International Journal of EXERCISE SCIENCE

Technical Note

Assessment of Differences in the Anthropometric, Physiological and Training Characteristics of Finishers and Non-finishers in a Tropical 161-km Ultra-marathon

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ABSTRACT

International Journal of Exercise Science 10(3): 465-478, 2017. This study aimed to compare and determine the differences in the physiological, anthropometric and training characteristics of the finishers (FIN) and non-finishers (N-FIN) in a 161-km race. Two groups of runners (FIN; N=12 and N-FIN; N=14) completed a series of anthropometric and physiological measurements over two separate sessions at least three weeks prior to the race. Training sessions starting from six weeks prior to the race were recorded. Sum of 7 skinfolds, arm and calf girths, VO2max and peak treadmill speed (PTS) were taken during session 1 while the lactate threshold (LT) and running economy (RE) were assessed during session 2. Effect size calculations showed moderate and clear differences in the lactate concentration at LT1 (ES = 0.88, P = 0.05), velocity at LT2 (ES = 0.70, P = 0.07), longest run attempted (ES = 0.73, P = 0.07) and number of cross-training hours (ES = 0.73, P = 0.06) between the FIN and N-FIN. The results suggest that from a physiological perspective, the ability to finish a 161-km race might be differentiated by metabolic attributes via LT measurements. Runners should not neglect the importance of the long runs and should incorporate cross-training to provide additional stimuli to the body while allowing the running muscles to recover from fatigue.

KEY WORDS: Ultra-endurance, ultra-run, ultra-runners, profiling, polarized training

INTRODUCTION

Running is a popular sports discipline that can be performed over many distances. Current trends in endurance running participation now include much longer athletic events or ultra-marathons. While there is no consensus on the definition of an ultra-marathon, it is usually regarded as a distance longer than the classic marathon distance of 42.195 km (20). There are two types of ultra-marathon events: single-stage (e.g. Western States 100 miles or Comrades Marathon) and multistage (e.g. Marathon Des Sables or Four Deserts Race). Both can occur on a mostly flat road or over various terrain trails.

Although physiological, anthropometric and training characteristics of endurance runners ranging from middle to marathon distance of varying participation levels have been widely reported in the scientific literature (1, 3), limited work has been done to capture the data of ultra-runners, especially across the full spectrum of the ultra-running community and not just the fastest. The limited research on the physiological profiling of ultra-runners tends to focus on small sample groups of elite athletes and is dated decades prior to the current growth in popularity of ultra-endurance racing (5, 30). Similarly, the relationship between these variables and actual ultra-marathon performance is also unclear. Until recently, there have been no data in the literature on the potential association between physiological or training parameters and race performance in ultra-runners competing in distances longer than 90 km (22, 29).

In endurance running, an excess of adipose tissue and body weight usually require a greater muscular effort to accelerate the legs, and in theory, the energy expenditure at the same velocity would be greater. For example, recent studies have shown that anthropometric variables such as body mass (BM), body mass index (BMI) and girth of the upper arm were indirectly associated with finishing time in a 100-km ultra-marathon (22), while in another study body fat percentage (BF%) was shown to have a significant negative correlation to 161-km race performance (14). No physiological reasoning was provided by the authors for these relationships, however.

Although it is accepted that maximal oxygen uptake (VO_{2max}), velocity at lactate threshold (vLT), running economy (RE) and fractional utilization (FU) of VO_{2max} are crucial factors determining endurance performance (18, 35, 36), only three studies have been dedicated to the characterization of these physiological parameters on ultra-running performance. These studies concluded that success at ultra-marathon distances ranging from 84 km to 150 km is dependent on VO_{2max}, a high FU during the run and peak treadmill speed (PTS) (5, 29, 30).

Besides accumulating a large training volume, endurance runners competing in distances ranging from 3000 m to the marathon also often engage a variety of training methods of different intensities to elicit specific physiological adaptations (17). Such information is currently unavailable in the ultra-marathon literature. Although a series of studies conducted by Knechtle and colleagues (22, 23, 26) found that participants racing in single-stage ultra-marathons tend to have a weekly running distance of 70 – 98 km with a training speed of 10.3 – 10.7 km/h, it is widely understood that exercise intensity prescribed according to an absolute external workload may produce large differences in internal cardiovascular and metabolic stress between individuals. Hence, the definition of training intensities in absolute terms are of limited value in practice to runners who differ in physiological and functional capacity.

