottom represent younger and older runners, respectively. Runners were grouped based on their marathon finish time in 30-min bins (120-150 min, 150-180, etc.), with the average marathon time and the number of runners also displayed.

The fraction of training time and total training time completed in each zone is summarised in Figure 2 and 3, respectively, and a more comprehensive analysis is displayed in Figure 4. Overall, runners within this dataset completed 49.0% of their training in Z1, 35.3% in Z2, and 15.7% in Z3. There were, however, large variations in the TID approaches adopted by runners with different marathon finishing times. Better runners progressively accrued higher overall training volumes by increasing training in Z1, whilst training time in Z2 and Z3 remained relatively stable for all runners, irrespective of their overall marathon performance or training phase (Figure 2 and Figure 3). The overall polarisation index was 1.25, and remained relatively constant at values with values <1.5, irrespective of the marathon finishing time (Figure 4), suggesting runners did not adopt a truly polarised TID approach. The popularity of each TID approach is displayed in Figure 4. Overall, the most popular TID was pyramidal. However, the proportion of runners adopting a pyramidal TID increased as marathon finish time decreased, reaching >80% of runners adopting a pyramidal TID in the fastest runners within the dataset (Figure 4).

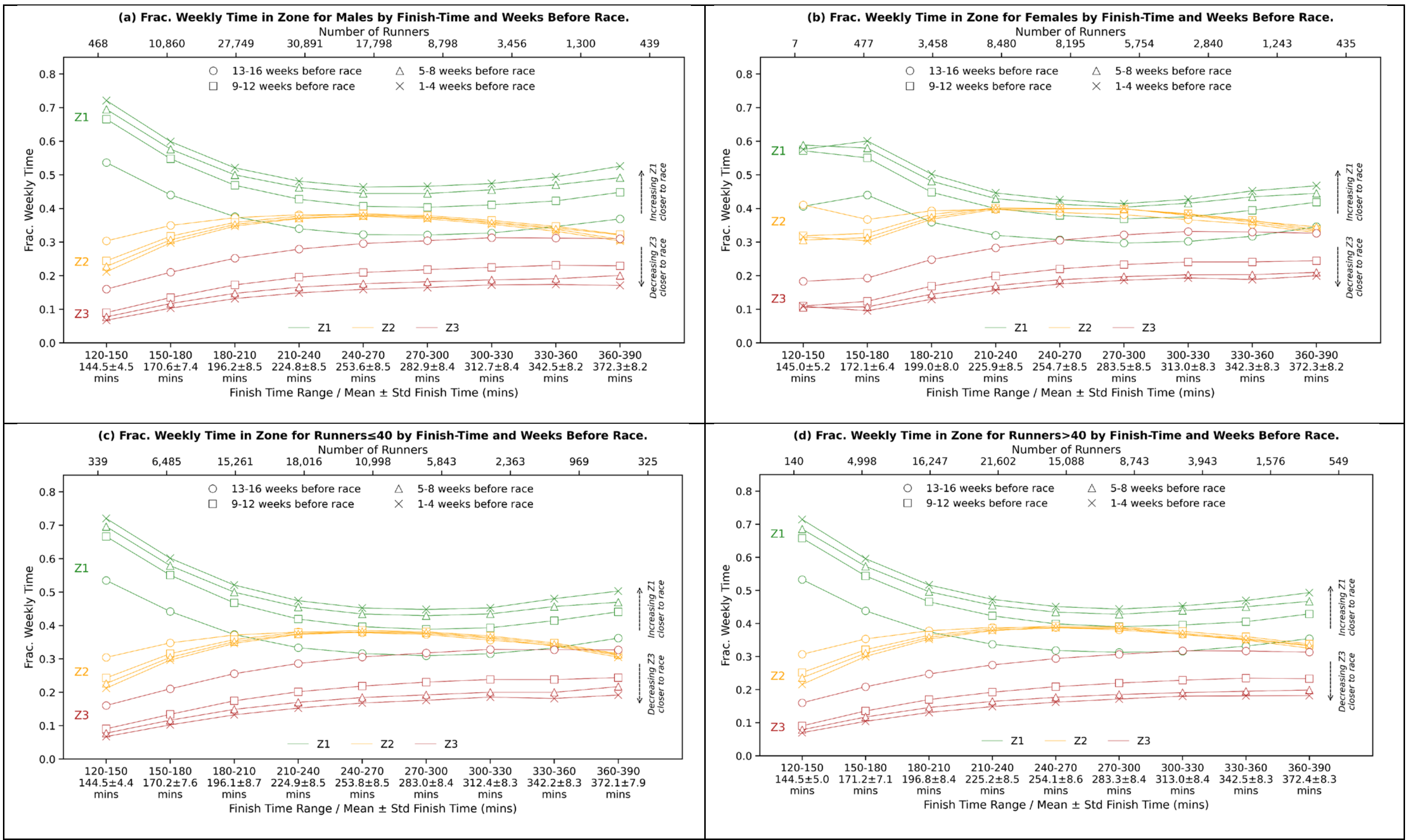


Figure 2. Training intensity distribution (TID) in recreational runners. The TID is reported as the fraction of training completed in each training zone for males and females (panels a and b, respectively), and for the younger and older runners (panels c and d, respectively). Each panel shows the fraction training time in zone 1 (green), zone 2 (yellow) and zone 3 (red). Runners were grouped based on their marathon finish time in 30-min bins (120-150 min, 150-180, etc.), with the average marathon time and the number of runners also displayed.

