WHO RUNS? PSYCHOLOGICAL, PHYSIOLOGICAL AND PATHOPHYSIOLOGICAL ASPECTS OF RECREATIONAL ENDURANCE ATHLETES

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WHO RUNS? PSYCHOLOGICAL, PHYSIOLOGICAL AND PATHOPHYSIOLOGICAL ASPECTS OF RECREATIONAL ENDURANCE ATHLETES

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Table of Contents

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Editorial: Who Runs? Psychological, Physiological and Pathophysiological Aspects of Recreational Endurance Athletes

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Editorial on the Research Topic

Who Runs? Psychological, Physiological and Pathophysiological Aspects of Recreational Endurance Athletes

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Exercise, especially aerobic, has been proven to have many health benefits. Accordingly, the number of individuals engaging in aerobic exercise, especially in endurance-based activities, is continually increasing as evident in the participation trends of endurance running events such as 10 km, half-marathons and marathons. While much is known about the physiological correlates of performance in endurance *elite* runners, little research has been done with regards to psychological, physiological, and pathophysiological aspects of *recreational* endurance runners.

One of the main research questions emerging from observing the increased participation in aerobic exercise and running events centered around the motives of the participants. In recent years, a few studies started exploring the motives leading runners to participate in marathon events, paying special attention to the sex-based and performance-based differences. Unfortunately, these studies based their findings on small samples making their findings to be considered with caution and in need of further research. Another important area of investigation to better understand the participation in endurance exercise and running events focuses on participants' personality traits and how they varied depending on sex, age, performance level, and race distance.

Another important research question related to the increasing participation in aerobic exercise and endurance athletes focuses on the health benefits that aerobic exercise bring to runners. While the long-term benefits of aerobic exercise on physical health have been clearly established in the literature (e.g., reduction of cardiovascular disease), less information is currently available about impact of these activities on participants' psychological health.

Although the health-benefits of exercise has been well-documented, one's participation in aerobic exercise and endurance activities is not without risks. Due to the increasing number of recreational athletes who, without sports experience, engage in endurance activities at much higher intensity than recommended by the international health organizations, the exploration of risk factors on health became of the outmost practical importance. Specifically, it appears imperative to identify and provide evidence-based recommendations for optimal exercise levels to maximize the benefits for physiological as well as psychological well-being, while minimizing possible related risks. The aim of the present Research Topic is to collect manuscripts addressing the existing relationship between participation in endurance-based exercise and psychological and physiological variables across all life-span.

This special issue includes manuscripts focusing on four main areas of research: (a) physiology; (b) psychology; (c) psychology and physiology, and (4) participatory studies. In addition to the original research studies, review articles were also considered.

Among the physiology studies, Mei et al. explored the changes in foot posture, joint kinematics, joint moments and joint contact forces in the lower extremity following a 5 km treadmill run. They found that recreational male runners presented an increased static foot pronation after 5 km treadmill running. They suggested that following mid-distance running foot pronation may be an early indicator of increased lower limb joint loading. Billat et al. sought to establish the relationship between racing strategy, cardiac drift, and performance in recreational marathoner. Runners were grouped into fallers and non-fallers, with the former showing a decrease in speed at the 26th km and a significantly lower performance and higher cardiac drift. The authors found that performance was correlated with the amplitude of the cardiac drift. Based on these findings, they recommend the use of cardiac cost as an objective tool for targeting marathon pace and learning how to self-pace long-distance run.

Nikolaidis et al. examined the relationship of age, body composition, and running speed with muscle strength and flexibility in recreational marathon male runners. The authors reported some age-related differences and showed a moderate relationship between the speed of race and relative isometric strength, but not with the other neuromuscular measures. Due to the relationship between these parameters and health-related physical fitness, the authors encouraged coaches and runners to include stretching and strengthening exercise in their weekly program to enhance all components of health-related physical fitness.

Finally, Olcina et al. described core temperature (Tcore) in top-level and well-trained age group triathletes during the marathon of Ironman World Championship 2014 in Kona-Hawaii under thermal stress conditions. They observed that Tcore increased during the race by $\sim$2°C and correlated negatively with the position in age group (r −0.949, $p = 0.051$), i.e., the higher the Tcore, the lower the performance.

Focusing on training, Festa et al. compared the impact of two different training intensity distributions in terms of conditional and performance parameters and time spent training in recreational runners. No differences were found between the polarized endurance training group and the focused endurance training group on any parameter investigated except their total training time. However, athletes in the focused endurance training group obtained similar improvements with a reduced training time. Alvero-Cruz et al. focused their work on exploring the ability to predict athletes' performance of physiological variables obtained in a laboratory as well as in a field test. They observed that half marathon race time could be predicted from the distance ran in the Cooper test as well as from the vVO_2max values obtained in a laboratory test. Matos et al. analyzed the relationship between variables related to the internal and external loads of training and competition and the perception of well-being in recreational male athletes. Exploring the inter- and intra-week differences, they found that small variations in training stimulus and an increase in maximal oxygen uptake led to improvements in the performance of trail running athletes when considering the running speed in the race.

A second group of the studies in this special issue focused primarily on psychological variable related to running. Waśkiewicz et al. explored marathoners' level of motivation in relation to selected demographics. They reported that experienced and inexperienced marathoners did not differ in their level of motivation, while female and male athletes differ in their motives to compete. These results seem to confirm the existing literature reporting age- and gender-based differences in terms of motivation among marathoners.

Two among these studies aimed to developed psychological profiles of athletes. In the first study, Olmedilla et al. explored the psychological profiles of athletes competing in two cycling sports (triathlon and road cycling). Their aim was to provide an applied model of optimal psychological profiling for sport psychologists, trainers, and coaches to use in promoting their athletes' peak performance. They reported statistically significant differences in few psychological aspects between triathlon and road cyclists and between professionals and amateur athletes. However, they did not find any statistically significant gender-based differences between athletes. In the second study, surveying 42 British athletes, Goddard et al. aimed to explore the construct of mental toughness in extreme ultra-marathoners, while also describing their personality traits. Their results showed a distinct ultra-endurance athlete personality profile characterized by high levels of extraversion and openness to experience. Moreover, their findings also support the literature supporting the argument that mental toughness may be measured by a general personality questionnaire.

On a different line of inquiry, Nogueira et al. sought to explore the relationship between Grit and Dark Traits of personality regarding the appearance of exercise addiction (EA) among amateur endurance athletes. They reported some gender differences, with men scoring higher for addiction levels and for narcissism and psychopathy factors. The authors highlighted how grit may be considered a protective factor against EA, while personality-based factors, such as Machiavellianism, may constitute a risk factor.

Finally, two studies focused their attention on clinically-related topics. For example, Vancini et al. compare quality of life, depression, anxiety symptoms, and profile of mood state of wheelchair basketball and rugby athletes and non-athletes. Not identifying any statistically significant differences between groups, they concluded that wheelchair athletes and non-athletes presented similar level of quality of life, depressive and anxiety symptoms, and mood profiles. Wickström et al. investigated the perception of overuse injury among long-distance runners with different exercise loads. They reported how the overuse injury was perceived to be characterized by the possibility of personal control, treatability, and comprehensibility of the injury context. They also identified some gender-based differences. They concluded that recognition among long-distance runners of the association between their decisions in overuse injury causation is accentuated by increased exercise loads.

In order to bridge the gap between psychologically focused and physiologically focused studies, some of the authors focused their studies on both these aspects. Belinchón-deMiguel et al. explored the possible differences in psychophysiological variables between finishers and non-finishers of a 100-km ultra-endurance mountain athletes. They reported that finishers presented lower levels in psychophysiological parameters before competition compared to non-finishers. They highlighted how their results may be helpful for trainers and athletes to improve their training, and for designing nutritional and psychological interventions aimed to ensure safer participation in these extreme events. Instead Larumbe-Zabala et al. described the longitudinal trends of self-perceptions and their link to physiological performance parameters in recreational marathoners. They reported that improving perceived physical condition predicted self-efficacy, while improvements in motivation were predicted by self-efficacy and perceived physical condition. While no physiological variables appeared to predict changes in psychological variables, their trends over time were correlated. Based on these findings the authors encouraged sport psychologists and coaches to integrate both approaches in training to enhance performance in marathoners. Exel et al. explored the effects of that varying levels of familiarity with the training environment and sensorimotor stimuli originate in the environment have on runners' speed, heart rate regularity degree, and short-term memory. The authors reported how runners showed higher overall short-term memory performance after unusual routes, indicating positive relation to attentional control. Their findings suggest that the contexts of practice may contribute to changing predictability from single to multiple timescales.

Finally, Calogiuri et al. as well as Lepers proposed two participation-based studies. Calogiuri et al. focused their work on mass participation sporting events (MPSE). Specifically, they aimed to analyze trends in women's participation, examined the characteristics of their participation and identified the key factors characterizing women's motivation to participate in different cross-country skiing races. The authors used a mixed methods approach encompassing qualitative analysis of open-ended answers and a machine learning approach to the analysis of sociodemographic characteristics, sport participation, and psychological variables. Their findings corroborate known trends and challenges in MPSE participation, while also providing a novel approach to the study of MPSE.

Lepers investigates the influence of sex on the performance of triathletes in elite and non-elite triathletes. The author reported that, while gender-based difference in triathlon performance may be due to physiological and morphological factors, it is important to explore psychological and participatory factors that may contribute to these differences. He argues that extending the understanding of the factors behind these differences may contribute to promoting more female participation and to helping female triathletes to achieve their maximal performance.

Finally, Gonçalves et al. contributed to this special issue with a review of the literature. They observed that acute and chronic interventions may modify most immune markers, but aspects such as gender, contraceptive pill use in women, physical capacity of the investigated individuals, environment, and type and intensity of the exercises may interfere with these markers as well as the data analysis.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Psychological Profiling of Triathlon and Road Cycling Athletes

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Psychological characteristics of athletes play a key role in sport performance and may moderate and mediate the influence of technical, tactical, and physical abilities athletes show. Different authors have emphasized the special attention such psychological characteristics should receive considering the extent they can influence athletes' behavior either in training or in competition. This paper is aimed at describing the psychological profiles of two cycling sports: triathlon and road cycling. One hundred and twenty-nine male and female professional and amateur cycling athletes (35.74 years old average age ±12.79; 14.94 average number of years practicing cycling ±11.20) were assessed on different psychological characteristics. For that purpose, the Psychological Characteristics related to the Sport Performance (CPRD) Questionnaire and the Psychological Skills Inventory for Sports (PSIS) was used. Results showed significant differences among triathlon and road cyclists (Stress control = $t_{116} = -3.711$, $p = 0.000$, $d = 0.48$; Influence of Performance Evaluation = $t_{115} = -3-115$, $p = 0.002$, $d = 0.49$; Motivation = $t_{124} = -5.520$, $p = 0.000$, $d = 0.82$; Mental Skills = $t_{119} = -4.985$, $p = 0.000$, $d = 1.02$). There were no significant differences between men and women though there were differences among pros and amateur athletes. Triathlon professional, compared to amateurs, showed higher scores in all the psychological dimensions assessed (Stress control = $t_{85} = 3.005$, $p = 0.003$, $d = 1.07$; Influence of Performance Evaluation = $t_{83} = 2.858$, $p = 0.005$, 0.77; Motivation = $t_{91} = 2.721$, $p = 0.008$, $d = 0.26$; Mental Skills = $t_{87} = 2.556$, $p = 0.012$, $d = 0.77$). The results of this descriptive study contribute to establishing a model of optimal psychological profiling applied to the different cycling groups that can be used by sport psychologist, trainers, and coaches in order to promote peak performance of these athletes.

Keywords: stress, performance, motivation, mental skills, sport

INTRODUCTION

Nowadays it is well known that psychological variables are quite significant aspects in sports performance, both in elite and amateur athletes (Morris, 2000; MacNamara et al., 2010; Castilla and Ramos, 2012; Abdullah et al., 2016; Swann et al., 2017). The role of psychological characteristics is relevant not only due to its direct impact on athlete's performance (e.g., coping with or choking under stress), but also as a mediator between the athlete's physical, technical, and tactical skills and his/her performance in competition, whether positively or negatively (Mahamud et al., 2005; Anderson et al., 2014; Arthur et al., 2017). In this vein, some seminal studies found that the physiological variables accounted for between 45 and 48% of the sport performance, but when psychological variables were added, the percentage of variance explained rose to about 79% and 85% in sports such as wrestling (Nagle et al., 1975; Silva et al., 1981; James et al., 2016).

There have been different approaches to the study of the role of psychological variables in sports performance. For instance, several authors analyzed the role of athletes' personality traits on their sport performance (Mahoney and Avener, 1977; Gould et al., 1981; Burnik et al., 2005; Rasmus and Kocur, 2006; Cabrita et al., 2014). That is the case with Gee et al. (2007), who conducted a piece of research over 15 years with professional ice hockey players in North America (NHL) and showed that competitiveness, self-confidence, and analytical disposition were significant predictors of the athletes' performance.

Likewise, some others focused on the differences in such variables between athletes (even those who do not compete in a regular basis) and non-athletes. For instance, Schurr et al. (1977) found team athletes were more extroverted, less dependent, with higher abstract reasoning and higher strength of self than non-athletes, and individual-sport athletes showed greater objectivity, greater dependence, less anxiety and more abstract thinking than non-athletes. More recently, Malinauskas et al. (2014) found higher Conscientiousness scores in athletes compared to non-athletes and higher Extraversion scores in team-sport athletes compared to individual-sport athletes. Similarly, Steca et al. (2018) found athletes who had experienced the most success in their careers showed higher scores in all big-five personality dimensions but Openness to Experience compared to non-athletes, and in all but Extraversion and Agreeableness compared to the less successful athletes. Moreover, they also found that individual-sport athletes were more energetic and open than team-sport athletes. In the same vein, Laborde et al. (2016) found athletes, compared to non-athletes, and individual-sport athletes, compared to team-sport athletes, scoring higher in positive personality trait characteristics. These results were in line with previous results these authors have found regarding mental toughness, athletes being tougher than non-athletes (Guillén and Laborde, 2014).

Despite all these efforts and results, evidence does not clearly support a specific personality profile distinguishing athletes from non-athletes (Weinberg and Gould, 2014). Moreover, such approaches have been also criticized by practitioners and applied researchers due to the scant usefulness of the information obtained. A more recent approach has focused on the study of mental strategies, skills, and behaviors that athletes use to compete and their relationship with the athletes' performance (Romero et al., 2010; Álvarez et al., 2014; García-Naveira et al., 2015).This approach has been able to provide a better knowledge of the most relevant psychological characteristics to athletes' performance as well as to observe the differences between different sports' practitioners and between different players' tactical positions in the same sport (Olmedilla et al., 2015, 2017).