In attempting to understand the physiology underpinning performance in ultra-distance running, a complicating factor is that all except three studies (14, 21, 25), have been conducted only on the event finishers. Unless an extensive comparison across parameters is made between the finishers and non-finishers, one cannot confidently conclude that such physiological, anthropometric and training characteristics are exclusive to the former. Should both finishers and non-finishers share similar attributes, their established predictive powers to race performance will thus become invalid. Although the reasons for not completing a 161-km race can stretch beyond that of physiological and/or training parameters to include issues like nausea during the run to blisters on feet (13), these dynamic factors can vary from race to race affecting both fast and slow runners and are beyond the scope and context of applied physiology. Therefore, the aim of this study was to compare and determine if there are any differences in the physiological, anthropometric and training characteristics of the finishers and non-finishers in a 161-km race.

METHODS

Participants

To increase the sample size, data were collected from two consecutive years of the same 161-km ultra-marathon. All entrants of the event in the year 2012 to 2013 were invited via a personal electronic newsletter from the organiser to participate in the study. An observational cohort was studied whereby 23 men and 3 women participated in this study. They were subsequently grouped according to their race results as either finishers (FIN; N=12; 2 women) or non-finishers (N-FIN; N=14; 1 woman). None of the runners had previously participated in a single-stage 161-km race. A personal follow up 48 h post-race was made with all participants in the N-FIN group. All the N-FIN did not complete the race due to fatigue. Specifically, none failed to complete due to injury problems, blisters or other sources of discomfort. Prior to participation in the study, all participants provided written informed consent. The study conformed to the standards set by the Declaration of Helsinki and the procedures were approved by the local Institutional Ethics Committee.

Protocol

All the laboratory measurements were conducted over two separate sessions (48 – 72 h apart) at least three weeks prior to the race. The participants' training status were recorded with logbooks and physiological profiles established with a lactate threshold (LT), PTS, VO_{2max} and RE tests on a motorized treadmill (Venus; HP-Cosmos, Nussduoff-Traunstein, Germany). Heart rate was continuously recorded throughout all running tests. All participants were also verbally encouraged to perform maximally during the testing sessions.

All participants completed the PTS and VO_{2max} tests during session 1. The test started at an initial velocity of 8 km/h (gradient = 1% throughout the test) with the speed increased by 0.5 km/h every 30 s until volitional exhaustion. Respiratory gas was analysed throughout the test using an open circuit spirometry system (TrueOne 2400MMS; Parvomedics, East Sandy, Utah, USA) and averaged every 30 s, and VO_{2max} determined based on highest 60-s average (e.g. average of two highest consecutive 30-s epochs). PTS was determined as the last stage completed. Anthropometric measurements including the sum of 7 skinfolds (33), arm and calf girths were taken before the PTS test. BF% was calculated using the Durnin and Womersley equations which had been validated in the Singapore population (6).

All participants completed the LT and RE tests during session 2. Both tests were performed concurrently at an initial velocity of 5 km/h (gradient = 1% throughout the test). The speed was increased by 1 km/h every 4 min, which was followed by 30-s of rest for the collection of blood samples from the finger tip. This was repeated until volitional exhaustion. Lactate concentration was determined from the blood sample by means of a portable lactate analyser (Lactate Pro; Arkray, Kyoto, Japan). From this protocol, a velocity-blood lactate profile was obtained for each participant. The velocities associated with LT1 (vLT1) and LT2 (vLT2) were established as the intensities at which the blood lactate concentration increased by 1 $mmol.L^{-1}$ above resting value and at the LT calculated via the modified D_{max} method, respectively (2, 10). Respiratory gas was collected throughout the session and RE was calculated as the average value of the oxygen consumption during the last minute of each velocity below LT2 (37).

All participants were provided with logbooks to record their training sessions starting from six weeks prior to the race. The information consisted of the number of weekly running sessions, kilometres and pace of each run, weekly kilometres run, weekly hours run and cross-training duration (if any). Training-intensity distributions were calculated by establishing the percentage of the total training time at velocities under vLT2, at vLT2 and above vLT2. In addition, all participants had to report their running experience, number and personal best time of marathons completed on a flat course in the past 2 years as well as number of ultra-marathons completed in the past 2 years.

The Craze Ultra-marathon in Singapore generally takes place during the third weekend in September on a relatively flat road course. Runners are allowed 32 h to complete the race. Eight aid stations offering a variety of food and beverages were positioned along the 80.5-km loop making up the route. In both years, the general weather conditions were similar, with the temperature at the start being 26 to 28°C, night lows of 24 to 26°C, and daily highs of 34 to 35°C. Humidity ranged from 65% to 98% with no rain or wind.