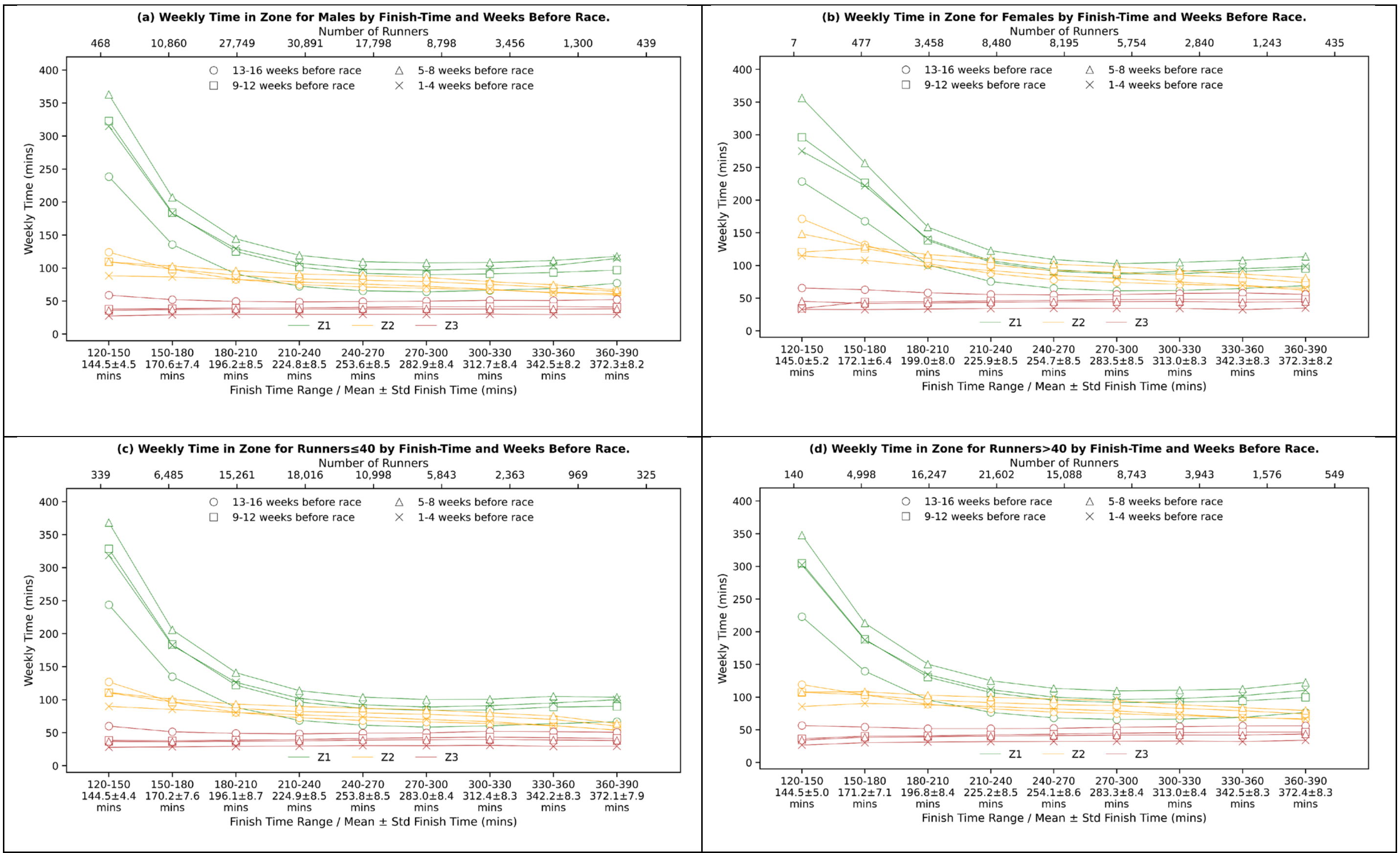
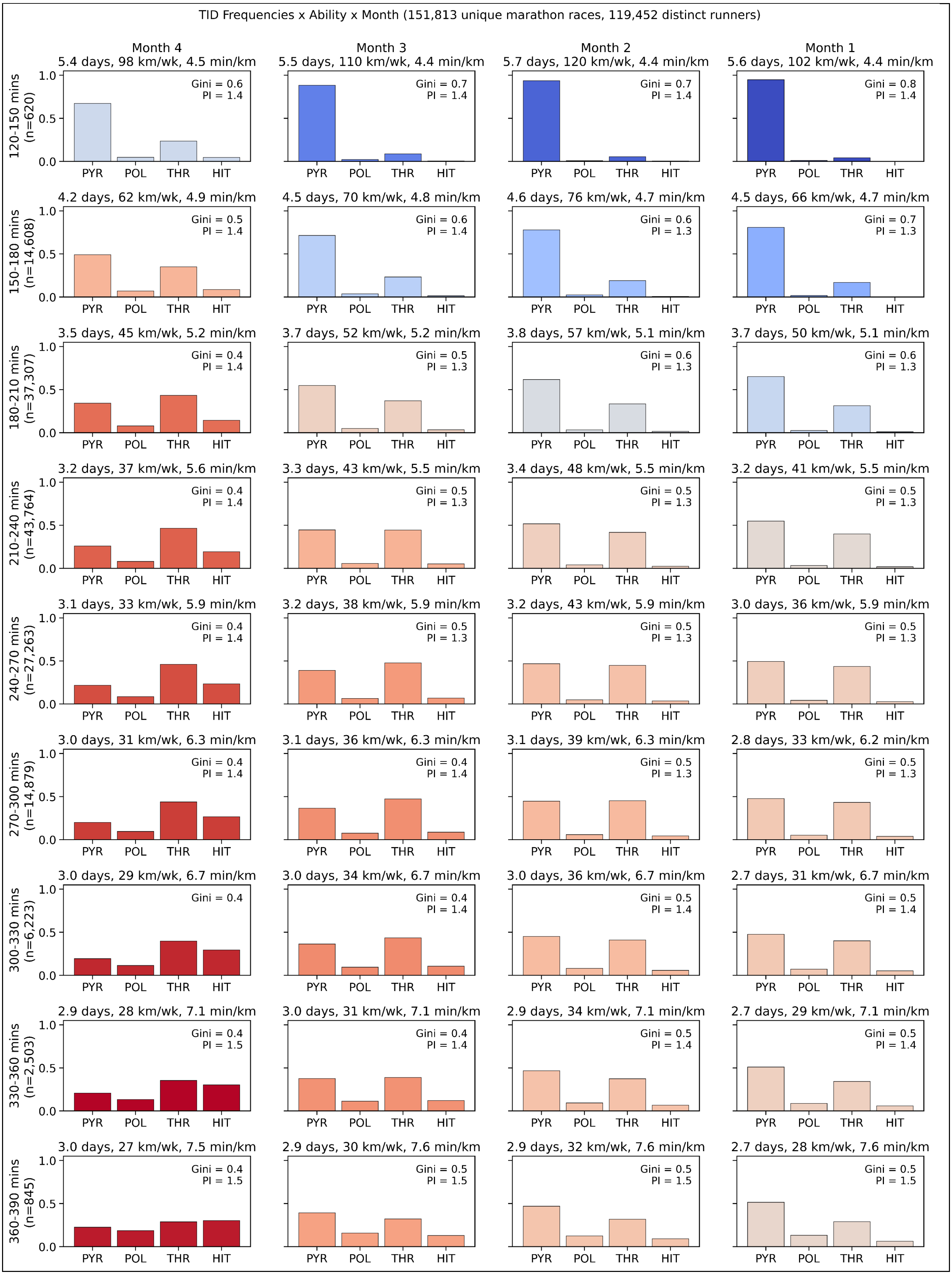