From an applied point of view, knowing athletes' psychological skills may allow establishing working hypotheses about the most appropriate psychological intervention to promote sports performance (Gimeno et al., 2007; Olmedilla et al., 2010, 2013; Abenza et al., 2014), not only to professional or peak-performance athletes, but also to amateurs and young trainees (Carmona et al., 2015).

Moreover, there are emerging sports that are currently congregating a large number of practitioners which had not drawn to much research attention till now (López-Cazorla et al., 2015). Additionally, some of these emerging sports such as trail-running, jogging, cycling, or triathlon do not have clear boundaries between competitive and amateur athletes, compare to the conventional sport distinction. The emergence of these sports and the lack of previous research over them, together with the request of an empirically-based recommendations to coaches and athletes for individualizing and optimizing training programs and improving sport performance, demand systematic studies to carry out (Reigal et al., 2018). Therefore, the objective of this study is to analyze the psychological characteristics (stress control, influence of performance evaluation, motivation and mental skill) related to sports performance in cyclists and triathletes.

MATERIALS AND METHODS

Participants

One-hundred and twenty-nine cyclists and triathletes (69% male and 31% female) voluntary participated in the study. Mean age was 30.74 ± 8.79 years and mean of years practicing the sport was 14.94 ± 8.20 years. Up to 74.4% of the sample were triathletes and 25.6% were cyclists. Regarding professionalism, 27.1% were pros and 72.9% were amateurs.

Measures

Psychological variables were assessed using the Psychological Characteristics Related to Sport Performance (CPRD, Gimeno et al., 2001) Questionnaire (see **Table 1**), based on the Psychological Skills Inventory for Sports (PSIS, Mahoney et al., 1987). The questionnaire consists of 55 items graded in a 5-option Likert scale (from totally disagree to totally agree). It also includes a response option "I do not understand" to avoid missing answers.

TABLE 1 | Psychological characteristics related to the sport performance questionnaire (CPRD).

Items	I totally disagree	I totally agree
1. I usually have difficulties in concentrating when competing		
2. I usually keep thinking about the next competition or match over and over when I go to bed		
3. I really trust in my technical skills		
4. Sometimes I don't feel like going to the training		
6. I seldom feel as tense as for interfering with my performance		
7. Frequently I mentally rehearse my performance immediately before starting my competition or match		
8. In most of competitions or matches I believe I will get it right		
9. When I fail, I usually lose my momentum		
10. It doesn't take much to undermine the confidence in myself		
12. I'm usually scared to death immediately before starting my competition or match		
13. When I fail, it's hard to me to refocus on what I have to pay attention to		
14. Any mild injury or bad training might erode the confidence in myself		
15. I set goals or objectives to pursue and usually I get them		
16. Sometimes I feel extremely uneasy when I am competing		
17. During my competition or match performance, my attention shifts again and again from the athletic performance and other things		
19. I usually doubt myself regarding getting it right when competing or playing a match		
20. I spend great deal of energy trying to keep calm before a match or a competition		
21. When I start off crooked, my confidence quickly decreases		
23. When I mentally rehearse my performance I see myself as if I was watching me on a TV screen		
24. I usually keep playing confidently whether I'm playing really bad		
25. When facing a match or a competition I try to picture from my own perspective what I will see, do and feel when the situation become real		
26. Confidence in myself is rather unstable		
28. I feel very nervous when I fail in a match or a competition		
29. At this moment, doing well in sport is my main focus		
30. I'm good controlling my anxiety		
31. Sport is my life		
32. I believe in myself		
33. I'm usually motivated to improve day by day		
34. I frequently lose my mental focus during the competition or the match due to referees or umpires wrong decisions against me or us		
35. When I fail during a match or a competition, I'm usually concern about what others might think (coach, mates, spectators)		
36. The day before a match or a competition I'm usually worried or anxious		
37. As a rule of thumb, I set goals which are 100% achievable regardless the others		
39 It's not worth to spend so much time and effort I put into sport		
40. I usually psych up when dealing with matches or competitions		
41. During a match or a competition, I often lose my focus due to I worry about the final score or mark		
42. I usually take criticism easily and try to learn from them		
43. I'm easily focused on what is really important at any time during a match or a competition		
44. I can hardly accept giving prominence to some other teammate's contribution despite mine		
45. When the match or the competition was finished, I objectively and specifically analyze my performance according to facts and the different match/competition phases		
46. I often lose my focus due to competitors' trash talking		
47. I'm really concern about coach's match/competition decision regarding me		
48. I don't mentally rehearse as an ordinary routine, something I should improve		
49. I am usually very focused during trainings		
50. I frequently set main goals before each training session or competition/match		
51. My confidence regards on previous competition or matches success		
52. My motivation regards on receiving recognition from others		
53. Coach's instructions, comments and gestures often negatively affects my concentration during matches or competitions		
54. I usually feel confident in myself even in tough matches or competition situations		
55. I'm willing to any effort to improve myself		

[1] *Buceta, J. M., Gimeno, F., and Pérez-Llantada, M. C. (1994). Based on the Psychological Skills Inventory for Sport (PSIS), Mahoney et al. (1987).*

CPRD includes five subscales: Stress Control (SC), Influence of Performance Evaluation (IPE), Motivation (M), Team Cohesion (TCOH), and Mental Skills (MSK), showing acceptable values of internal consistency for the total scale (α = 0.85) and for most of the subscales (α_{SC} = 0,88; α_{IPE} = 0,72; α_{M} = 0,67; α_{TCOH} = 0,78; α_{MSK} = 0,34). According to the authors, the low internal consistency of MSK is probably related to this dimension tapping a wide range of different skills but they kept the subscale due to the factorials loads showed by the items of this factor (over 0.30, Gimeno and Pérez-Llanta, 2010). Moreover, other studies that used the original PSIS had got similar results regarding that subscale (Chartrand et al., 1992). TCOH subscale has not been used in this study due to the nature of the targeted sports.

Procedure

After the corresponding author's institution IRB approval (UM1551/2017), athletes were connected by cycling and triathlon sport clubs. The researchers informed athletes about the objectives and use of the information and those who voluntarily participated signed an informed consent.

Data Analysis

T-test for independent samples were used to test differences between sport modality (cycling vs. triathlon), gender and level (pro vs. amateur) regarding to the different psychological variables.

In addition to the univariate analyses, the psychological measures of the athletes between sports (cycling and triathlon), gender (men and women), and categories (i.e., professional and amateur) were compared by the method of magnitude-based inferences (MBI) (standardized Cohen's *d* values and their 90% Confidence Intervals). The comparison on each psychological measure was done using the Hopkins' spreadsheet with the smallest worthwhile difference (Batterham and Cox, 2006). This method calculated 0.2 times the standardization, estimated from the between-subjects standard deviation. According to the authors (Hopkins et al., 2009) the differences can be defined as unclear if the confidence intervals for the difference in the means included substantial positive and negative values (± 0.2*standardization) simultaneously. In order to assess the differences between pairs of comparisons, the magnitude of a clear difference was assessed as follows: >0.25, trivial; 0.25–75% possibly, 75–95% likely, 95–99% very likely, >99% most likely (Hopkins, 2007). All data analyses were carried out using the SPSS v. 21.0 Statistical package.

RESULTS

Table 2 shows means and *SD*s of each one of the psychological variables assessed according to sport modality as well as inferential statistics.

As can be seen, triathletes scored significantly higher than cyclists in the four psychological dimensions studied (SC = t_{116} = −3.71, p = 0.000; IPE = t_{115} = −3.11, p = 0.002; M = t_{124} = −5.52, p = 0.000; MSK = t_{119} = −4.98, p = 0.000). In addition, qualitative probabilistic inference according to MBI resulted in the differences in Mental Skills being as very likely (95–99% probability of the effect being substantially positive), the differences in Motivation being likely (75–95%), and the differences in both Stress Control and Influence of Performance Evaluation being possible (25–75%)

Tables 3, **4** shows the results regarding gender and sport modality.

Results show there were no statistically significant differences between men and women either in cycling (SC = t_{29} = −1.70,

TABLE 2 | Mean, *SD*, *p* value and effect size of each psychological variable according to sport modalities.

	Clycling (*n* = 33)	Triathlon (*n* = 96)	Total (*N* = 129)	*P* value	ES	MBI
SC	28.68 ± 16.70	42.68 ± 18.47	39.00 ± 19.00	0.000	0.48 (0.16–0.80)	Possibly
IPE	18.81 ± 9.39	25.94 ± 11.58	23.99 ± 11.44	0.002	0.49 (0.16–0.32)	Possibly
M	11.24 ± 5.55	17.81 ± 5.97	16.09 ± 6.52	0.000	0.82 (0.51–1.12)	Likely
MSK	12.41 ± 5.49	19.99 ± 7.93	17.98 ± 8.08	0.000	1.02 (0.68–1.37)	Very Likely

SC: Stress control; IPE: Influence of Performance Evaluation; M: Motivation; MSK: Mental Skills; ES = Effect size values for standardised Cohen's d; MBI = magnitude based inference effects.

TABLE 3 | Mean, SD, *p* value and effect size of each psychological variable according to sport modalities and gender in Cycling.

Subscale	Cycling				
	Males	Females	ES	MBI	*P*-value
Stress Control	26.00 ± 16.62	37.86 ± 14.47	0.51 (0.07–0.96)	Possibly	0.099
Influence of Performance Evaluation	17.63 ± 10.10	22.38 ± 6.05	0.42 (0.04–0.80)	Possibly	0.221
Motivation	11.16 ± 5.40	11.50 ± 6.39	0.04 (−0.65–0.72)	Possibly	0.883
Mental Skills	11.92 ± 4.56	14.14 ± 8.28	0.27 (−0.68–1.21)	Possibly	0.353

ES: Effect size values for standardised Cohen's d; MBI = magnitude based inference effects

TABLE 4 | Mean, SD, *p* value and effect size of each psychological variable according to sport modalities and gender in Triathlon.

Subscale	Triathlon				
	Males	**Females**	**ES**	**MBI**	***P*-value**
Stress Control	44.16 ± 19.25	40.13 ± 17.07	0.24 (−0.11–0.58)	Possibly	0.328
Influence of Performance Evaluation	26.41 ± 11.70	25.03 ± 11.50	0.27 (−0.10–0.64)	Possibly	0.606
Motivation	17.52 ± 5.99	18.39 ± 6.00	−0.19 (0.23–0.42)	Possibly	0.511
Mental Skills	20.30 ± 7.71	19.44 ± 8.42	0.10 (−0.28–0.48)	Possibly	0.626

ES: Effect size values for standardised Cohen's d; MBI = magnitude based inference effects.

$p = 0.099$; IPE = $t_{30} = -1.25$, $p = 0.221$; $M = t_{31} = -0.15$, $p = 0.883$; MSK = $t_{30} = -0.94$, $p = 0.353$) or in triathlon (SC = $t_{85} = 0.98$, $p = 0.328$; IPE = $t_{83} = 0.52$, $p = 0.606$; $M = t_{91} = -0.66$, $p = 0.511$; MSK = $t_{87} = 0.49$, $p = 0.626$) in any of the psychological characteristics. Additionally, the results of the MBI showed the probability of the effect being substantially positive just possible for all the variables.

Tables 5, **6** shows the results according to professional level (pros vs. amateurs) in both modalities.

T-tests showed no significant differences between professional and amateur cyclists in any of the variables analysed (SC = $t_{29} = 0.88$, $p = 0.387$; IPE = $t_{30} = 1.022$, $p = 0.315$; $M = t_{31} = -1.52$, $p = 0.315$; MSK = $t_{30} = -0.61$, $p = 0.545$). However, MBI results showed professional cyclists scoring very likely higher in Influence of Performance Evaluation than amateurs and possibly higher in Stress Control but possibly lower in Motivation and Mental Skills (see **Table 5**).

Conversely, professional triathletes scored higher than amateurs in all the variables explored (see **Table 6**) (SC = $t_{85} = 3.00$, $p = 0.003$; IPE = $t_{83} = 2.86$, $p = 0.005$; $M = t_{91} = 2.72$, $p = 0.008$; MSK = $t_{87} = 2.56$, $p = 0.012$). Moreover, the results of the MBI reflected the relevance of these differences. There were a substantial difference in Stress Control (95–99% probability), a large difference in Influence of Performance Evaluation and Mental Skills (75–95% probability), and moderate difference in Motivation (25–75%).

DISCUSSION

This study has explored the psychological profile of two different endurance sports, cycling, and triathlon, and analyzed whether gender and professionalism level present differences in athlete's core psychological characteristics. The results of this study have shown there are differences in the psychological characteristics explored between modalities and between level of professionalism. Unlike other studies that have not clearly found differences between practitioners of these two sports (see Schurr et al., 1977), this study did find significant differences in all the variables studied: triathletes scored higher than cyclists in all the variables with an important size of effect in two of them: the athletes' mental skills and their motivation.

TABLE 5 | Mean, SD, *p* value and effect size of each psychological variable according to sport modalities and professional level in Cycling.

Subscale	Clycling				
	Professional	**Amateur**	**ES**	**MBI**	***P*-value**
Stress Control	33.57 ± 17.49	27.25 ± 16.58	−0.01 (−0.67/0.65)	Possibly	0.387
Influence of Performance Evaluation	21.75 ± 4.10	17.83 ± 10.48	−1.83 (−3.19/−0.47)	Very Likely	0.315
Motivation	8.89 ± 5.18	12.13 ± 5.53	0.45 (−0.13/1.03)	Possibly	0.315
Mental Skills	11.44 ± 3.00	12.78 ± 6.23	0.09 (−0.65/0.84)	Possibly	0.545

ES: Effect size values for standardised Cohen's d; MBI = magnitude based inference effects.

TABLE 6 | Mean, SD, *p* value and effect size of each psychological variable according to sport modalities and professional level in Triathlon.

Subscale	Triathlon				
	Professional	**Amateur**	**ES**	**MBI**	***P*-Value**
Stress Control	52.17 ± 14.56	39.27 ± 18.64	1.07 (−0.54/1.59)	Very Likely	0.003
Influence of Performance Evaluation	31.77 ± 23.90	23.90 ± 11.76	0.76 (0.28/1.25)	Likely	0.005
Motivation	20.42 ± 16.79	16.79 ± 5.36	0.26 (0.13/0.64)	Possibly	0.008
Mental Skills	23.52 ± 18.76	18.76 ± 8.14	0.77 (0.31/1.23)	Likely	0.012

ES: Effect size values for standardised Cohen's d; MBI = magnitude based inference effects.