Statistical Analysis

The data were analyzed using version 20 of the SPSS software package (SPSS Inc., Chicago, Illinois, USA). Normality of data was assessed using Shapiro-Wilk test. Independent *t* tests were performed on data that were normally distributed while data which were not normally distributed were analyzed using Mann-Whitney U test. The level of significance was set at $P \leq 0.05$ and all data are presented as mean ± SD. Cohen's effect sizes were also calculated to quantify the magnitude of the differences between groups, with modified descriptor values of <0.2, 0.2-0.6, >0.6-1.2, >1.2-2.0, and >2.0 considered trivial, small, moderate, large and very large, respectively (15). Effect sizes with 90% confidence limits (CLs) not overlapping and overlapping zero were defined as *clear* and *unclear*, respectively. A comparison of data on selected parameters between the current study and that of Millet et al. (29) was also done using the same statistical procedures as above. This was possible as the data of each individual runner were reported in the study by Millet and colleagues.

RESULTS

The mean race time for the 161-km FIN was 27:36 ± 4:34 (hh:mm), with an average race pace of 6.0 ± 1.1 km/h. The fastest and slowest time recorded were 19:24 (hh:mm) and 31:55 (hh:mm), respectively. The mean race distance covered by the N-FIN was 90.3 ± 22.5 km in 16:52 ± 4:37 (hh:mm), with an average race pace of 5.4 ± 0.4 km/h. The longest and shortest race distance completed was 139 km and 65 km, respectively. The general and anthropometric characteristics of the 26 runners, 12 in FIN and 14 in N-FIN, are shown in Table 1. There were no significant differences between the groups.

Table 1. General Characteristics of the Participants (mean ± SD)

	FIN (n = 12)	CL (90%)	N-FIN (n = 14)	CL (90%)
Age (y)	37 ± 6	34 – 40	37 ± 8	34 – 41
Height (cm)	172 ± 8	168 – 176	173 ± 7	170 – 177
Weight (kg)	64.0 ± 5.1	61.4 – 66.7	67.8 ± 11.3	62.4 – 73.1
Body mass index (kg/m^2)	21.7 ± 1.6	20.9 – 22.6	22.5 ± 2.7	21.2 – 23.8
Sum of skinfolds (mm)	56.3 ± 20.4	45.7 – 66.9	72.3 ± 31.1	57.5 – 87.0
Upper arm girth (cm)	29.5 ± 1.9	28.5 – 30.5	31.0 ± 4.7	28.8 – 33.3
Body fat (%)	16 ± 7	13 – 20	18 ± 7	15 – 21
Calf girth (cm)	39.3 ± 2.4	38.1 – 40.5	38.3 ± 3.3	36.8 – 39.9

FIN = finishers; N-FIN = non-finishers; CL = confidence limits.

Table 2. Physiological Characteristics of the Participants (mean ± SD**)**

	FIN (n = 12)	**N-FIN (n = 14)**	**ES; ±90% CL**	**Clear / Unclear**
FU during race (%)	39.4 ± 12.4	35.8 ± 7.0	0.37; ±0.69	Unclear
VO_2max (mL/kg/min)	50.9 ± 5.9	49.0 ± 6.0	0.21; ±0.65	Unclear
PTS (km/h)	15.9 ± 1.6	15.5 ± 1.4	0.16; ±0.65	Unclear
vLT1 (km/h)	10.2 ± 1.3	9.6 ± 1.0	0.45; ±0.66	Unclear
Lac.Con.LT1 (mmol/L)	1.8 ± 0.5*	2.4 ± 0.8	0.88; ±0.68	Clear
RER at LT1	0.93 ± 0.03*	0.96 ± 0.01	1.15; ± 1.10	Clear
vLT2 (km/h)	12.3 ± 1.3	11.5 ± 1.0	0.70; ±0.67	Clear
Lac.Con.LT2 (mmol/L)	3.9 ± 0.8	4.6 ± 1.3	0.88; ±0.89	Unclear

†Magnitudes of ES: < 0.2 = trivial, 0.2–0.6 = small, >0.6–1.2 = moderate, >1.2–2.0 = large, and >2.0 = very large. * $P \leq 0.05$. FIN = finishers; N-FIN = non-finishers; CL = confidence limits; ES = effect size; FU = fractional utilization; VO_2max = maximal oxygen uptake; PTS = peak treadmill speed; vLT = velocity at lactate threshold; Lac.Con.LT = lactate concentration at lactate threshold; RER = respiratory exchange ratio.