Figure 3. Training intensity distribution (TID) in recreational runners. The TID is reported as training completed in each zone in males and females (panels a and b, respectively), and younger and older marathon runners (panels c and d, respectively). Each panel shows the total training time completed in zone 1 (green), zone 2 (yellow) and zone 3 (red). Runners were grouped based on their marathon finish time in 30-min bins (120-150 min, 150-180, etc.), with the average marathon time and the number of runners also displayed.



TID Frequencies x Ability x Month (151,813 unique marathon races, 119,452 distinct runners)
Month 4
Month 3
Month 2
Month 1
5.4 days, 98 km/wk, 4.5 min/km
5.5 days, 110 km/wk, 4.4 min/km
5.7 days, 120 km/wk, 4.4 min/km
5.6 days, 102 km/wk, 4.4 min/km
120-150 mins (n=620)
Gini = 0.6 PI = 1.4
Gini = 0.7 PI = 1.4
Gini = 0.7 PI = 1.4
Gini = 0.8 PI = 1.4
4.2 days, 62 km/wk, 4.9 min/km
4.5 days, 70 km/wk, 4.8 min/km
4.6 days, 76 km/wk, 4.7 min/km
4.5 days, 66 km/wk, 4.7 min/km
150-180 mins (n=14,608)
Gini = 0.5 PI = 1.4
Gini = 0.6 PI = 1.4
Gini = 0.6 PI = 1.3
Gini = 0.7 PI = 1.3
3.5 days, 45 km/wk, 5.2 min/km
3.7 days, 52 km/wk, 5.2 min/km
3.8 days, 57 km/wk, 5.1 min/km
3.7 days, 50 km/wk, 5.1 min/km
180-210 mins (n=37,307)
Gini = 0.4 PI = 1.4
Gini = 0.5 PI = 1.3
Gini = 0.6 PI = 1.3
Gini = 0.6 PI = 1.3
3.2 days, 37 km/wk, 5.6 min/km
3.3 days, 43 km/wk, 5.5 min/km
3.4 days, 48 km/wk, 5.5 min/km
3.2 days, 41 km/wk, 5.5 min/km
210-240 mins (n=43,764)
Gini = 0.4 PI = 1.4
Gini = 0.5 PI = 1.3
Gini = 0.5 PI = 1.3
Gini = 0.5 PI = 1.3
3.1 days, 33 km/wk, 5.9 min/km
3.2 days, 38 km/wk, 5.9 min/km
3.2 days, 43 km/wk, 5.9 min/km
3.0 days, 36 km/wk, 5.9 min/km
240-270 mins (n=27,263)
Gini = 0.4 PI = 1.4
Gini = 0.5 PI = 1.3
Gini = 0.5 PI = 1.3
Gini = 0.5 PI = 1.3
3.0 days, 31 km/wk, 6.3 min/km
3.1 days, 36 km/wk, 6.3 min/km
3.1 days, 39 km/wk, 6.3 min/km
2.8 days, 33 km/wk, 6.2 min/km
270-300 mins (n=14,879)
Gini = 0.4 PI = 1.4
Gini = 0.4 PI = 1.4
Gini = 0.5 PI = 1.3
Gini = 0.5 PI = 1.3
3.0 days, 29 km/wk, 6.7 min/km
3.0 days, 34 km/wk, 6.7 min/km
3.0 days, 36 km/wk, 6.7 min/km
2.7 days, 31 km/wk, 6.7 min/km
300-330 mins (n=6,223)
Gini = 0.4
Gini = 0.4 PI = 1.4
Gini = 0.5 PI = 1.4
Gini = 0.5 PI = 1.4
2.9 days, 28 km/wk, 7.1 min/km
3.0 days, 31 km/wk, 7.1 min/km
2.9 days, 34 km/wk, 7.1 min/km
2.7 days, 29 km/wk, 7.1 min/km
330-360 mins (n=2,503)
Gini = 0.4 PI = 1.5
Gini = 0.4 PI = 1.4
Gini = 0.5 PI = 1.4
Gini = 0.5 PI = 1.4
3.0 days, 27 km/wk, 7.5 min/km
2.9 days, 30 km/wk, 7.6 min/km
2.9 days, 32 km/wk, 7.6 min/km
2.7 days, 28 km/wk, 7.6 min/km
360-390 mins (n=845)
Gini = 0.4 PI = 1.5
Gini = 0.5 PI = 1.5
Gini = 0.5 PI = 1.5
Gini = 0.5 PI = 1.5
PYR POL THR HIT
1.0 0.5 0.0

Figure 4. Prevalence of training intensity distribution (TID) approaches adopted prior to 151,813 marathons. There are 36 graphs in the figure, grouped in 9 rows and 4 columns. Each graph contains the prevalence of four TID approach identified: pyramidal (PYR), polarised (POL), threshold (THR), and high-intensity training (HIT) (see main text for further details); and the bars in each graph display the fraction of runners who adopted each TID approach. The Gini score and polarisation index for each group of athletes are displayed in each graph, and the colour of the bars also demonstrate the Gini scores (red indicating closer to 0.25, blue indicates closer to 1.0, with higher values denoting high prevalence of one TID over the rest). On top of each graph, the average number of training days, training volume, and pace is reported. Each graph represents runners based on their marathon finish time (rows) and as training progresses (columns). The fastest runners within the dataset, with a marathon finish time of 120-150 min, are displayed on top row, and subsequent rows show progressively slow runners in 30-min bins (150-180 min, etc.). Columns display data within each 4-week (~1 month) block, starting with data from 4-months prior to the marathon displayed in the far-left column. Of note in this figure is the increase in popularity of the pyramidal TID in progressively faster runners.

3.2 Prediction of marathon performance from training characteristics and TID

Table 2 provides the results of three OLS regression models, where the dependant variable in each model is marathon finish time in minutes for each runner. Modelling considering the fraction in Z1 (Z1 Model), Z2 (Z2 Model), and Z3 (Z3 Model) resulted similar predictive capabilities of around ~60%.

Table 2. Ordinary least squares (OLS) regression analysis of marathon finish time as a function of training characteristics.