Whether the differences between the two sport modalities are due to the difference in the nature of the two sports more than the differences between the practitioners is still open. Triathlon embeds cycling, and in triathlon competitions, perhaps for some athletes the cycling competition is instrumental, and only make sense in conjunction with the other two swimming and running parts. Eventually, these results are in line with Reigal et al.'s (2018) who compared triathlon to some other sports modalities in mental skills and found differences not just only between triathletes and soccer and golf players but also between triathletes and track and field athletes.

An explanation might be related to the fact that while the training and preparation schedules may be similar, the situations and competitions are very different, cycling being much more tactical than triathlon. If the physical differences, not the tactics, tip the balance towards the side of the triathletes, perhaps the same should happen with the psychological ones, among which the mental ability and the motivation to persist in the sport stand out. Moreover, the reduced sample size of cyclists demands to be cautious.

Regarding gender, this study has shown that in these two sports, there are no differences among men and women regarding psychological variables. This result is in agreement with recent work in the same line (Hanton et al., 2009). Nevertheless, we must be cautious before extrapolating the results. For example, although no differences have been found regarding the competitive anxiety when is considered globally, in other studies we have found clear differences between the two genders when analyzing the factor of competitive anxiety related to the worry for the athletes' performance (Ponseti et al., 2017).

In line with a possible blurring between the professional and amateur categories in these two sports, no differences have been found in cycling. Although professional Stress Control and Influence of Performance Evaluation scores were higher – this one showing with a relevant MBI score – there were no statistically significant differences supporting a possible subdivision of the variables studied by the CPRD in these two blocks.

Conversely, professional triathletes clearly showed significant differences in all psychological variables, SC and IPE being particularly likely according MBI values. These results are perfectly compatible with the competitive restrains. Again, the same scheme is repeated, and perhaps should be with the same explanations, as when the data are considered globally regarding the differentiation between the two sports.

The results of this study provide relevant information regarding the psychological characteristics of the practitioners of these two sports, cycling and triathlon, and such psychological profiling may be a useful tool for designing general psychological training, and/or specific interventions (Olmedilla et al., 2013).

Limitations and Future Research Directions

As with any cross-sectional study, the lack of repeated measures to determine stability across the different competitive and training situations should be taken into account and future studies should include follow-up assessment which might be able to capture the effects of situational and transitional events the athlete has to cope with.

In addition, we must bear in mind that this descriptive study did not include an objective assessment of sport performance, which should also be considered in the future. Finally, there should be noted that there is a reduced cyclist sample size. Therefore, generalizations should be made cautiously.

CONCLUSION

(1) There are significant differences between cyclists and triathletes, with respect to all the variables studied with the CPRD.
(2) No gender differences have been found with respect to sports practiced, nor in terms of psychological variables.
(3) There are some differences between amateur and professional practitioners in psychological characteristics, but they did not show a consistent pattern among the two modalities, except for stress management and performance evaluation.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the Declaration of Helsinki. The protocol was approved by the Comité de Ética de la Universidad de Murcia (reference: UM 1551/2017). All subjects gave written informed consent in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

AO, AG-M, and EO contributed with the conception and design of the study. ED organized the database. ED and EO performed the statistical analysis. AO wrote the first draft of the manuscript. VR, AG-M, GT-L, and EO wrote sections of the manuscript. All the authors contributed to the revision of the manuscript, and read and approved the presented version.

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frontiers in Physiology

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Foot Pronation Contributes to Altered Lower Extremity Loading After Long Distance Running

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This study presents an investigation of the changes in foot posture, joint kinematics, joint moments and joint contact forces in the lower extremity following a 5 k treadmill run. A relationship between knee and ankle joint loading and foot posture index (FPI) is developed. Twenty recreational male heel-strike runners participated in this study. All participants had a history of running exercise and were free from lower extremity injuries and foot deformities. Foot posture was assessed from a six-item FPI to quantitatively classify high supination to high pronation foot poses. The FPI is scored using a combination of observations and foot palpations. The three-dimensional marker trajectories, ground reaction force and surface electromyography (EMG) were recorded at pre and post-gait sessions conducted over-ground and 5 k running was conducted on a treadmill. Joint kinematics, joint moments and joint contact forces were computed in OpenSim. Simulated EMG activations were compared against experimental EMG to validate the model. A paired sample *t*-test was conducted using a 1D statistical parametric mapping method computed temporally. Hip joint moments and contact forces increased during initial foot contact following 5 k running. Knee abduction moment and superior-inferior knee contact force increased, whereas the knee extension moment decreased. Ankle plantarflexion moment and ankle contact forces increased during stance. FPI was found to be moderately correlated with peak knee and ankle moments. Recreational male runners presented increased static foot pronation after 5 k treadmill running. These findings suggest that following mid distance running foot pronation may be an early indicator of increased lower limb joint loading. Furthermore, the FPI may be used to quantify the changes in knee and ankle joint moments.

Keywords: foot posture, pronation, knee, ankle, contact force, OpenSim, statistical parametric mapping

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INTRODUCTION

Long distance running has increased in popularity (van Gent et al., 2007; Hulme et al., 2017) due to practicality in many environments, low cost, and links to preventing health issues (Mei et al., 2018). Extensive running participation may lead to increased running-related injuries (RRI) reported as 2.5–33.0 injuries per 1000 h of running (Videbæk et al., 2015; Hulme et al., 2017) with up to 79.3%

RRI reported at the knee joint (van Gent et al., 2007). The human foot, as the primary interface with our environment, presents morphological and postural changes following prolonged running, which is a key intrinsic factor contributing to RRI (Barnes et al., 2008; Nigg, 2011; Nigg et al., 2015; Mei et al., 2018). A 6-item scale (foot posture index, FPI) was previously developed and validated to define foot postures including high supination, supination, neutral, pronation and high pronation in multiple planes and anatomical segments under static palpation measurements and clinical settings (Redmond et al., 2006). This FPI may play a role as a low-cost assessment of foot postures without requiring a lab or imaging evaluation.

Over 90% of recreational marathon runners adopt a heel-strike style (Larson et al., 2011). This is associated with a drop in foot arch following long distance running (Mei et al., 2018), which is consistent with a recent finding reporting reduced arch ratio and foot pronation (Fukano et al., 2018). A recent study reported that competitive runners exhibited higher local dynamic foot stability quantified by the "Maximal Lyapunov Exponent" compared with recreational runners during an exhaustive 5 k run (Hoenig et al., 2019). A high-intensity treadmill run exhibited symmetry in step length, step frequency, contact time, flight time, maximum force and impulse but asymmetry in impact force (at 5 k), and flight time together with impact force (at 7.5–10 k) (Hanley and Tucker, 2018). Skeletal joint work shifted proximally from the ankle to the knee and hip joints reducing long distance running economy (Sanno et al., 2018).

Foot pronation and joint impact forces have been proposed as predictors of RRI (Nigg, 2011; Brund et al., 2017). Gait retraining programs (Bowser et al., 2018) and real time feedback studies (Yong et al., 2018) evaluated potential factors contributing to impact RRI, such as peak tibial shock (peak vertical acceleration), and average and peak loading rates. Conflicting opinions concerning foot pronation as a risk factor has reported for neutral shoes (Nielsen et al., 2014), and standard versus motion control shoes (Malisoux et al., 2016). The contradicting results may be explained in part by different runners' experience, running footwear preferences, and different study designs. Bertelsen et al. (2017) proposed a framework to analyze the etiology of RRI, whereby cumulative load exceeding a maximum load capacity would trigger injury. Studies have revealed alterations in gait symmetry, joint stability and power contribution in competitive long distance runners (Hanley and Tucker, 2018; Sanno et al., 2018; Hoenig et al., 2019). The literature presents multiple factors contributing to RRI in competitive athletes, however, few studies consider the effects on recreational runners, who are the majority of the running population (Knechtle et al., 2018; Vitti et al., 2019). Foot pronation has been reported as a predictor of altered joint kinetics and running related injuries (Nigg, 2011; Brund et al., 2017), however, a quantitative measure between the clinical FPI (a score that measures pronation) and joint kinetics has not been presented to date.

Thus, the aim of this study was to investigate the changes of foot posture, joint kinematics, joint moments and joint contact forces in the lower extremity following a 5 k treadmill run in recreational runners. We present the FPI and its relation to lower limb kinetics pre and post-5 k running. It is hypothesized that (1) joint kinematics, joint moments and joint contact forces in the lower extremity will change post-5 k running, and (2) the FPI will quantify changes in joint kinetics following mid distance running.

MATERIALS AND METHODS

Participants

Twenty recreational male heel strike runners (25.8 $\pm$ 1.6 years, 67.8 $\pm$ 5.3 kg, 1.73 $\pm$ 0.05 m) participated in this study, consistent with previous running studies (Hanley and Tucker, 2018; Sanno et al., 2018; Hoenig et al., 2019). The inclusion criteria was participants would have over ground or treadmill running history with an average distance of 30 km per week and preference using typical running shoes. Participants were free from lower extremity disorders and injuries. Foot deformities, such as hallux valgus, over pronation or supination, pes planus, and pes cavus, were excluded during recruitment. Written consent was obtained prior to the test. Ethics was approved from the Human Ethics Committee at Ningbo University (RAGH20161208).

Experimental Protocol

Baseline data (pre 5 k run) were collected with the participant standing barefoot (static) followed by running barefoot on the over ground runway at their self-selected speed. This included a static foot posture assessment, static marker positions, dynamic marker trajectories, ground reaction force and surface electromyography (EMG). The assessment of foot posture was performed following the established FPI (Redmond et al., 2006), including six observations from the (1) talar palpation, (2) malleoli, (3) inversion/eversion of calcaneus in the rearfoot, (4) talonavicular joint, (5) medial longitudinal arch, and (6) forefoot abduction/adduction to define foot postures in multiple planes and anatomical segments. An eight-camera motion capture system (Vicon Metrics Ltd., Oxford, United Kingdom) was used to track the marker trajectories at 200 Hz, and an in-ground force plate (AMTI, Watertown, MA, United States) was utilized to record the ground reaction force at 1000 Hz. The force plate was located in the middle of an over ground runway. A 37-marker set was used for all participants during the test, which has been validated in previous studies (Hamner and Delp, 2013; Rajagopal et al., 2016). Surface electromyography (EMG) signals were recorded via a EMG system (Delsys, Boston, MA, United States) for muscle activities, including rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), semitendinosus (ST), tibialis anterior (TA), medial gastrocnemius (MG), and lateral gastrocnemius (LG).

After warm-up and lab familiarization, the FPI was evaluated and recorded as scores (from −2 to 2 per item). The total score would be classed as high supination (−12), supination (−5), neutral (0), pronation (5), and high pronation (12) while static barefoot standing with shoulders' width apart (Redmond et al., 2006). Data of marker trajectories and ground reaction force from two static and five running trials were collected of the right foot striking the force plate. After the baseline test, participants ran 5 k on the treadmill at their self-selected speed (which were recorded in the range of 10–12 km/h) using participants' own typical running shoes. This was not chosen to elicit fatigue but elicit submaximal effort (Hanley and Tucker, 2018). The post-5 k test started within 5 min of finishing the treadmill run, following the same protocols as the baseline test (with participants barefoot).

Musculoskeletal Model

An updated version of the original OpenSim musculoskeletal model (Delp et al., 2007), which included the patella (DeMers et al., 2014), was used for this study. This model included the torso and lower extremity, which had six degrees of freedom at the pelvis, a ball-and-socket joint with three degrees of freedom at the hip, pin joints at the ankle, subtalar and metatarsophalangeal joints. A non-frictional patella articulated with the femur and prescribed by the knee angle was also added to direct the quadriceps force, wrapping around the patella and attaching to the tibial tuberosity (DeMers et al., 2014). The default model included a hinge joint for flexion-extension of the knee, and was extended to include abduction-adduction motion based on a previous study (Meireles et al., 2017).

Data processing was performed in OpenSim v3.3 as per the established workflow (Delp et al., 2007). Marker trajectories and ground reaction forces were low pass filtered at 6 Hz with a zero-phase fourth order Butterworth filter. The model was firstly scaled to each participant's anthropometric measures collected from static marker positions and body mass. Muscle insertion points and moment arms were scaled to match each participants' segment lengths (DeMers et al., 2014). The "*Inverse kinematics*" (IK) algorithm minimized errors between virtual markers in the model and experimental marker trajectories to compute joint angles, and "*Inverse Dynamics*" (ID) was performed to compute joints moment (Delp et al., 2007).

Muscle forces were previously reported as the main factors affecting joint contact forces (DeMers et al., 2014; Lerner et al., 2015; Lerner and Browning, 2016). The "*Static Optimization*" (SO) with weighted factors was employed to compute muscle activation and forces, which improves the accuracy of joint contact force prediction (DeMers et al., 2014; Lerner and Browning, 2016). Following previously established protocols to reduce prediction errors (Lerner et al., 2015; Lerner and Browning, 2016), the weighting factors for muscles were set at 1.5 for the gastrocnemius, 2 for the hamstrings and 1 for other muscles in this study. The contact forces to the hip, knee and ankle joints in the anterior/posterior (x), superior/inferior (y), and medial/lateral (z) directions were computed using "*Joint Reaction*" (JR) analysis for the femur, tibia and talus, respectively.

Model Validation

Muscle electromyography (EMG) signals were used to validate model-simulated muscle activations (**Supplementary Material 1**), which included the rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF), semitendinosus (ST), tibialis anterior (TA), medial gastrocnemius (MG), and lateral gastrocnemius (LG). Joint kinematics, joint kinetics, and joint contact force were compared with previous literature.