Physiological characteristics of both FIN and N-FIN are presented in Table 2. Of all the physiological measures, only the lactate concentration and RER at LT1 were statistically significant (P = 0.05), with effect sizes falling into the category of "clear, moderate" (ES = 0.88 and 1.15, respectively). vLT2 had an effect size of 0.7 (moderate), with the confidence limits value of 0.67 describing this as "clear".

RE (VO_2) at speeds lower than vLT2 are presented in Figure 1. While some participants had their vLT2 above 11 km/h, these data were not used for comparison due to inadequate sample sizes for both FIN and N-FIN groups from this point on. No statistical differences existed in the RE of both groups across speeds 6 – 11 km/h. Unclear small effect sizes (ES = 0.39, 0.33, 0.24, 0.26 and 0.23) were obtained for RE at speeds 6, 7, 8, 9 and 11 km/h, respectively.

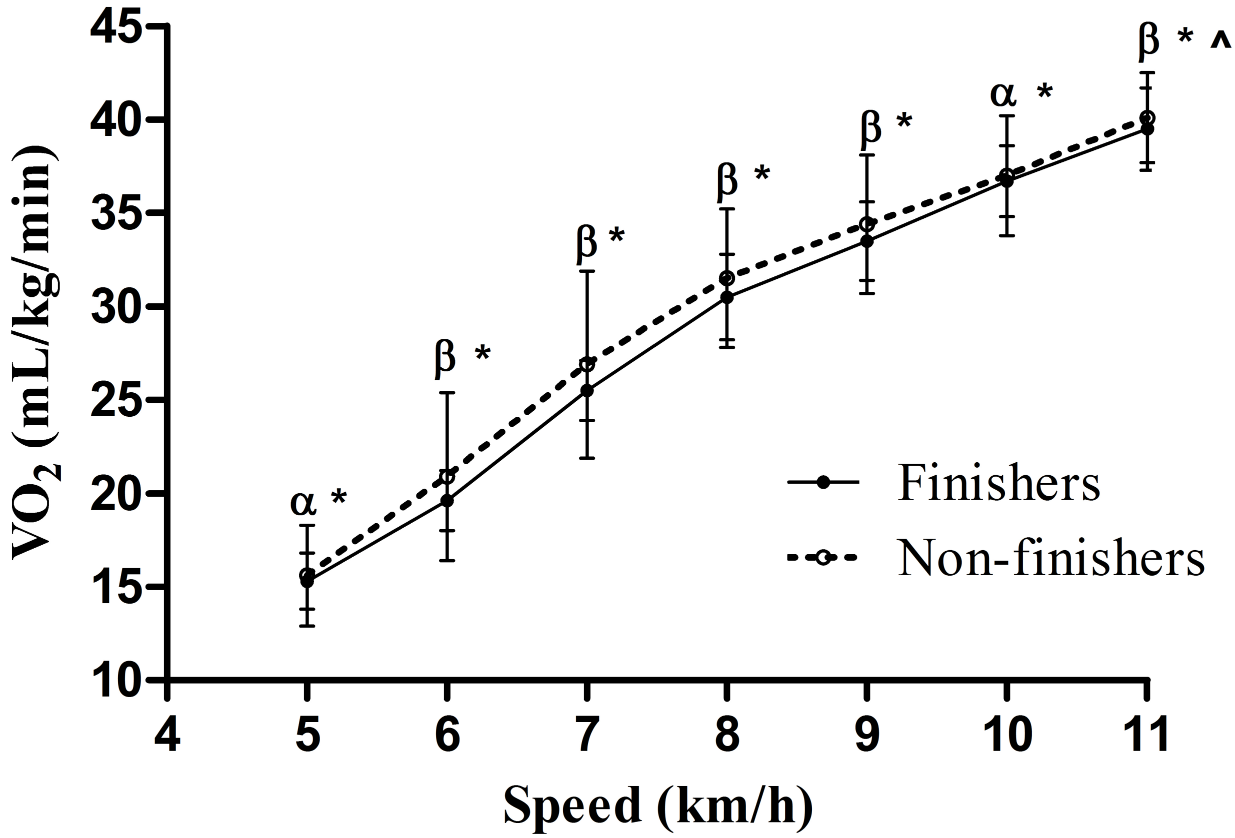

Figure 1. Running economy of the finisher and non-finisher group for speeds below the LT2 (α = trivial effect, β = small effect, * = unclear, ^ = 10 finishers and 11 non-finishers). Values are presented as mean ± SD. VO_2 = rate of oxygen (mL/kg/min) consumed.