	Z1 Model	Z2 Model	Z3 Model
Z1 (% of total training time)	-0.2993 (0.0054) *		
Z2 (% of total training time)		0.3355 (0.0086) *	
Z3 (% of total training time)			0.7574 (0.0113) *
Total distance (km)	-0.3317 (0.0010) *	-0.3328 (0.0010) *	-0.3307 (0.0010) *
Total time (min)	0.0581 (0.0002) *	0.0578 (0.0002) *	0.0582 (0.0002) *
Number of active days	-0.0505 (0.0108) *	-0.0518 (0.0109) *	-0.0363 (0.0108) *
Number of long runs	2.6964 (0.0839) *	2.7625 (0.0845) *	2.8271 (0.0834) *
Total distance in long runs (km)	-0.1297 (0.0030) *	-0.1331 (0.0030) *	-0.1306 (0.0029) *
Polarisation index (a.U.)	-6.8330 (0.2783) *	-4.3029 (0.3454) *	-17.3588 (0.2575) *
Sex (positive favours female)	-6.3570 (0.1788) *	-6.9000 (0.1793) *	-6.0574 (0.1781) *
Constant	273.9580 (0.4341) *	246.8035 (0.7756) *	257.9696 (0.4776) *
Adjusted R^2	0.596	0.592	0.600

* denotes significant difference from 0, P < 0.01. Values in brackets are standard errors. Three models have been constructed due to the high-colinearity between Z1, Z2 and Z3 fractions.

Figure 5 shows the correlation analysis of marathon finishing times versus training characteristics. There were strong ($R^2 \geq 0.85$), negative relationships between marathon time and total training distance, total training time, total active days, number of long runs, total long run distance, and fraction of distance covered in Z1. The fraction of distance covered in Z2 and

Z3 demonstrated strong (R^2 = 0.86 and R^2 = 0.97), but *positive* correlations with marathon finish time, whereas the polarisation index was not associated with marathon time.