Data and Statistical Analysis

A simulation of stance phase from right heel strike to toe off was analyzed in this study. Variables included FPI scores, joint angles, joint moments and joint contact force in the anterior/posterior (**ant-post**) (x), superior/inferior (**sup-inf**) (y), and medial/lateral (**med-lat**) (z) directions during pre-5 k and post-5 k tests. For the time sequential kinematics, kinetics and contact force data, raw data from five trials of each participant were interpolated to 50 in data length to represent stance, and averaged for each participant for statistics. The joint moments (flexion/extension, adduction/abduction, and internal/external rotation moments of the hip, flexion/extension and adduction/abduction moments of the knee, dorsi/plantar flexion moment of the ankle, inversion/eversion moment of subtalar) and contact forces were normalized to body mass (Nm/kg) for moments and body weight (xBW) for contact forces,

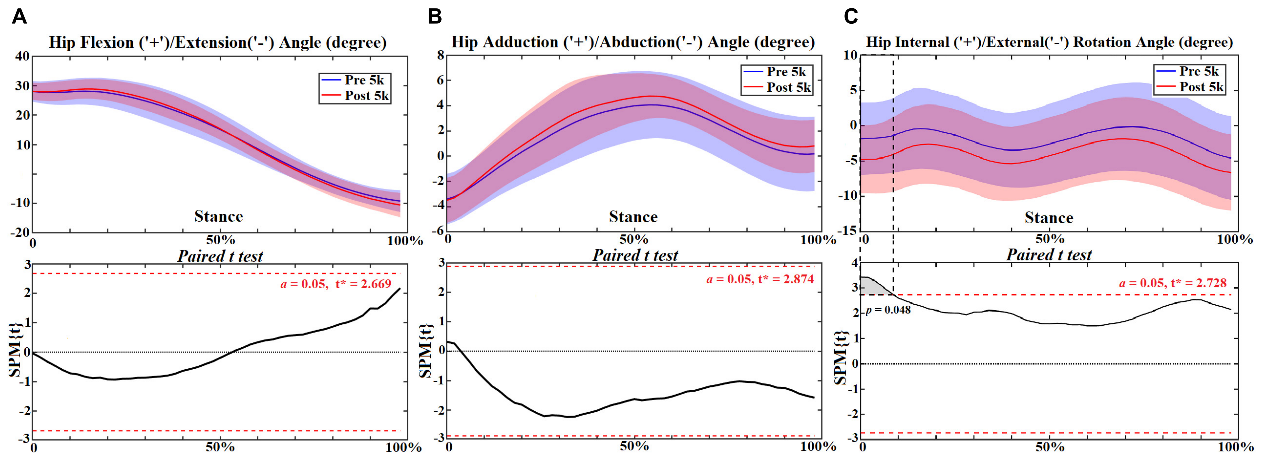

FIGURE 1 | The hip joint angles **(A–C)** during stance with statistics (spm{t}) from spm1d ("+" and "–" represent directions).

TABLE 1 | FPI scores, speed, and contact time (Mean ± SD [95% Confidence Interval]).

Variables	Pre-5 k [95% CI]	Post-5 k [95% CI]	*p*-value
FPI scores	1.7 ± 1.84 [0.84, 2.56]	7.3 ± 1.87 [6.43, 8.17]	<0.001
Speed (m/s)	3.068 ± 0.128 [3.0, 3.13]	3.137 ± 0.152 [3.07, 3.21]	0.007
Contact time (s)	0.253 ± 0.023 [0.242, 0.263]	0.249 ± 0.027 [0.236, 0.262]	0.230

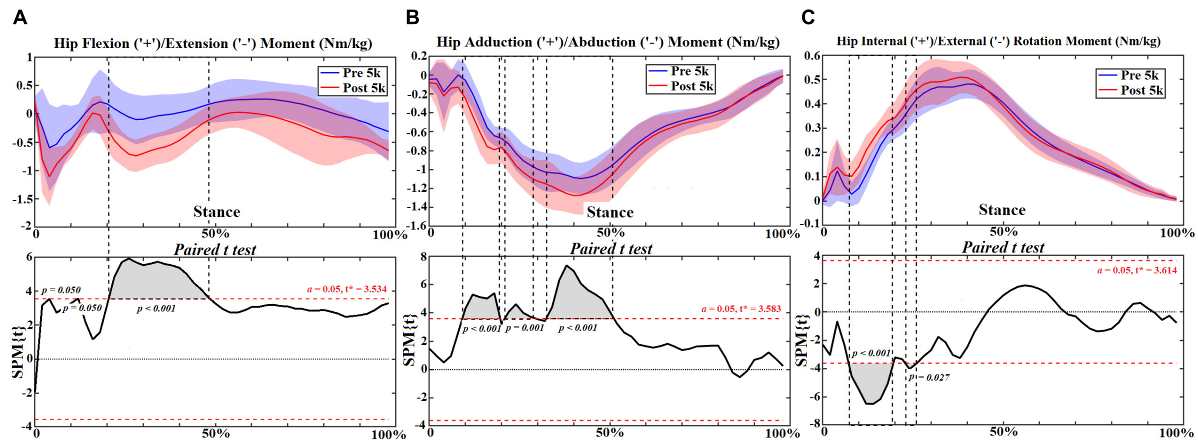

FIGURE 2 | The hip moments **(A–C)** during stance with statistics (spm{t}) from spm1d ("+" and "−" represent directions).

respectively. Peak values of joint moments and joint contact forces were selected for statistics. Previously published studies concerning knee **sup-inf** contact force showed similar patterns with vertical ground reaction force (Steele et al., 2012; Gerus et al., 2013; Knarr and Higginson, 2015), thus this study calculated the vertical instantaneous loading rate (VILR) (unit: xBW/%stance) of **sup-inf** knee contact force using an established protocol (Ueda et al., 2016), to provide extra loading information to the knee joint. Stance was divided into three sub-phases as per previous studies (Novacheck and Tom, 1998; Dugan and Bhat, 2005), including initial contact (0∼50%), mid stance (∼50%∼), and push off (50∼100%).

Data normality was checked prior to statistical analysis. A paired sample *t*-test was performed to analyze the difference in FPI scores, running speed, contact times, peak joint moments and joint contact forces. Due to the one-dimensional (1D) time-varying characteristics of joint kinematics, joint moments and joint contact force (Pataky, 2010; Pataky et al., 2015), the open source Statistical Parametric Mapping 1D package (SPM1D), which relies on Random Vector Field theory to account for data variability, was utilized for the statistical analysis. All statistical analyses were performed in MATLAB R2018a (The MathWorks, MA, United States), with significance level set at $p < 0.05$.

RESULTS

Foot Posture and Gait Parameter Changes

The FPI scores measured pre-5 k and post-5 k running showed significant increase toward pronation. The pre and post-5 k running speeds measured during the gait test were found to be ∼3.1 m/s on average. Participants were instructed to run 5 k at their self-selected speed, and actual speeds were recorded in the range of 10–12 km/h (2.8–3.3 m/s), with completion time between 25.3 and 29.7 min. A statistically significant increase of running speed was observed post-5 k running but stance times remained unchanged (**Table 1**).

Hip Joint

At the hip joint during post-5 k running, external rotation angle increased at 0–10% ($p = 0.048$) (**Figure 1**) and rotation moment increased at 10%–20% ($p < 0.001$) and 26%–28% ($p = 0.027$) (**Figure 2C**). Increased extension moment was observed across stance at 6% ($p = 0.050$), 14% ($p = 0.050$) and 24%–50% ($p < 0.001$) (**Figure 2A**). Abduction moment increased at 12%–20% ($p < 0.001$), 24%–30% ($p = 0.001$), and 36%–52% ($p < 0.001$), respectively (**Figure 2B**). The contact force increased in the ant-post-direction at 22–28% ($p = 0.001$) (**Figure 3A**), in the med-lat direction at 16–28% ($p < 0.001$) (**Figure 3B**), and in the sup-inf direction at 48–52% ($p = 0.009$) (**Figure 3C**). Peak hip moments and contact force are presented (**Table 2**), with increased peak hip extension moment ($p = 0.024$) and abduction moment ($p < 0.001$), and peak hip contact force in the ant-post ($p = 0.001$), med-lat ($p < 0.001$), and sup-inf ($p = 0.002$) directions during post-5 k running.

Knee Joint

At the knee joint, flexion angle showed no change (**Figure 4A**) but adduction reduced at 12–14% ($p = 0.050$) of stance (**Figure 4B**). However, reduced extension moment was observed at 22–24%

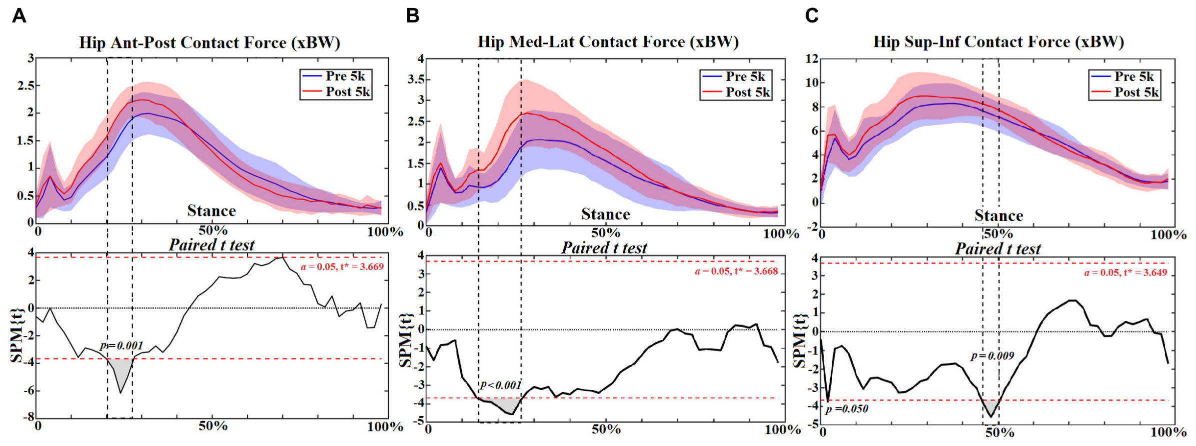

FIGURE 3 | The hip contact forces **(A–C)** during stance with statistics (spm{t}) from spm1d ("+" and "–" represent directions).

TABLE 2 | The peak hip moments and joint contact forces in the ant-post, med-lat, and sup-inf directions during stance (Mean ± SD [95% Confidence Interval]).

Variables	Pre-5 k [95% CI]	Post-5 k [95% CI]	*p*-value
Ext moment (Nm/kg)	1.13 ± 0.39 [0.95, 1.31]	1.35 ± 0.44 [1.15, 1.56]	0.024
Abd moment (Nm/kg)	1.14 ± 0.17 [1.06, 1.22]	1.3 ± 0.21 [1.20, 1.40]	<0.001
Rot moment (Nm/kg)	0.51 ± 0.06 [0.48, 0.54]	0.52 ± 0.07 [0.50, 0.56]	0.087
Ant-post contact force (xBW)	2.10 ± 0.39 [1.91, 2.28]	2.36 ± 0.3 [2.21, 2.50]	0.001
Med-lat contact force (xBW)	2.4 ± 0.72 [2.06, 2.74]	3.0 ± 0.81 [2.62, 3.38]	<0.001
Sup-inf contact force (xBW)	8.76 ± 1.61 [8.0, 9.5]	9.71 ± 1.65 [8.9, 10.48]	0.002

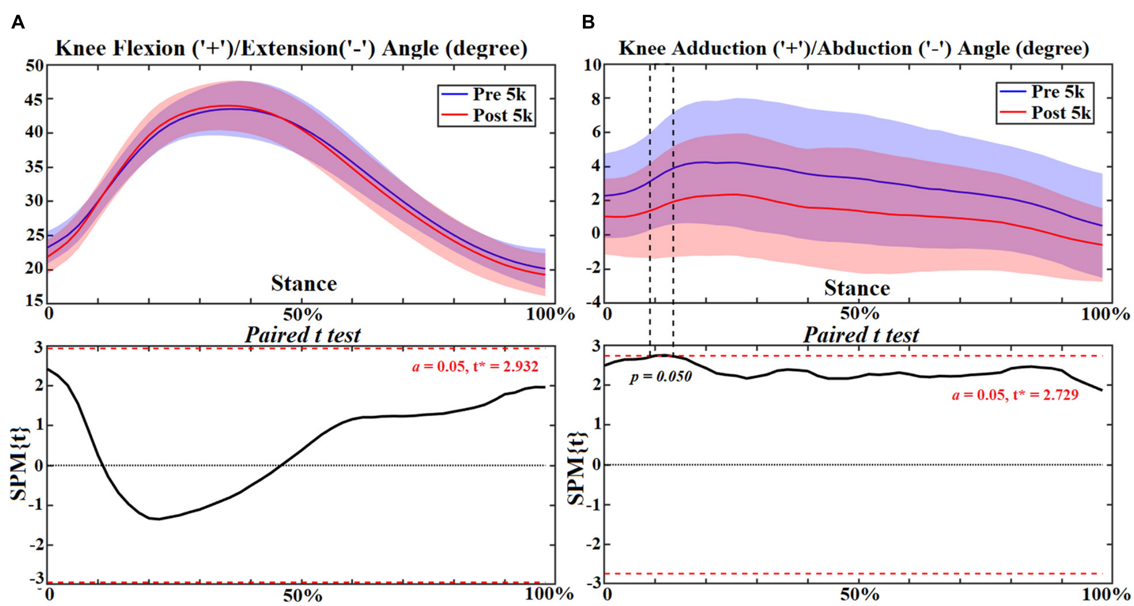

FIGURE 4 | The knee joint angles **(A,B)** during stance with statistics (spm{t}) from spm1d ("+" and "–" represent directions).

(p = 0.031) and 36–96% ($p < 0.001$) (**Figure 5A**). Increased knee abduction moment was observed at 12–20% (p = 0.002) and 26% (p = 0.044) during initial contact, and at 74–88% ($p < 0.001$) and 92–96% (p = 0.017) during push off, respectively (**Figure 5B**). The knee contact force increased during mid stance (46–58%, $p < 0.001$) in the sup-inf direction (**Figure 6C**) but no significance in other directions (**Figures 6A,B**). **Table 3** presents the peak knee joint extension (p = 0.001) and abduction (p = 0.002) moments, and the VILR ($p < 0.001$) and peak values of sup-inf (p = 0.005) knee contact force.