Training variables and prerace experiences of both FIN and N-FIN are presented in Table 3. All the participants did their training runs on a relatively flat terrain. Despite having only near-statistical differences in the longest run attempted (P = 0.07) and hours spent in cross-training (P = 0.06) in both groups, the effect sizes of both variables indicated that these differences were moderate (ES = 0.73) and clear. From a descriptive point of view, Table 4 shows the performance, number of cross-training hours and types of cross-training done by the participants. Out of the 18 participants who engaged in cross-training, 12 (7 FIN and 5 N-FIN) utilized aerobic exercises while 6 (3 FIN and 3 N-FIN) opted for resistance training.

Table 3. Training Variables and Prerace Experience of the Participants (Mean ±SD)†

	FIN (n = 12)	N-FIN (n = 14)	ES; ±90% CL	Clear /Unclear
Running experience (y)	5.6 ± 2.9	6.5 ± 8.1	0.12; ±0.65	Unclear
Finished marathons in past 2 years	4 ± 3	5 ± 4	0.28; ±0.65	Unclear
Personal best time in marathon (min)	229 ± 82	237 ± 72	0.10; ±0.65	Unclear
Number of finished ultra-marathons	5 ± 4	3 ± 3	0.57; ±0.66	Unclear
Distance ran per week (km)	58.6 ± 25.4	48.8 ± 38.4	0.30; ±0.65	Unclear
Longest run completed (km)	55.8 ± 30.1	38 ± 16.8	0.73; ±0.67	Clear
Cross-training (h)	19.3 ± 27.9	4.6 ± 5.3	0.73; ±0.67	Clear

†Magnitudes of ES: < 0.2 = trivial, 0.2–0.6 = small, >0.6–1.2 = moderate, >1.2–2.0 = large, and >2.0 = very large. FIN = finishers; N-FIN = non-finishers; CL = confidence limits; ES = effect size.

Table 4. Performance and Cross-training Background of the Participants over 6 weeks

Runner	Race Time (hh:mm)	Distance Completed (km)	Cross-training (h)	Types of cross-training
FIN 1	19:24	-	30.9	Boxing
FIN 2	22:33	-	0	-
FIN 3	22:36	-	97.9	Kayaking; Team Sports*
FIN 4	23:13	-	35	Swimming; Cycling
FIN 5	26:20	-	28.9	Swimming; Cycling
FIN 6	28:20	-	16	Kayaking
FIN 7	31:14	-	1	Resistance Training
FIN 8	31:20	-	11.5	Swimming; Cycling
FIN 9	31:23	-	0	-
FIN 10	31:27	-	2.2	Swimming
FIN 11	31:29	-	0.4	Resistance Training
FIN 12	31:54	-	8	Resistance Training
N-FIN 1	-	139	0	-
N-FIN 2	-	121.5	15.8	Swimming; Cycling
N-FIN 3	-	121.5	0	-
N-FIN 4	-	95.5	0	-
N-FIN 5	-	95.5	1.5	Cycling
N-FIN 6	-	90.5	9	Tennis
N-FIN 7	-	80.5	12	Resistance Training
N-FIN 8	-	80.5	2	Resistance Training
N-FIN 9	-	80.5	0	-
N-FIN 10	-	80.5	0	-
N-FIN 11	-	78	14.7	Resistance Training
N-FIN 12	-	70	8	Swimming
N-FIN 13	-	65	0	-
N-FIN 14	-	65	0.8	Swimming

FIN = finisher; N-FIN = non-finisher; *Includes badminton, basketball and soccer.

The training intensities distributions of both groups are shown in Figure 2. In the FIN group, 94.7 ± 6.8%, 1.6 ± 2.9% and 3.8 ± 6.0% of the total training time were performed at velocities below vLT2, at vLT2 and above vLT2, respectively. In the N-FIN group, 83.5 ± 24.9%, 11.3 ± 25.1% and 5.3 ± 6.3% of the total training time were performed at velocities below vLT2, at vLT2 and above vLT2, respectively. Although there were no statistical differences in the training intensities distributions between both groups, the effect sizes indicated that there were moderate (ES = 0.62) and small (ES = 0.54) differences at the percentage of training time utilizing velocities below vLT2 and at vLT2. However, these effects were unclear.