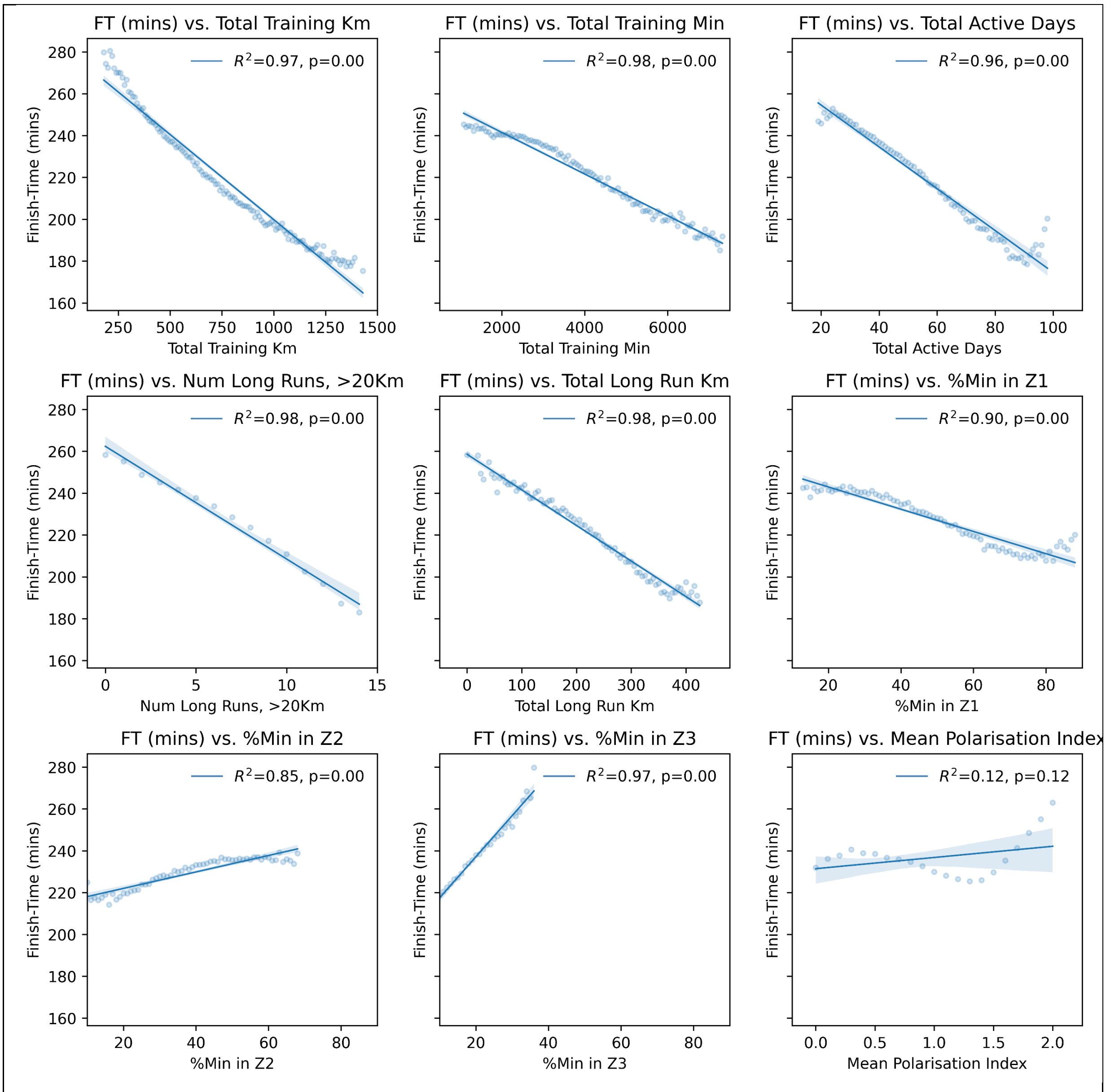


Figure 5. Relationship between marathon finish time (FT) and training characteristics, including training volume, expressed as total training distance and time, number of active days (days where running activity have been detected), number and distance covered during long-runs, defined as runs longer than 20 km, and training intensity distribution, expressed as the percentage of training time completed zone 1, 2 and 3 (Z1, Z2, and Z3, respectively), and the polarisation index. : fraction of running time completed in Z1, Z2 and Z3, respectively. Z1, Z2 and Z3 indicate zones 1, 2, and 3, representing exercise within the moderate, heavy and severe domain, respectively. See main text for further details.

4. Discussion

This is the first study to perform a comprehensive analysis of the training characteristics and TID in a large sample of marathon runners across different performance levels. The key findings from this study were: i) large differences in training volume were observed, with faster runners (marathon times of 120-150 min) completing more than three-times as much training compared to slower runners; ii) higher training volume observed in faster runners was achieved by accruing higher volume in Z1, whereas absolute training volume in Z2 and Z3 remained relatively stable; iii) most runners followed a pyramidal TID approach, and the proportion of runners following a pyramidal TID approach was highest among the fastest runners within the dataset; iv) regression models considering training characteristics and fraction of training completed in Z1, Z2 or Z3 resulted in similar predictive capabilities of around ~59%; and v) there were strong negative correlations between marathon finishing time and training characteristics related to training volume, including total training distance, total training time, and number of long runs. The results from the study suggest training volume is a hallmark of successful marathon running. The data suggests that the most popular TID approach, particularly among the fastest runners within the dataset, was pyramidal, as it may enable runners to accumulate a large training volume.

4.1 Training volume as a hallmark of marathon running

The analysis of training characteristics in this large sample of marathon runners revealed differences in the training characteristics between runners with different finishing times. A key finding was that the best runners within the dataset, those with marathon times of 120-150 min, accumulated a training volume of ~107 km·week^{-1}, which was ~60% higher than the training volume of runners within the next performance group (marathon times of 150-180 min), and over three-fold higher than those with slow marathon times (e.g., marathon time of >270 min; Figure 1, Figure 