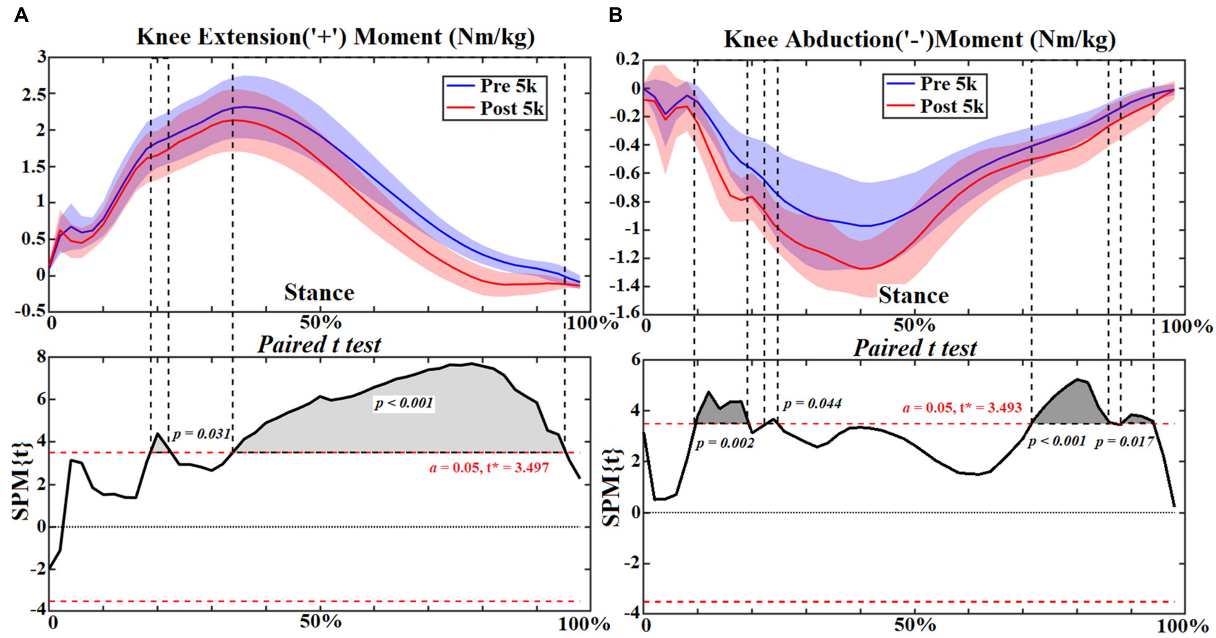

FIGURE 5 | The knee joint moments **(A,B)** during stance with statistics (spm{t}) from spm1d ("+" and "–" represent directions).

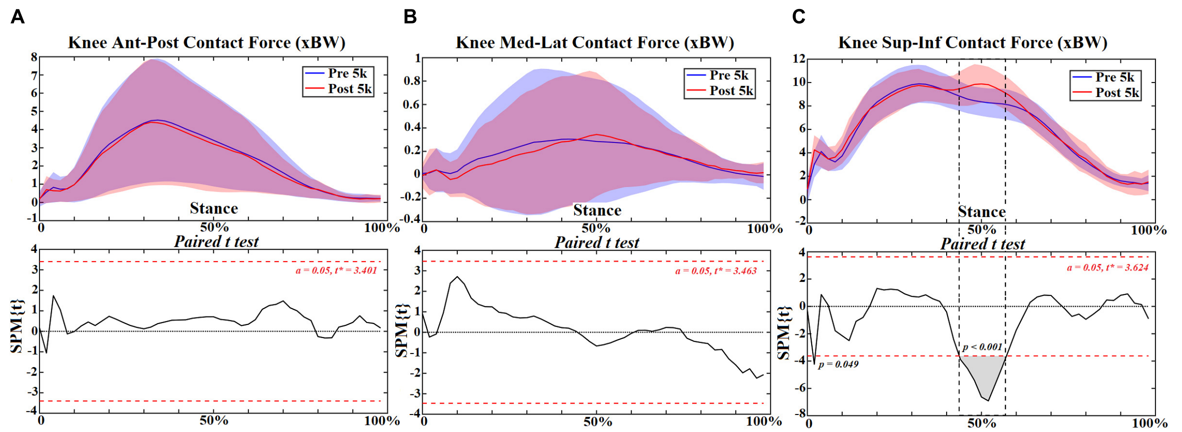

FIGURE 6 | The knee joint contact forces **(A–C)** during stance with statistics (spm{t}) from spm1d ("+" and "–" represent directions).

Correlation between FPI scores pre-5 k and post-5 k with peak knee flexion moment, peak knee abduction moment and VILR are presented in **Figure 7**. There was a moderate correlation between FPI and peak knee flexion moment (0.35–0.47), during pre- and post-5 k treadmill running (**Figure 7A**). The correlation between FPI and peak knee abduction moment was also moderate (0.39–0.44), during pre and post-5 k (**Figure 7B**). Interestingly, the correlation between FPI and VILR was only moderate post-5 k (0.39) (**Figure 7C**).

Ankle Joint

At the ankle joint increased plantarflexion was observed during push off at 80–92% ($p = 0.030$) (**Figure 8A**), and the plantarflexion moment increased at 6–98% ($p < 0.001$) during stance (**Figure 9A**). However, the subtalar joint eversion angle (**Figure 8B**) and subtalar moment (**Figure 9B**) showed no change. The ankle contact force in the ant-post direction increased at 6%-48% ($p < 0.001$) but decreased at 76–82% ($p = 0.011$) (**Figure 10A**). The med-lat ankle contact force decreased at 28–44% ($p < 0.001$) (**Figure 10B**). The sup-inf ankle contact force increased at 20–64% ($p < 0.001$) and 72–86% ($p < 0.001$) (**Figure 10C**), respectively. **Table 4** presents the peak ankle plantarflexion moment ($p < 0.001$), ankle contact force in the ant-post ($p < 0.001$) and sup-inf ($p < 0.001$) directions. The correlations between FPI and peak ankle moment (0.5–0.6) and subtalar moment (0.44–0.49) were moderate in both cases (**Figures 11A,B**).

TABLE 3 | The peak knee moments and joint contact forces in the ant-post, med-lat, and sup-inf directions (Mean ± SD [95% Confidence Interval]).

Variables	Pre-5 k [95% CI]	Post-5 k [95% CI]	*p*-value
Ext moment (Nm/kg)	2.33 ± 0.44 [2.12, 2.53]	2.15 ± 0.44 [1.94, 2.35]	0.001
Abd moment (Nm/kg)	0.99 ± 0.31 [0.85, 1.14]	1.11 ± 0.28 [0.97, 1.23]	0.002
VILR (BW/Stance%)	100.1 ± 33.04 [84.65, 115.58]	131.73 ± 28.83 [118.24, 145.22]	<0.001
Ant-post contact force (xBW)	4.95 ± 3.0 [3.55, 6.35]	4.74 ± 3.3 [3.19, 6.28]	0.46
Med-lat contact force (xBW)	0.63 ± 0.34 [0.47, 0.80]	0.58 ± 0.4 [0.39, 0.77]	0.52
Sup-inf contact force (xBW)	10.12 ± 1.58 [9.38, 10.86]	10.88 ± 1.49 [10.18, 11.58]	0.005

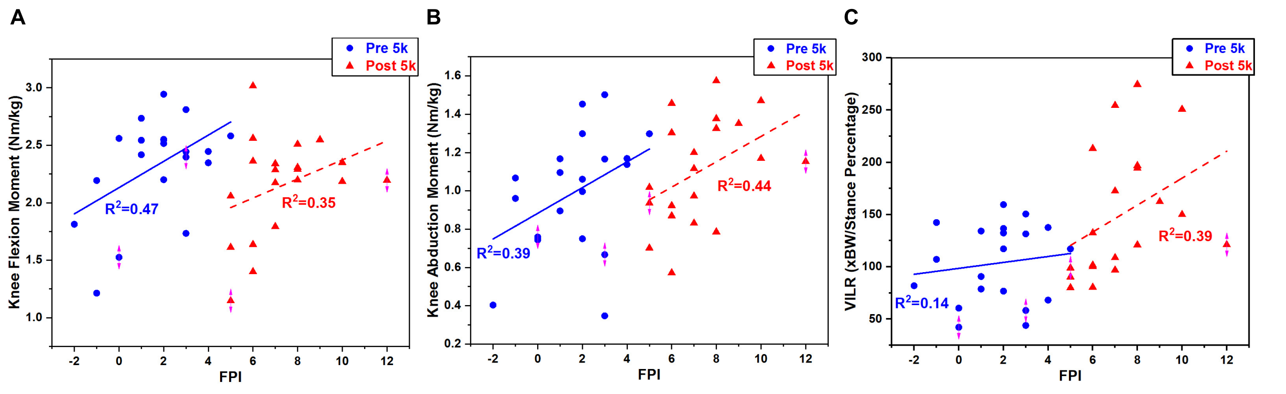

FIGURE 7 | The correlation of peak knee joint loadings (**A,** flexion moment; **B,** abduction moment; **C,** vertical loading rate) with FPI.

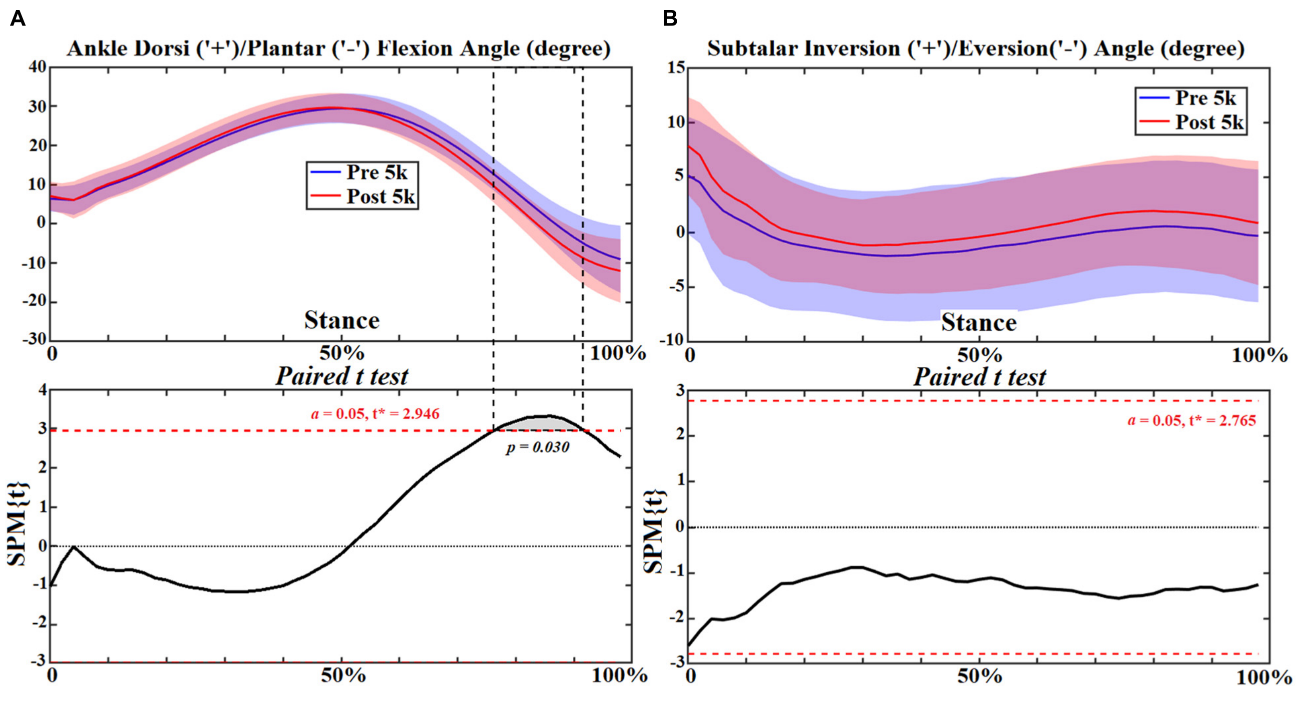

FIGURE 8 | The ankle and subtalar joint angles **(A,B)** during stance with statistics (spm{t}) from spm1d ("+" and "−" represent directions).

DISCUSSION

The findings in this study suggest that joint moments and joint contact forces in the lower extremity are altered with increased foot pronation following 5 k running. Specifically, hip joint moments and hip contact force increased during stance. Knee joint extension moment decreased but abduction moment increased, and sup-inf contact force increased during

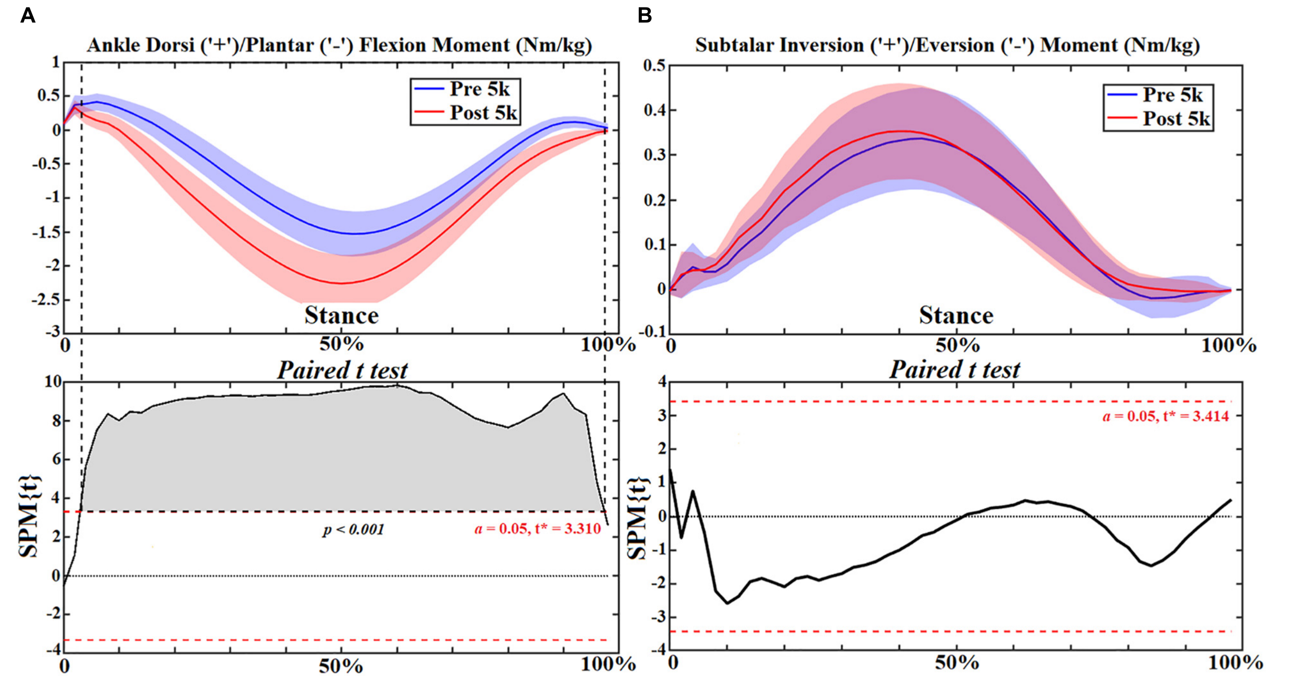

FIGURE 9 | The ankle and subtalar joint moments **(A,B)** during stance with statistics (spm{t}) from spm1d ("+" and "−represent directions).