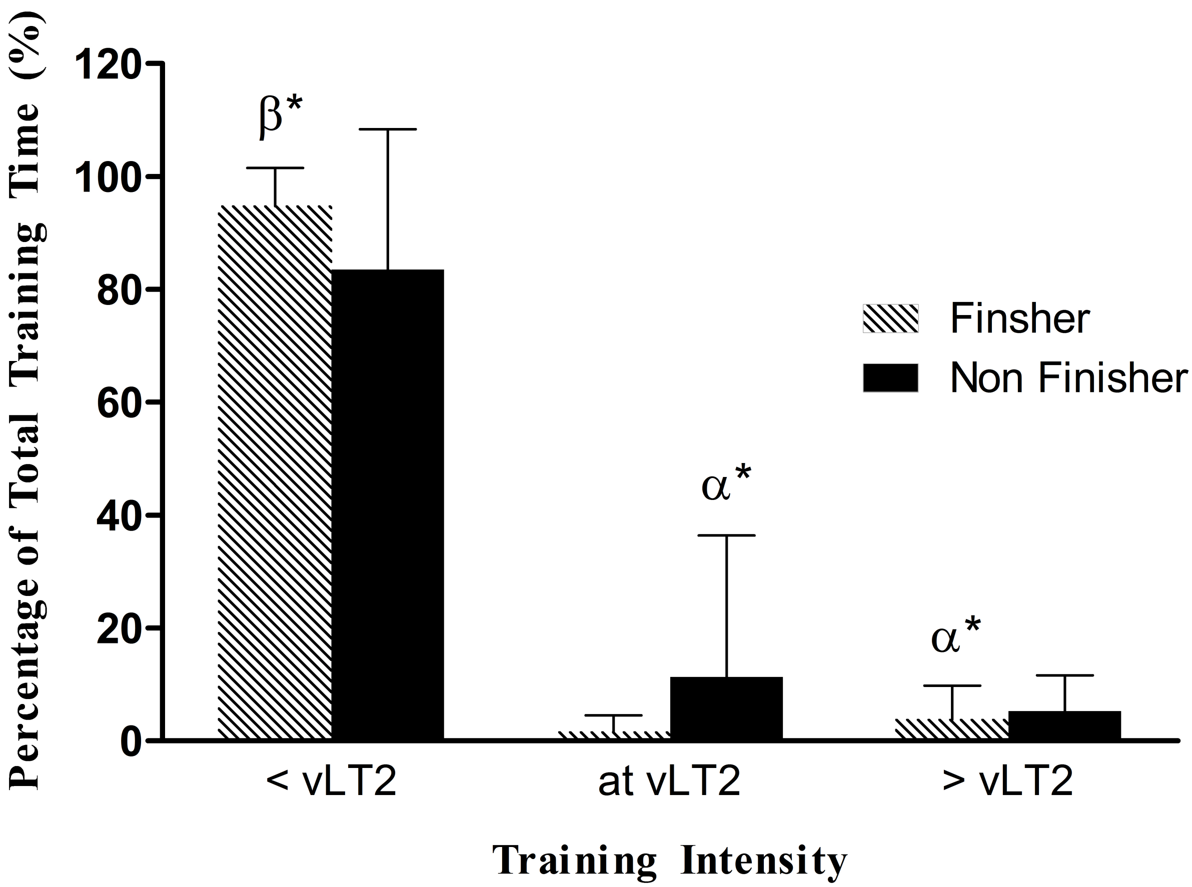

Figure 2. Training intensity distribution calculated relative to the velocity at the LT2 (α = small effect, β = moderate effect, * = unclear,). Values are presented as mean ± SD. vLT2 = velocity at the second lactate threshold.

DISCUSSION

This is the first study to conduct such an extensive comparison of parameters between FIN and N-FIN in a 161-km race. The main findings of the study were that (i) FIN had a substantially lower lactate concentration at LT1 and faster vLT2 than N-FIN and (ii) FIN ran farther for their longest training run and cross-trained more than N-FIN. The results suggest that from a physiological perspective the ability to finish a 161-km race might be differentiated by lactate measurement and that training should extend to beyond just endurance running-specific activities.

The FIN had a mean finishing time of 27:36 (hh:mm) which is slower than previous studies where participants ran similar distances of 149 – 160 km in 24 – 26 h (ambient temperature ranged from 12.2°C to 37.6°C; mean temperature of 24.3°C) (14, 29). The N-FIN completed approximately 90.3 km in 16:52 (hh:mm). These values are still slower than previous field studies where subjects completed 84.6 – 100 km in 6 – 12 h (ambient temperature ranged from 8°C to 28°C; mean temperature unavailable) (5, 22, 30). The slow timings of the participants in the current study are likely due to the fact that they were novice athletes who aimed to simply finish the event, as well as adverse conditions of high temperature and humidity.