2, Figure 3). Furthermore, there were strong, negative relationships between marathon finishing time and markers of training volume, such as total training distance, training time, or active days (Figure 5). The regression analyses demonstrated that markers of training volume, including total running distance, number of active days, or distance covered in long runs were typical features of runners with fast marathon times. The finding that marathon performance in a large heterogenous group of runners is strongly associated with a high training volume is consistent with previous literature from elite marathon runners. For example, up to 59% of world class long distance running performance can be predicted by total volume of training [30], and very high training volumes of 160-220 km·week^{-1} have been reported in elite marathon runners [18]. The current study suggests that training volume is also a key determinant of marathon performance in recreational runners. Combined with previous studies, these data suggest that high training volume is a hallmark of successful marathon performance.

4.2 Training zones and marathon running

The higher training volume observed in the fastest runners was accrued, almost exclusively, by increasing training volume in Z1, as total training time completed within Z2 and Z3 remained relatively stable irrespective of marathon performance. Interestingly, however, the highest proportion of training in Z1 was completed by the fastest males (~67%) and females (~57%) of the dataset (Figure 2), which falls short of the ~80% of training time in Z1 typically reported in elite athletes [1,13,18]. The discrepancy between the current study and best practice from elite athletes may be an artefact of a lower overall training volume in the current study (~107 km·week^{-1}) when compared to elite marathon runners (160-220 km·week^{-1}) [18].

The benefits of accumulating training time in Z1 are likely multifaceted. Notably, compared to other endurance sports and, particularly, compared to non-weight-bearing exercises such as cycling or swimming, running is associated with greater mechanical load [31]. Indeed, the vertical loading rate has been shown to increase concomitantly with oxygen consumption during flat running [32]. Further to mechanical loading, exercise performed in Z1 is associated with lower metabolic perturbation [6] and systemic stress responses [33]. Combined, it is plausible that a greater amount of time in between sessions may be required to facilitate recovery following training in session with a high component of Z2-Z3 training, compared to Z1. Moreover, the association between Z1 training volume and marathon finishing time may be related to improvements to metabolic efficiency by increasing mitochondrial density and angiogenesis [34–36].