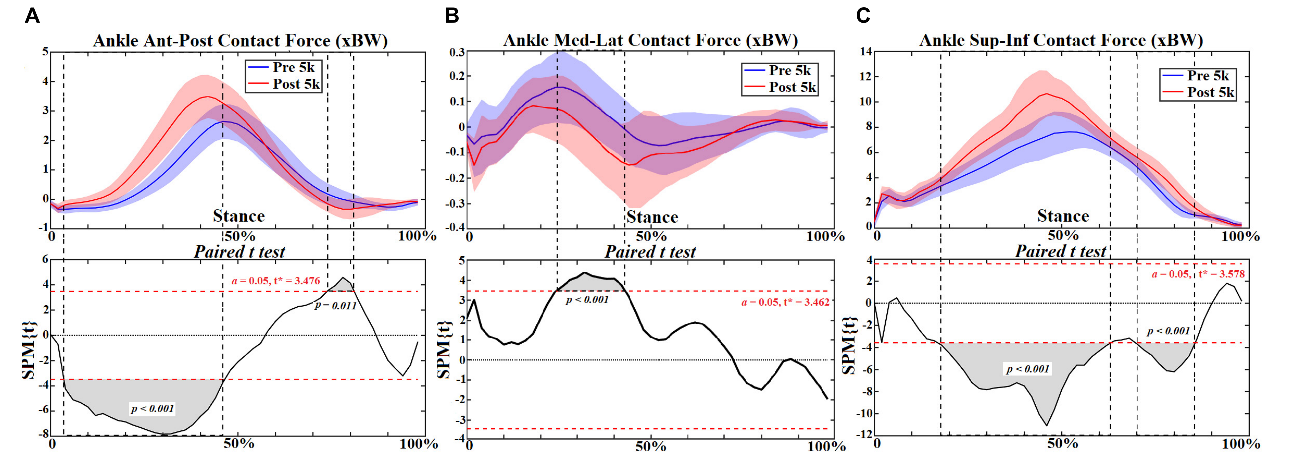

FIGURE 10 | The ankle joint contact forces **(A–C)** during stance with statistics (spm{t}) from spm1d ("+" and "−" represent directions).

mid stance. Ankle plantarflexion moment increased throughout stance, and ankle contact force increased in the ant-post and sup-inf directions but decreased in the med-lat direction. The FPI was found to correlate moderately with knee and ankle moments pre- and post-5 km running.

The human foot attenuates shock at the arch during weight bearing in stance. Due to repetitive loading from prolonged running activities, reduced arch height and pronated foot posture are reported in long distance runners (Fukano et al., 2018; Mei et al., 2018), which is consistent with the increased foot pronation assessed using the FPI in this study. Foot pronation may be associated with several RRI, which remain a conflicting issue in the biomechanics community. High arch runners present with higher incidence of ankle injuries, in contrast low arch runners exhibit more knee injuries (Williams et al., 2001), specifically the medial tibia stress syndrome among lower arch and pronated foot runners (Bennett et al., 2001). Greater knee abduction moment has been reported during walking and running in athletes with a low foot arch (Powell et al., 2016). This is consistent with the current study that showed a moderate correlation between FPI (pronated with low arch) and peak abduction moment. It should be acknowledged that participants in this study wore their preferred shoe design and this was not controlled for. Shoe design has been shown to influence pronation including motion control

TABLE 4 | The peak ankle and subtalar moments and ankle joint contact forces in the ant-post, med-lat, and sup-inf directions (Mean ± SD [95% Confidence Interval]).

Variables	Pre-5 k [95% CI]	Post-5 k [95% CI]	*p*-value
Plantarflexion moment (Nm/kg)	1.54 ± 0.34 [1.38, 1.39]	2.26 ± 0.43 [2.05, 2.47]	<0.001
Inversion moment (Nm/kg)	0.34 ± 0.12 [0.29, 0.39]	0.36 ± 0.11 [0.31, 0.41]	0.350
Ant-post contact force (xBW)	2.77 ± 0.62 [2.48, 3.06]	3.71 ± 0.66 [3.41, 4.02]	<0.001
Med-lat contact force (xBW)	0.25 ± 0.11 [0.20, 0.30]	0.27 ± 0.12 [0.22, 0.33]	0.410
Sup-inf contact force (xBW)	8.09 ± 1.55 [7.36, 8.82]	11.24 ± 1.76 [10.4, 12.06]	<0.001

shoes (Malisoux et al., 2016), maximal, neutral, and minimal shoes (Mei et al., 2014; Pollard et al., 2018; Xiang et al., 2018). Footwear design or wearing no shoes at all may influence the motor control system during running (Feng and Song, 2017; Santuz et al., 2017).

Stance contact time after 5 k running was consistent with a recent study of intersegmental work contribution during a prolonged run (Sanno et al., 2018). However, the average speed of runners in this study was ∼3.1 m/s, which was slower than the study of exhaustive maximal 10 k treadmill running (Hanley and Tucker, 2018) reported as ∼4.7 m/s. This is likely due to runners in that study being competitive compared to the recreational class of the runners in the present study. Comparison with other recreational running studies revealed speeds of 3.3–3.4 m/s (Hoenig et al., 2019) and 3.2 m/s (Chan-Roper et al., 2012), which was consistent with our findings.

Sagittal and coronal hip kinematics remained unchanged post-5 k running in this study. This was consistent with a 10 k treadmill study of recreational runners at the same 5 k mark (Sanno et al., 2018). In overuse injuries in recreational runners it has been reported that hip flexor, abductor and external rotator muscle strength is reduced (Niemuth et al., 2005; Luedke et al., 2015; Kollock et al., 2016). The reduced muscles lead to an imbalance of the hip joint moments and the net result is increased extension, abduction and internal rotation moments. This is consistent with the current study where we found increased extension moment, abduction moment and internal rotation moment during the initial contact of stance.

The sup-inf hip contact force from this study was 8.8–9.7 BW at 3.1 m/s, which was consistent with a previous running study that reported hip contact forces of 9.47 BW when running at 3.05 m/s (Giarmatzis et al., 2015). It should be noted that the hip contact force in the current study further highlighted that sup-inf contact force increased during mid stance, whereas the med-lat and ant-post contact forces only increased during initial contact. Further, the pattern of sup-inf knee contact force was similar to the vertical ground reaction force, which is consistent with previous studies (Steele et al., 2012; Gerus et al., 2013; Knarr and Higginson, 2015).

Knee flexion and adduction kinematics and joint moments were consistent in profile and magnitude range with previous running studies (Hamner et al., 2010; Bonacci et al., 2013; Hamner and Delp, 2013). Simulated knee crossing muscle activation patterns (vastus lateralis, rectus femoris and vastus medialis) were in good temporal agreement with EMG signals recoded in our study (see **Supplementary Material**). Significantly decreased knee extension moment was observed from mid stance to push off during post-5 k running, which may be partly explained by the weak extensor muscles reported for recreational runners (Kollock et al., 2016).

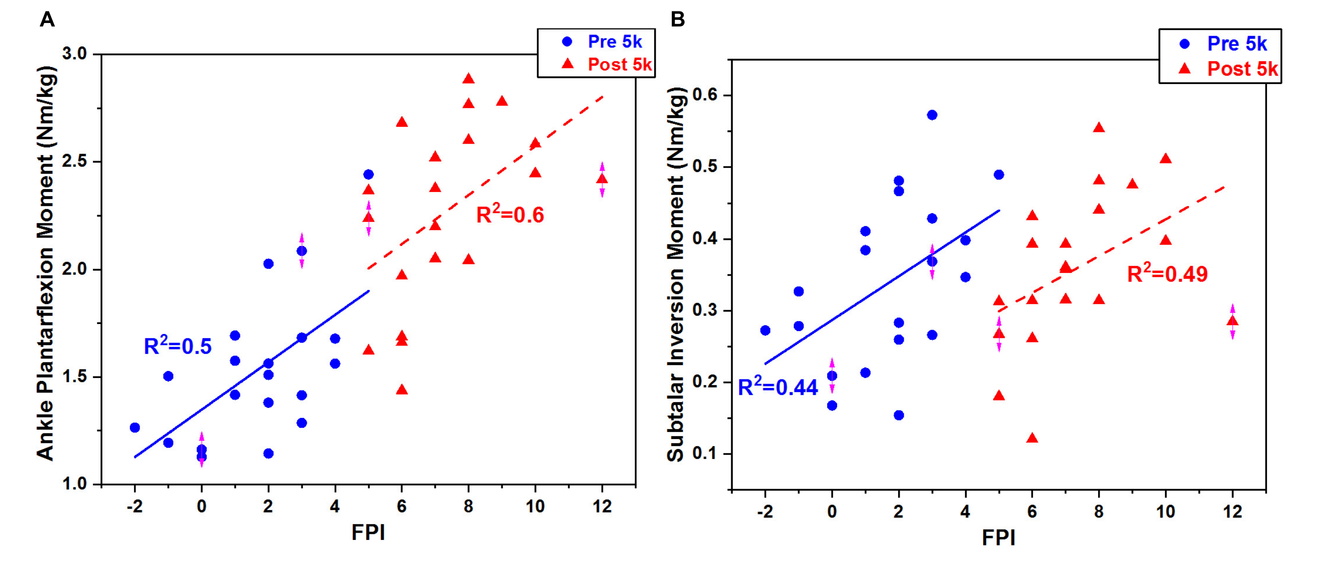

FIGURE 11 | The correlation of peak ankle **(A)** and subtalar **(B)** moments with FPI.

The FPI was found to partly explain the knee flexion and knee abduction moments both pre and post-5 k running. Specifically, as the foot pronates knee abduction increases. This is interesting since increased knee abduction (or reduced knee adduction) has been associated with reduced medial knee loading in people who walk with increased foot pronation (Levinger et al., 2013). However, in contrast increased pronation has also been reported to be associated with medial loading and tibia stress (Barnes et al., 2008; Levinger et al., 2010) and everted foot kinematics during locomotion (Levinger et al., 2012). This suggests that foot pronation plays a role in medial knee joint loading and should not be too over pronated or supinated.

Ankle joint kinematics at heel strike and toe off during pre-5 k and post-5 k were consistent with recent studies (Reenalda et al., 2016; Sanno et al., 2018) showing similar profiles and range of motion. The subtalar joint angle and moment patterns were unchanged post-5 k running, however, the single calcaneus marker used in this study may not be suited for dynamic subtalar joint motions in the frontal plane and should be considered as a limitation (Wang and Gutierrez-Farewik, 2011; Fischer et al., 2017). Our study showed increased plantarflexion during push off and plantarflexion joint moment throughout stance post-5 k running. One item exhibited from the FPI in this study was increased calcaneus eversion at the subtalar joint post-5 k running. This is consistent with a study that reported subtalar over eversion was found to enlarge the plantar flexors and tibialis anterior muscles (Wang and Gutierrez-Farewik, 2011). Further, increased plantar flexor muscles and tibialis anterior (dorsiflexor) may contribute to increased ankle contact forces. This is consistent with the increased ankle contact force observed in this study.

CONCLUSION

This study presents an investigation of the changes in foot posture, joint kinematics, joint moments and joint contact forces in the lower extremity following a 5 k treadmill run in 20 participants. A relationship between knee and ankle joint loading and FPI was developed. It was found that hip joint moments and contact forces increased during initial foot contact following 5 k running. Knee abduction moment and superior-inferior knee contact force increased, whereas the knee extension moment decreased. Ankle plantarflexion moment and ankle contact forces increased during stance. A useful finding was that the FPI was moderately correlated with peak knee and ankle moments. The FPI showed that recreational male runners presented increased static foot pronation after 5 k treadmill running. These findings suggest that following mid distance running change in foot pronation may be an early indicator of increased lower limb joint loading. Furthermore, the FPI may be used to quantify the changes in knee and ankle joint moments. Specifically, increase in FPI leads to an increase in knee flexion moment, knee abduction moment, ankle plantarflexion moment and subtalar inversion moment.

DATA AVAILABILITY

The raw data supporting the conclusions of this manuscript will be made available by the authors, without undue reservation, to any qualified researcher.

ETHICS STATEMENT

This study was approved by the Ethical Committee in the Research Academy of Grand Health, Ningbo University (RAGH20161208).

AUTHOR CONTRIBUTIONS

QM, YG, and JF conceived and designed this study. QM and LX conducted the test, collected, and analyzed the data. QM, YG, JB, and JF prepared the manuscript. QM, YG, LX, JB, and JF commented, revised the manuscript, and all approved for the submission.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fphys.2019.00573/full#supplementary-material

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Entropy Measures Can Add Novel Information to Reveal How Runners' Heart Rate and Speed Are Regulated by Different Environments

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Ecological psychology suggests performer-environment relationship is the appropriate scale for examining the relationship between perception, action and cognition. Developing performance requires variation in practice in order to design the attractor-fluctuation landscape. The present study aimed to identify the effects of varying levels of familiarity and sensorimotor stimuli within the environment in runners' speed and heart rate (HR) regularity degree, and short-term memory Twelve amateur runners accomplished three 45-min running trials in their usual route, in an unusual route, and an athletics 400-m track, wearing a GPS and an HR monitor. Sample entropy (SampEn) and complexity index (CI), over speed and HR, were calculated. Pre and post-trial, participants performed the Backward Digit Span task for cognitive assessment. Higher entropies were found for the 400-m track, compared to the usual and unusual routes. Usual routes increased speed SampEn (63% of chances), but decreased HR CI when compared to unusual routes (60% of chances). Runners showed higher overall short-term memory performance after unusual routes, when compared to usual routes (85% of chances), indicating positive relation to attentional control. The contexts of practice may contribute to change predictability from single to multiple timescales. Thus, by considering that time structuring issues can help diagnosing habituation of training routes, this study brings novel information to the long-term process of training.