Many anthropometric variables have been shown to be related to ultra-running performance, such as BMI (12), body fat percentage (14) and circumference of the upper arm (24). These findings, however, could not be demonstrated consistently in ultra-marathon research, with only three studies having a N-FIN group for comparison (14, 21, 25). The participants of the current study were found to vary widely in body composition and girth values. For instance, BMI values, BF%, arm girth and calf girth ranged from 19.3 – 28.7 kg · m^{-2}, 7.5 – 31.7 %, 25.3 – 43.5 cm and 27.5 – 44.2 cm, respectively. These values are comparable to those from other investigations conducted at 161-km races and single/multistage ultra-marathons (12, 14, 21, 22, 24, 25). Similar to the works of Knechtle and colleagues (21, 25), there were no anthropometric differences between the FIN and N-FIN (Table 1). Interestingly, Hoffman et al. (14) showed lower percentage body fat values in both male and female FIN than N-FIN in a 161-km race. These findings likely differ from the results of the current study due to the larger sample sizes (45 FIN vs 27 N-FIN) of Hoffman and colleagues.

Despite the suggestion by Noakes et al. (30) that "there may be no unique physiological characteristics that distinguish long distance runners, marathon runners and ultra-marathon runners as is usually believed", the FIN had a significantly lower lactate concentration at LT1 (ES = 0.88, P = 0.05) and were moderately faster at vLT2 (ES = 0.88, P > 0.05) than the N-FIN. While an overwhelming number of studies exist to show the strong correlations between vLT2 and endurance running performance (7), the relationship between lactate concentration at the LTs and endurance performance is not widely explored. From the substrate utilization perspective, since lactate is a by-product of carbohydrate oxidation, a higher lactate accumulation at a given exercise intensity may indicate increased carbohydrate metabolism (4). As carbohydrates are stored as glycogen in the liver and muscle in finite quantities, a greater dependency on these substrates would accelerate the depletion of endogenous stores and ultimately lead to fatigue, along with the reduction in running speed. Hence, the lower lactate concentration of the FIN at LT1 might indicate superior lipid metabolism (thus sparing glycogen and delaying the onset of fatigue) at the lower range of submaximal speeds which coincide with their paces during the race. This explanation can also be supported by the significantly lower RER values of the FIN, which indicate a greater reliance on lipid as a fuel. These findings suggest that a combination of lactate concentration at LT1 and vLT2 might differentiate a FIN from a N-FIN among ultra-marathon participants.

Possessing a high maximal aerobic capacity has long been accepted as a marker of elite endurance running performance. Theoretically, this is also beneficial to ultra-marathon performance since the metabolic profile of the runner (e.g. substrate utilization, muscle metabolism by-products) is determined by the relative intensity of the exercise, i.e. the % VO_{2max}. Hence, the higher the aerobic power, the easier to run at a given submaximal speed

(29). Success in endurance running can also be explained by FU at race pace. In this respect, studies conducted on both homogeneous and heterogeneous samples demonstrated positive relationships between FU and ultra-marathon performance. For example, Davies and Thompon (5) reported that the elite ultra-runners tested in their study were able to sustain approximately 67% VO_{2max} over 84 km while Millet et al. (29) concluded that trained runners can maintain at about 34% VO_{2max} for a 24-h race. The three studies dedicated to the characterization of physiological attributes of ultra-runners unanimously identified a strong correlation between maximal aerobic capacity (expressed as either VO_{2max} or PTS) and FU with success in ultra-marathons (5, 29, 30). In contrast to these findings, the current study showed nonsignificant differences with small and unclear effect sizes in the VO_{2max}, PTS and FU between FIN and N-FIN. A comparison of available data revealed no statistical or magnitude differences in the VO_{2max} between the runners of Millet et al. (29) and the runners participating in the current study (the work of Millet and colleagues was selected on the basis of similar event distance). This clearly demonstrates that a good maximal aerobic capacity and high FU are insufficient to allow one to finish an ultra-marathon lasting up to 160 km, let alone predict ultra-running performance.

Theoretically, a strong RE benefits ultra-marathon performance beyond the obvious substrate conservation (a better RE would result in lower energy expenditure, which in turn reflect a lower fat and carbohydrate metabolism in absolute quantity). A lower metabolic rate reduces thermogenesis, thus allowing less heat exchange and sweating while channelling more blood to the working muscles at a given cardiac output (31). Moreover, lower oxygen consumption might generate fewer reactive oxygen species and lessen oxidative stress. This in turn can reduce neuromuscular fatigue and muscle damage while maintaining mitochondrial efficiency (8). As suggested by Figure 1, the RE across a range of submaximal speeds (5 – 11 km/h) were similar for both groups. This further strengthens the observations of previous investigations which showed no direct relationship between ultra-marathon performance and RE.