The OLS regression demonstrated that predicted marathon performance was improved only through increasing the fraction of training spent in Z1. The further two models in Table 2 underline the importance of limiting the fraction of training performed in Z2 and Z3, as an additional percentage point in Z2 and Z3 was predicted to increase finishing time. However, it should be noted the modest constant in the regression models, which predict that an additional percentage point in Z1 reduces marathon time by 0.30 min, whereas each additional training percentage point in Z2 and Z3 will increase marathon time by ~0.33. and ~0.76 min. Therefore, some training time in Z2 and Z3 is likely beneficial in order to reduce marathon finish time (see section 4.3).

Training in Z2, herein defined as intensities between the estimated lactate threshold and CS, has been implicated with marathon performance [16]. However, a greater fraction of time spent in Z2 was associated with a slower marathon time (Figure 5) in the present study. Nonetheless, it is notable in the current dataset that the fastest runners completed >20% of their training in

Z2, and did not adopt a truly polarised approach to training. Our findings support the notion that some ~20% of training in Z2 may be required for marathon performance, but there is likely a point of diminishing returns. Indeed, additional running beyond ~20% of time spent in Z2 observed in the fastest runners within the dataset was not associated with improvements to marathon performance (Figure 5). Importantly, a previous analysis of the same dataset has shown that most marathon runners complete the marathon at ~85% of their CS, which sits close to Z1-Z2 boundary [22]. This is lower than that reported for elite marathon runners [37,38]. Therefore, it is plausible that some runners accumulated training at their marathon pace, which is likely to sit in the upper part of Z2 [16,22]. Time spent in Z2 may also provide greater training specificity, a central tenet of successful training paradigms. Indeed, previous investigations in marathon runners have shown a substantial proportion of training (15-30%) dedicated to runs at or near marathon pace [13,14,16]. Given the marathon is likely to be performed predominantly somewhere within the athlete's heavy domain (i.e., Z2, [37–39]), some training within this domain would ensure preparation specific to the demands of the race. Indeed, previous work has shown a trend for elite marathon runners to increase the amount of Z2 work in the weeks leading into a marathon [18]. Such a strategy was not evident in the current dataset, with runners opting to decrease the time in Z2 as the marathon approached. This could be explained because slower runners may do so at lower relative intensities (i.e. Z1). This effect may be exacerbated if slower runners had worse durability [40–42]. Durability in this context refers to resilience to the loss of speed at the transitions between intensity domains during prolonged exercise [41,42], and studies in cyclists show marked inter-individual variability in durability characteristics [43,44]). If the slower runners in the dataset had worse durability, and therefore experienced greater or more rapid reductions in speed at the intensity corresponding to exercise domain transitions as the marathon progressed, a lower initial relative intensity would be required to achieve an even pacing strategy.

The fraction of training completed in Z3 (i.e., above CS) was negatively correlated with marathon performance. Our results (Figure 5; Table 2) show that increasing the proportion of training in Z3 was negatively correlated to marathon performance. Previous research has demonstrated the incorporation of HIT, including sprint interval training (SIT) can be a useful strategy to increase endurance performance [45,46]. However, these studies have been conducted in athletes with an already well-developed fitness, and therefore caution should be exercised by recreational runners performing excessive HIT sessions in preparation for a marathon. Therefore, it is plausible HIT benefits endurance performance in very well trained athletes, but recreational runners may not benefit from this approach. In recreational runners, there may be a trade off between increasing overall training volume, typically by accruing training in Z1, and accumulating some HIT training. Further research may investigate the effect of incorporating some HIT/SIT sessions within an endurance training programme in recreational runners.

4.3 Polarised vs pyramidal training intensity distribution approaches

Given the apparent importance of accumulating Z1 training in endurance running discussed above, coupled with the apparently small benefits of allocating additional training to Z2 and Z3, two TID approaches appear best suited for marathon runners: pyramidal and polarised TID. The results from this study demonstrate that the most commonly TID approach adopted in recreational runners was pyramidal. Further, a true polarised TID was uncommon in the current dataset (Figure 4). The polarisation index remained <2.0 a.U. for all performance groups (Figure 4), only reaching values of >2.0 a.U. and, therefore deemed as a truly polarised TID [11], in the small subset of runners which primarily adopted a polarised TID and completed the marathon 120-150 min (data not shown).