Keywords: heart rate, speed, running, training, entropies, dynamical systems

INTRODUCTION

Ecological psychology suggests that the association between the performer of an action and the practice environment is the most appropriate scale of analysis for examining the relationship between perception, action, and cognition. Related to sports, running is one of the most practiced activities worldwide (Hulteen et al., 2017) and its popularity is reflected in the continuous increase in the number of master athletes (>40 years old) participating in endurance and ultra-endurance events over the past years (Zaryski and Smith, 2005; Lepers et al., 2016). Middle- and long-distance runners perform a considerable part of training outdoors, which has been positively associated with psych-physiological markers along with peoples' well-being and health status (Triguero-Mas et al., 2017). However, the tendency to repeat and stabilize decisions and behaviors in daily life (Betsch, 2011), also reflected in the choices of training environments, might negatively influence the interactions among the complex network of physiological pathways existing on the human body. The reduction in such interactions may lead to reduced point-to-point fluctuations in the outcomes (Lipsitz, 2002), leading to an unwanted decreased capacity of the body in adapting to the important effects promoted by physical activity on health and performance (O'Donovan et al., 2010).

Thus, developing performance requires variation in the training stimuli in order to challenge the attractor-fluctuation landscape and offset the internal and external perturbations that act on the body during exercise, so body system adaptive capacity can be increased (van Emmerik and van Wegen, 2002). Ecological-based research demonstrates that athletes regulate exercise intensity according to the environment (Konings and Hettinga, 2017), number and behavior of eventual opponents (Gonçalves et al., 2017), and stage of competition (Hettinga et al., 2017), by controlling speed in the actualization of the available affordances. Literature encourages the introduction of challenging motor demands to increase the adaptability of body complex motor patterns, which is key to improving sport performance in various environments (Button et al., 2006; Moras et al., 2018). From this perspective, it seems that information about the task might not be only stored in the brain, but also granted by the local environment and over time (Schmidt, 2007; Gibson, 2014). Additionally, variability is one of the presumable links between cognition and action, which is a current hot topic in sports sciences and health. Constant, but variate, external stimulation induces positive and enduring modifications in adults' brain structure and functions by maintaining the working plasticity properties, thus generating major positive impacts in terms of lower-level body functions (Woollett and Maguire, 2011). However, the relationship between the regulation of action and the performance determinants in sports has not been totally explained. In fact, it is still not clear how habituation over contexts (i.e., training in the same place or in the same route) or environments (i.e., training with variate or repetitive landscape) of practice is reflected in biological complexity and cognition, which would provide evidence on to what extent basic modifications in practice benefits performance and health.

In this sense, the dynamical systems perspective has presented a valued approach to assessing changes in variability, providing complementary information of the underlying dynamics of biological signals under various conditions (Costa et al., 2002). Using non-linear methods for quantifying the level of unpredictability at all relevant time-resolution levels of performance outcomes, as sample and multiscale entropies, provides measures of its complexity. For example, heart rate activity (HR) is a key internal variable that provides information about the cardiovascular responses to exercise and sports (Hautala et al., 2003; Kiviniemi et al., 2010). The *beat-to-beat interval* (R-R interval) and *beats-per-minute* (BPM) are the standard heart beat measurements, and differ in the degree to which they provide information about the heart beat dynamics (Wallot et al., 2013). BPM is assumed as the standard statistic for exercise prescription and, therefore, is the most common available measure. Although R-R intervals preserve the natural variability of HR activity, some studies might critically depend on the retained temporal structure of HR time-series, which are characteristic of BPM, but not R-R interval (Konvalinka et al., 2011).

Constant, but variate, external stimulation induces positive and enduring modifications in adults' brain structure and functions by maintaining its plasticity properties working, thus generating major positive impacts in terms of lower-level body functions. Therefore, the present study aimed to quantify the relationship between variate environmental features to the degree of regularity in cognition, and mechanical and physiological variables. The current research protocol was designed to use training routes with different degrees of familiarity and sensorimotor stimuli to understand how variability is associated to motor and cognitive function. This study hypothesized that routes frequently used by runners (usual routes) yield higher regularity in biological signals when compared to new routes (unusual routes).

MATERIALS AND METHODS

Participants

The sample comprised 12 middle and long-distance runners (42 ± 7.1 years, 174.3 ± 8 cm height, and 73.1 ± 10.1 kg body mass). To be included in the study, they should be engaged in amateur competition and an organized training schedule including specific outdoor running practices for, at least, 3 times a week. They also would have to present no history of musculoskeletal, neurological, or orthopedic disorder for the last year. Participants were fully informed about the purpose, benefits and risks of the study, and provided written informed consent before the study started. The study protocol was approved and followed the guidelines stated by the Ethics Committee of the of University of Trás-os-Montes and Alto Douro, based at Vila Real (Portugal), and conformed to the recommendations of the Declaration of Helsinki.

Protocol

The participants were asked to accomplish three 45-min running trials in 3 different scenarios: their usual training route, an unusual route and at a standard 400-m track. The usual route would have to be the most practiced or the standard trail/road route covered at regular training sessions. For the unusual route, each participant would have to choose a trail/road route which had never been chosen for training before the assessments. The 400-m track was chosen to represent an environment with a flat, repetitive, and monotonous sensory-motor stimuli of practice. Participants were asked to perform the running trials during their usual training days.

Running speed and heart rate BPM were assessed using GPS (SPI-PRO, GPSports, Canberra, ACT, Australia) synchronized with a HR belt (Polar Team Sports System®, Polar Electro Oy, Finland), at 5 Hz sampling. The course altitudes for all training trials were obtained using the latitude and longitude data from the GPS Visualizer's Elevation Lookup Utility (Schneider, 2013).

Experiments have demonstrated that there is a difference in the interactions people experience during tasks performed in different environments, reflected in the cognitive functioning at the short-term memory level (Berman et al., 2008). To assess short-term memory, we used the Backward Digit Span task, which measures short-term memory in adults through directed-attention mechanisms, as items are moved in and out of the focus of attention during tasks such as running outdoors (St Clair-Thompson, 2010). The test was adapted into a dedicated game app for mobiles that was installed in the personal smartphone of all participants. When started, the game would show a sequence of numbers on the screen. Then, a blank space and keyboard would appear on the screen to allow the user to type the sequence of numbers, but in the reverse order. The game included different number sequences, so the user was challenged across levels. In each level, an extra number was added to the sequence. The game was interrupted when 2 trials were missed in the current level. The final score of the game was available to the user in the end, including the option of being sent to an e-mail address dedicated to the study. The game final score accounted for the last level achieved, the number of correct answers, number of failed answers, and average time per answer.

Participants followed the same protocol for all running trials. Before each trial, the runners would have to turn on and wear the GPS and HR monitor, and then perform the backward digit span test. They would have to email the final scores of the test right after finishing the game. After the running trials, participants were instructed to perform the short-memory test again, email the results, to then undress and turn off the tracking device.

Data Processing

Data analyses were performed using the middle 20 min of each running trial. Speed data was smoothed using LOESS quadratic fit function (Cleveland, 1979) with 0.001 as the smoothing parameter, which is related to the size of the window used for each partial adjustment. This smoothing parameter was defined after observing the quality of time series derivatives and residual analysis (Winter, 2009).

The presence of non-linear features in the data was identified by estimating the difference between the sample entropy (SampEn) calculated for both time series and its surrogates, as well as analyzing the highest Lyapunov Exponent. The amplitude-adjusted Fourier transform algorithm was used for the HR time series, and pseudo-periodic surrogate function was applied to the speed time series (Stergiou, 2016). Low levels of regularity in the HR time series were found, so a 3rd order polynomial was fitted to de-trend the data (Stergiou, 2016). SampEn is a method of modified entropy computation from the approximate entropy method and consists of four steps: reconstruction, definition of distance, definition of the criterion for similarity, and entropy calculation (Lee and Choi, 2018).

In the first step, for a N points time series $x_N = \{x_1, x_2, \ldots, x_n\}$, the reconstruction of x_N into multidimensional vectors is performed as follows:

$$X_m^{\partial}(i) = \left\{x_i, x_{i+\partial}, \ldots, x_{i+(m-1)\partial}\right\} \tag{1}$$

where m denotes the embedding dimension and ∂ denotes the time delay factor.

Then, the distances between two different vectors are defined as the maximum difference of their corresponding components as follows:

$$d\left[X_m^{\partial}(i), X_m^{\partial}(j)\right] = \max\left\{\left|x_{i+k\partial} - x_{j+k\partial}\right| : 0 \le k \le m-1\right\} \tag{2}$$

where i and j are not equal.

The criterion for similarity is defined if the distance $d\left[X_m^{\partial}(i), X_m^{\partial}(j)\right]$ is less than a threshold parameter r. When the embedding dimension is m and $m+1$ (B_i^m and B_i^{m+1}1, respectively):

$$B^m = \frac{1}{N-m\partial}\sum_{i=1}^{N-m\partial} B_i^m,\ B^{m+1} = \frac{1}{N-m\partial}\sum_{i=1}^{N-m\partial} B_i^{m+1} \tag{3}$$

the SampEn can be finally defined:

$$SampEn\ (x_N, m, r, \partial) = -\ln\left[\frac{B^{m+1}}{B^m}\right] \tag{4}$$

In the present study, r was defined as $0.2^*\sigma$, where σ is the standard deviation of the original time series x_N (Stergiou, 2016).

Multiscale entropy (MSE) was used to quantify the level of regularity in HR and speed across multiple time scales, for each different training scenario. MSE integrates a coarse graining procedure to the SampEn algorithm to calculate the entropy value at each time scale, affording insight into the point-to-point fluctuations over a range of time scales, as follows:

$$y_j^{\tau} = 1/\tau \sum_{i=(j-1)\tau+1}^{j\tau} x_N,\ 1 \le y_j \le N/\tau \tag{5}$$

where τ is the timescale of interest, y_j is a data point in the constructed time series, x_N is a data point in the original time series and N is the length of the original time series.

The reconstruction of the embedding dimension and definition of the time lag (using average mutual information) were performed for the time series individually (Goldberger Ary et al., 2000; Costa et al., 2002, 2005). The area under the multiscale entropy curves were also calculated to provide an insight of the integrated complexity of the variables over all time scales, and was defined as the complexity index (Busa and van Emmerik, 2016).

Data Analysis

Speed and HR SampEn of the original time series and its surrogates were compared to verify whether the variability found in the data was not only a product of random noise (Stergiou, 2016). Thus, the data normality was tested using the Shapiro-Wilk test and, as the hypothesis of data coming from a normal distribution was rejected, the Mann–Whitney non-parametric test was applied ($P < 0.05$). A one-way repeated measures ANOVA was performed to compare the effect of different running routes in the entropy variables ($P < 0.05$). To determine the differences in the cognitive performance pre and post running trials, a one-way ANCOVA was performed ($P < 0.05$). The *post-hoc* was performed using magnitude-based inferences and precision of estimation (Batterham and Hopkins, 2006; Wilkinson and Winter, 2018). The speed and HR SampEn, as well as the complexity index across running routes with different degrees of familiarity (usual and unusual routes) and sensorimotor stimuli (standard 400-m track) were compared through post-only crossover spreadsheet (Hopkins, 2017). To realize the possible decrease/increase effects of running routes on athletes' cognitive measurements, data were analyzed using a specific spreadsheet for pre-post crossover trial (Hopkins, 2017). Differences in group means were expressed in raw units with 90% confidence limits. Smallest worthwhile differences were assessed using the standardized units multiplied by 0.2. Uncertainty in the true effects of the conditions were evaluated through non-clinical magnitude-based inferences. Magnitudes of clear effects were considered using the following scale: >5%, unclear; 25 to 75%, possibly; 75 to 95%, likely; 95 to 99%, very likely; >99%, most likely (Hopkins et al., 2009). Standardized (Cohen) mean differences, and respective 90% confidence intervals were also computed as magnitude of observed effects sizes (Batterham and Hopkins, 2006; Hopkins et al., 2009; Wilkinson and Winter, 2018). Thresholds for effect size statistics were: <0.2, trivial; 0.6, small; 1.20, moderate; 2.0, large; and >2.0, very large (Hopkins et al., 2009). The analysis of the relative variability in the terrains covered by runners in their individual trials was performed by calculating the coefficient of variation (CV) in the altitude time series.

RESULTS

Heart Rate and Speed Entropies

The mean SampEn of the usual, unusual and 400 m track surrogates for HR (0.021 ± 0.01; 0.015 ± 0.006 and 0.12 ± 0.08, respectively) and speed (0.25 ± 0.18; 0.18 ± 0.12 and 0.85 ± 0.38, respectively) were significantly higher ($P < 0.05$) than the SampEn of the original time series (mean and standard deviation, SD, are described in **Table 1**), indicating that the variability contents of HR and speed are meaningful from the non-linear perspective.

The ANOVA showed an effect of the running routes in the speed SampEn [$F_{(2,16)} = 16.99$, $P < 0.001$, partial eta squared = 0.321]. Differences were also identified for the HR complexity index [$F_{(2,16)} = 6.73$, $P = 0.008$, partial eta squared = 0.457]. The practical inferences for the *post-hoc* multicomparison among all entropy variables are described in **Table 1**. SampEn for speed showed to be possibly lower for unusual routes when compared to usual routes (moderate effect). The complexity index and SampEn for HR presented unclear mean changes, although the complexity index showed an almost 60% chance of increase for unusual routes when compared to usual routes. Overall, the entropy measures for the 400 m track presented higher values when compared to usual and unusual routes (large to very large effects), so it was the training scenario that demanded lower regularity in a single timescale for HR and speed, and with a multiple range of time scales for HR.

Terrain Altitude

The coefficient of variation in the altitudes covered by the runners in the usual and unusual training scenarios was very low. The usual routes of runners presented a CV of 3.3% ± 1.4% in the terrain altitude, while the unusual routes showed a CV of 4.6% ± 2.7%. As expected, the 400-m track presented a negligible CV of 0.2%. **Figure 1** depicts a summary of the mechanic and physiological regularity, as well as short-term memory outcomes the different training scenarios.

Cognitive Outcomes

Table 2 describes the results of the cognitive test pre and post all training scenarios. After training in usual routes, runners had a likely decrease in the levels achieved in the test (with 85% of chances), compared to the performance after training in unusual routes. Although it was not consistent, there is a 66% chance of decrease of the number of correct attempts after running in a 400-m track. There were no consistent differences in the number of fails in the cognitive test after running in the 400-m track and unusual route, but the results showed chances between 69 and 73% of increase, respectively. The average time to perform the test was not different between usual and unusual routes compared to the 400-m track, but most likely decreased after training in usual, compared to unusual, routes.