Studies examining the relationship between training indices and ultra-marathon performance remain equivocal. The FIN and N-FIN in the current study had a mean weekly running distance of 58.6 km and 48.8 km, respectively. There were no statistical nor clear ES differences in the weekly running distance between the two groups. These values are much lesser than the 70 – 86 km and 80 – 115 km documented in the literature for participants attempting single stage and multi-stage ultra-marathons, respectively (21-23, 25). While the recent writings of Knechtle and colleagues (22, 23) showed that weekly training volume was a strong predictor of ultra-marathon performance, their earlier findings from multi-stage ultra-marathons revealed no differences in the weekly distance ran between the FIN and N-FIN (21, 25).

Evidence supporting a high-low-intensity volume training, combined with a substantial high intensity training (> vLT2) has emerged in recent years (34). Such distribution of work away from the LT intensity region is called polarized training. It is noteworthy that although a true polarization of training intensity was not found since the percentage of total training time spent above vLT2 were very low, a moderate yet unclear effect size (ES = 0.61, $P > 0.05$) was observed when the training load below vLT2 was compared between groups (Figure 2).

Perhaps a longer monitoring period is required to accurately reflect the training practices of the runners.

Among the training indices, the FIN completed a longer run (ES = 0.73, *P* = 0.07) and cross-trained more (ES = 0.73, *P* = 0.06) than the N-FIN. Cross-training, defined as combining an alternative training mode with task-specific training, is usually engaged with the intent to derive a physiological and performance benefit similar or better than exclusive sport-specific training (27). Since there were no significant differences in the weekly running distance between groups, a simplistic explanation would be that a higher number of cross-training hours resulted in a greater amount of training stimuli experienced by the FIN. This in turn might lead to better physiological adaptations not measured in this study (e.g. at neuromuscular level) and improved performance, in line with the "dose-response" principle (27). Another viable reason is that the high cross-training hours (3 - 4 h per week) contributed to the FIN's resilience to neuromuscular fatigue, which has been shown in recent research to affect ultra-marathon performance (28). It is well documented that the mechanical stress of ultra-running can cause significant muscle and cartilage damage after just 50 km of running (16, 19). Utilizing dissimilar modes (same energy system but different muscle groups) of cross-training might have strengthened the overall strength and integrity of the locomotor muscles, tendons and joints of the FIN, allowing peripheral fatigue (decline in knee extensor and plantar flexor forces) to be reduced and neuromuscular fatigue to be delayed. Indeed, most of the FIN engaged in aerobic activities like kayaking, cycling and swimming in addition to their running routine (Table 4). While some of the N-FIN also engaged in cross-training, the exercise duration might have been too short (< 2 h per week) to induce any tangible fitness benefits. Furthermore, two of the three N-FIN who cross-trained more than 2 h per week engaged in resistance training, which, although has never been shown to have a negative influence on distance running performance, might not provide a stimulus intense enough to challenge the aerobic system of the runners (38).

Unlike previous studies which showed VO_{2max}, a high FU during the run and PTS to be predictors of ultra-marathon performance, no differences were demonstrated in these physiological parameters between FIN and N-FIN in the current study. The findings suggest that from a physiological perspective, the ability to finish a 161-km race might be differentiated by metabolic events reflected by differences in LT measurements. Training data of the FIN also revealed that runners whose aim is to finish a 161-km ultra-marathon should not neglect the importance of the long run during training and should run at least 35% (56 km) of the race distance based on the findings from the longest run (mean value) attempted by the FIN. Runners should also engage in 3 – 4 h of cross-training weekly to provide additional training stimuli to the body while allowing the running muscles to recover from fatigue.

A limitation of the study was the relatively short monitoring period (six weeks) to establish the training-intensity distribution. Extending the duration to 10 – 12 weeks could provide clearer findings as to whether ultra-runners polarize their training intensity in a manner similar to endurance runners. Reporting of training indices in future ultra-marathon research should include the type and quantity of cross-training. Another potential yet often overlooked area of research is the psychological aspect of ultra-running. Existing studies have primarily examined the motivations of ultra-runners (11) and changes in mood states during the race (32), offering limited practical applications. The long duration of an ultra-marathon would inevitably lead to soreness and pain in the lower limbs. Therefore, ultra-runners would need a certain level of mental toughness and resilience towards pain to complete the race. The latter characteristic was documented in a recent study where 11 finishers of the 4487 km TransEurope FootRace demonstrated low pain perception (9). Future comparisons between FIN and N-FIN should include establishing the mental toughness and pain tolerance level of these participants.

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