The pyramidal TID approach was most popular among the fastest runners, and the proportion of runners adopting a pyramidal TID decreased as marathon times increased (Figure 4). It should be noted however that in these slow runners, Z1 may fall into walk-run transition. For example, for runners with marathon times of 240 - 270 min or slower, the Z1 to Z2 boundary was estimated at <10 $km \cdot h^{-1}$. Any activity recorded at higher speeds would have been classified in the current study as Z2 or Z3, which may explain why these runners accumulated a high proportion of training in Z2 and Z3 (Figure 4). Increasing running in Z2, however, would not allow for high volumes. Therefore, recreational runners may want to consider alternative avenues to accumulate higher training volumes in Z1, without the associated mechanical loads of running, or reduce training monotony, for instance incorporating cross-training or cycling. The data analysed within the current study did not allow for quantification of supplemental cross-training workouts, but could be an interesting approach for future research. Although this type supplementary training has been reported previously [18,47,48], little attention has been paid to this approach in empirical studies. It is also worth noting that very few runners adopting a threshold TID, typically characterised by a large component (>35%) of Z2 [49]. A threshold TID appears to be adopted by some elite level athletes (e.g. elite Kenyan marathon runners – [1]). However, in the context of these data, threshold TID appear to reflect slow running speeds in some recreational runners within the dataset, and the fact that at lower speeds, Z1 may be difficult to achieve as can get to close to the walk-to-run transition.

4.4 Effect of training progression, sex, and age on marathon training chracteristics

Our results demonstrated that training volume increases as training progresses and runners get closer to race day, before undertaking a taper phase and reducing training volume. This pattern was adopted irrespective of the marathon performance, but was not clearly associated with an increase in average intensity [50], or the adoption of a different TID approach (e.g. high-intensity or polarised TID). This is likely to represent an attempt to increase training volume throughout the training cycle through increasing Z1 training, especially in weekly long runs. The increase in training volume was likely achieved mainly by increasing the length of individual training sessions and, to a lesser extent, increasing the number of sessions (Figure 4). This may represent an acknowledgement of the relative importance of total training volume by recreational runners.

The training characteristics and TID approaches adopted by runners were similar in male and female runners, and runners aged ≤40 and >40 years, in that those with fastest marathon finishing times accumulated more training volume and adopted a pyramidal TID more often compared to slower runners (Figure 1, 2 and 3). However, the results demonstrated that for a given marathon finishing time, female runners accumulated lower training volume compared to males. This is in agreement with the literature, although studies reporting training volume in female marathon runners have typically been limited to small sample sizes [51,52], and may be a consequence of physiological differences between male and female athletes [53], which results in females runners not being able to accumulate as much training volume as male marathon runners. The results demonstrated virtually no difference in the training characteristics and TID approach adopted by younger and older marathon runners, suggesting the benefits of accruing high training volumes remain independent of age.

4.5 Limitations / methodological considerations

There are some limitations and methodological considerations that need to be noted. The dataset only contained data for 16 weeks prior to a marathon. There is evidence that athletes, particularly well-trained athletes, train for longer in preparation for this event [13,18]. Further, it has been noted that the most successful endurance performance stems from years of systematic training [18,54]. Therefore, the current dataset precludes an understanding of the long-term training approach undertaken by the recreational marathon runners. It is also worth highlighting that the analysis of TID is subject how the boundaries between training zones are determined [17]. In the present study, training zones were established based on speed, instead of heart rate. The demarcation of Z2 and Z3 was established based on habitual training data to estimate CS, instead of more conventional laboratory-based protocols [55]. However, previous investigations have shown comparable estimates of CS derived from time trials and habitual training data [56,57]. The demarcation of Z1 and Z2, however, was estimated on the basis of a systematic review, and the percentage at which the first threshold occurs was kept constant. This fraction may be dependent on the performance level of the athlete [28], with plausible differences also existing between male and females [22,53]. Therefore, a degree of caution is warranted when interpreting or extrapolating these results to an individual athlete. It is worth noting that the nature of this study is descriptive, and caution should also be exercised when inferring causal links until further prospective studies are conducted. Finally, it needs to be stressed that we used all available data, but some training sessions may not have been included in dataset, yet still have an effect on endurance running performance (e.g. strength training [59]).

5. Conclusion

The aim of this study was to investigate the training characteristics and TID of recreational runners prior to a marathon. We observed large variation in training characteristics in runners based on their marathon finishing time. The fastest runners within the dataset, those with marathon performance of 120-150 min, accrued ~107 km·week^{-1}, but training volume rapidly decreased in runners with slower marathon times. Importantly, the higher training volume was accrued by accumulating more training in Z1. Indeed, training time in Z2 and Z3 remained relatively stable, irrespective of marathon finish time, and indeed the most prevalent TID approach was pyramidal, characterised by completing most training volume in Z1, and progressively less training in Z2 and Z3. Further, the proportion of runners adopting a pyramidal TID increased among athletes with faster marathon finishing times, possibly to enable runners to accumulate large training volumes.

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Author contributions

DMP conceived the idea and drafted the first draft of the manuscript. BS analysed the data and constructed the figures. All authors (DMP, BH, SM, EM and BS) edited the manuscript and approved the final version.

Availability of data

The data supporting the findings of the current study have been provided by Strava® under a limited research license with University College Dublin and Professor Barry Smyth. The data are thus not publicly available. Requests to access these data should be directed to Strava®.

Code availability

The code used to analyse the data is available upon reasonable request to Prof. Barry Smyth (barry.smyth@ucd.ie).

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