DISCUSSION

The present study aimed to identify the effects of habituation in the environments and contexts of outdoor running through the degree of regularity in speed, HR, and short-term memory performance in a group of runners. Habituation refers to familiarity over the environment of practice related to individuals' usual training route, a certain degree of unpredictability in the environment of practice at an unusual training route, and, finally, the monotony over a practice at the standard 400 m track. Although mechanical, physiological and cognitive aspects of physical exercise while interacting with surroundings rich with inherently different sensory-motor stimuli have already been reported in literature, it has never been analyzed as to how it is affected by time structure in training tasks, here represented by habituation levels over practice environments.

From a dynamical systems perspective, it was hypothesized that usual routes would demand decreased complex fluctuation patterns in major biological responses when compared to unusual routes. The HR complexity index presented a tendency to be higher in unusual, when compared to usual, routes. Aerobic fitness and HR variability are closely related, as previously reported in literature, although most of the studies available have used linear methods to analyse HR signal magnitude (Plews et al., 2012; Nakamura et al., 2015). By stimulating some degree of unpredictability in training, there is a solicitation of the mechanism underlying running endurance through the increase of parasympathetic activity (Da Silva et al., 2014), which enhances cardiorespiratory fitness (Sumi et al., 2006). The decrease in HR complexity across time and the further impacts on health has been an issue of interest in literature for

TABLE 1 | Descriptive and practical inferences of the speed and heart rate (HR) entropy measures across running routes with different degrees of familiarity (usual and unusual routes) and sensorimotor stimuli (standard 400-m track).

Variables (a.u.)	Usual (mean ± SD)	Unusual (mean ± SD)	400 m (mean ± SD)	Group comparison outcomes as: Mean changes (raw; ± 90%CL) % Chances (decrease/trivial/increase) Practical inferences		
				Usual vs. Unusual	Usual vs. 400 m	Unusual vs. 400 m
Speed SampEn	0.22 ± 0.18	0.16 ± 0.11	0.81 ± 0.42	–0.36; ± 0.6 63/24/13 possibly –ive	2.11; ± 0.60 0/0/100 most likely +ive	2.54; ± 0.74 0/0/100 most likely +ive
HR SampEn	0.004 ± 0.003	0.004 ± 0.002	0.022 ± 0.026	0.08; ± 0.60 21/43/36 unclear	2.33; ± 0.84 0/0/100 most likely +ive	2.2; ± 0.70 0/0/100 most likely +ive
HR complexity index	0.56 ± 0.31	0.66 ± 0.33	3.10 ± 1.29	0.29; ±0.74 13/29/58 unclear	3.08; ± 0.88 0/0/100 most likely +ive	2.80; ± 0.80 0/0/100 most likely +ive

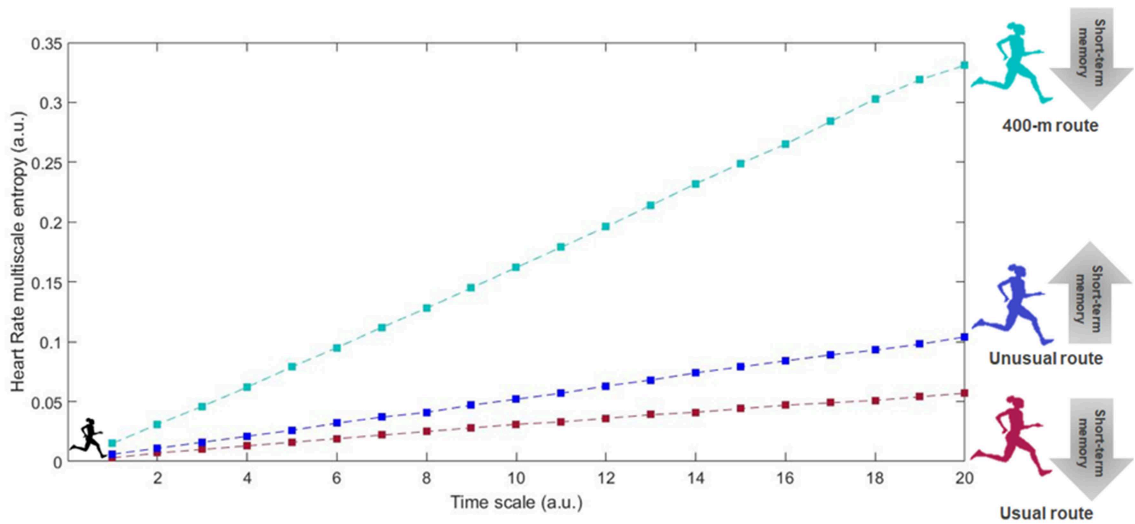

FIGURE 1 | Representative case of the physiological factors in the multiscale entropy dynamics associated to training routes with different degrees of familiarity and sensory-motor stimuli, and its effects on life health span in adults. The usual route would be the most practiced or the standard trail/road route covered in individuals regular training sessions. The unusual route was chosen as the trail/road route which had never been part of training routine before the study assessments. The 400-m track was chosen to represent the sensory-motor stimuli of a flat, repetitive, thus, monotonous environment of practice.

over two decades (De Meersman, 1993; Costa et al., 2002) and can still be considered a hot topic in recent times (Togo and Takahashi, 2009). Consequently, health status is closely related to the degree of complex variability in system function, specially by its susceptibility to its beneficial and adaptive aspects. This premise lays on the loss of complexity hypothesis of Lipsitz (2002), which states that a path to frailty is identified by a certain amount of loss of variability in the fundamental outcomes that reflect aging or biological function over time, leading to the emergence of an injury or disease.

The present entropy results indicate that the contexts of practice may also influence the level of interactions in the complex network of physiological pathways. For example, the analysis of SampEn and complexity index provides a wider idea about the extent of the alterations in the HR and speed variability. While the first measure indicates, in a single time scale, that different sensory-motor stimuli increases biological signals unpredictability, the second summarizes the interaction of multiple scales through time, aligning to the multiscale complexity of the human body as a biological system (Costa et al., 2002).

In this sense, it was hypothesized that the usual route would yield lower single and multiscale regularity in speed and HR than the 400 m track race. The variation in the altitude terrain along the task elicited mechanical adjustments; running on uneven ground demands different timing for the muscle activation of

TABLE 2 | Descriptive and practical inferences of the Backward digit-span performance outcomes pre and post running in routes with different degrees of familiarity (usual and unusual routes) and sensorimotor stimuli (standard 400 m track).

Cognitive Outcomes	**Usual route (mean ± SD)**			**Unusual route (mean ± SD)**			**400 m track (mean ± SD)**			**Group comparison outcomes as:** **Mean changes (raw; ± 90%CL)** **% Chances (decrease/trivial/increase)** **Practical inferences** **Effect size (Standardized Cohen; ±90%CL)**		
	Pre	Post	Δ	Pre	Post	Δ	Pre	Post	Δ	Usual vs. Unusual	Usual vs. 400 m	Unusual vs. 400 m
Level (*n*)	5.4 ± 0.7	6.1 ± 1.1	0.8 ± 0.9	6.4 ± 1.7	6.5 ± 1.2	0.1 ± 1.1	6.3 ± 1.1	6.4 ± 2.2	0.3 ± 2.1	−0.6; ± 0.6 85/14/1 likely –ive −0.44; ±0.41	−0.5; ± 1.6 62/16/22 unclear −0.43; ±1.46	0.2; ± 1.7 32/24/45 unclear 0.11; ±1.15
Correct (*n*)	7.6 ± 1.2	9.0 ± 1.9	1.4 ± 1.6	8.8 ± 2.7	9.6 ± 2.5	0.9 ± 2	9.7 ± 1.9	9.6 ± 2.8	0.4 ± 2.2	−0.5; ± 1.8 54/29/18 unclear −0.23; ±0.8	−0.9; ± 2.5 66/16/17 unclear −0.49; ±1.29	−0.4; ± 1.7 49/33/18 unclear −0.18; ±0.72
Failed (*n*)	3.1 ± 0.8	3.3 ± 0.7	0.1 ± 0.8	3.0 ± 1.2	4.1 ± 3.6	1.1 ± 4.1	3.1 ± 0.9	3.9 ± 1.2	0.7 ± 2.1	1.0; ± 2.9 23/8/69 unclear 0.95; ±2.79	0.6; ± 1.3 14/13/73 unclear 0.67; ±1.42	−0.4; ± 3.7 54/8/38 unclear −0.38; ±3.42
Average time (*s*)	4.8 ± 1.3	7.1 ± 4.5	2.3 ± 4.4	6.3 ± 3.7	5.2 ± 1.0	−1.2 ± 4.5	5.0 ± 1.3	5.5 ± 1.6	0.4 ± 1.1	−3.5; ± 3.9 90/5/4 likely –ive −1.18; ±1.32	−1.9; ± 2.8 86/5/9 unclear −1.45; ±2.1	1.6; ± 3.3 12/16/72 unclear 0.53; ±1.09

lower limbs (Oliveira et al., 2016) and modifies kinematic gait patterns (Muller and Blickhan, 2010; Sinclair et al., 2013), so runners are able to alter step length and frequency during the task (Schubert et al., 2014). In fact, these are strategies that allow dynamic stability to cope with the terrain uncertainties while navigating the changing running surface (Muller and Blickhan, 2010; Larsen et al., 2016), thus, adapting to the modifications of the environment. It was found, though, that SampEn for speed, and consequently HR, was the highest for the standard 400 m track race when compared to unusual and usual routes. These findings may be related to the boring and monotonous quality of continuous running in a 400 m track for prolonged time. Monotony is related to the degree of predictability and affects familiarity and habituation over a task, as running in flat, round and repetitive terrain for a long period of time (Scerbo, 1998; Thiffault and Bergeron, 2003). In addition, the task-capability interface model suggests that the control of speed during a task can be influenced by the cognitive workload being experienced, as an attempt to increase the arousal levels (Fuller, 2005). Therefore, speed variability during prolonged sustained activity is increased in order to feel less sleepiness, fatigue and keep better vigilance over the task (Ma et al., 2018). The participants of this study reported, indeed, that using the 400 m track for middle- and long-distance running practice or training is rare, so it is an environment less visited. Additionally, when the amateur runners experienced a training session at the unusual route, picked as one never used to practice before the assessments, although it was not clear that it stimulated lower speed regularity, there was a tendency of the HR complexity index to be higher.

The present results align with other studies that explored the temporal capacity of structured and organized training in balance flexibility and stability so the benefits of variability in system function would occur (Moras et al., 2018). However, even though training in new terrains outdoors is challenging, less monotonous than the 400-m track, and mechano-physiologically varied, it is also under the training principle of adaptation. The training environment, i.e., routes defined for training sessions, should also be altered at a certain point in time to increase the demands of the body dynamic interactions. That would lead to higher biological entropy, thus enhancing body adaptive capacity to the training effects over time (Busa and van Emmerik, 2016).

Another component essential to integrate and interpret sensorimotor information of everyday life is cognition, which is also affected by age (Reuter-Lorenz and Park, 2010). Physical activity is reported to affect brain plasticity and positively influence cognition and well-being (Gutchess, 2014; Mandolesi et al., 2018), while variability holds it all together (Woollett and Maguire, 2011). Hereupon, the effect of different environments of practice regarding to route familiarity and sensory motor stimuli in short-term memory was also verified. The participants showed higher overall performance on the short-term memory test after practicing in the unusual, when compared to the usual, route. Short-term memory is specialized for the temporary storage of information within particular informational domains. It is also related to mechanisms of the attentional control in reactivating memory traces and inhibiting irrelevant information (St Clair-Thompson, 2010). Although unclear, results of the overall performance showed a tendency to worsen after practice in the 400 m track when compared to usual routes. There was also a tendency of decreasing the number of correct sequences after practice in the 400 m track, compared to the unusual route. Repetitive or absent stimulation is reported to generate cognitive underload (Larue, 2010), which could be related to the familiarity in the usual route or the monotony of prolonged running in a 400 m track. Low cognitive workload leads to hypervigilance due to a lack of desire to continue performing the task, and negatively affects the vigilance and alertness state, as well as attention (Sussman and Coplen, 2000). Even though the runners varied speed as a strategy to suppress monotony in the continuous running at the 400 m track, it may not have been successful to avoid cognitive underload. The unclear results for the cognitive test, though, might have been limited by the sample size. We understand that the profile of participants for the sample should approximate the model which integrates the effects of aging, exercise and health in master athletes (Lazarus and Harridge, 2007), however, it is challenging to find large groups of runners engaged in amateur competitions who are homogeneous in terms of involvement in organized training.

The present study described how runners regulate mechanical and physiological responses during training practice under courses that differ in its level of familiarity and sensorimotor stimuli. Higher entropies were found for the 400 m track race, compared to usual and unusual routes. Usual routes increased speed SampEn, but decreased HR complexity index when compared to unusual. Runners showed higher overall short-term memory performance after unusual routes, when compared to usual routes. Although runners might be able to vary speed, thus affording higher entropy levels to HR responses, at cognitive level this is not very effective. Thus, by approaching this issue with non-linear analysis, it was possible to identify evidences on the importance of manipulating basic training constraints to increase the adaptive demands and avoid routines that can preclude such adaptations. New research lines should consider different contextual variations to investigate issues related to training adaptability in runners.

DATA AVAILABILITY

All datasets generated for this study are included in the manuscript and/or the supplementary files.

ETHICS STATEMENT

The study protocol was conformed to the recommendations of the Declaration of Helsinki, and was approved and followed the guidelines stated by the local Institutional Research Ethics Committee.

AUTHOR CONTRIBUTIONS

JS: conceptualization. JE, NM, BG, and CA: methodology. JE and BG formal analysis. JE and JS: writing—original draft preparation. JE, BG, NM, CA, JC-G, and JS: writing—review and editing.

CONTRIBUTION TO THE FIELD

General population physical activity levels are a global concern but its regulation seems tricky in modern society. The gap in the practical and academic approach might be in not considering how specific behaviors from specific socio-environmental agents determine motivation to change habits and maintain engagement in physical activity. Humans tend to repeat and stabilize decisions and behaviors in daily life, and choices of physical activity practice and training contexts are constantly under the influence of habituation, leading to monotony. The lack of variability in daily life might impair an important link in a healthy body function: action and cognition. When one's perception capabilities are challenged by the surroundings, there is an enhance of body capacity in coordinating activities, as well as increased levels of awareness. Thus, by considering the environment-individual relationship in physical activity as a complex system, the current study brings novel contributions on how habituation of training contexts affects runners physiological and cognitive adaptations. Although performers find a way to increase physiological variability in highly monotonous and habitual tasks, it is still not effective in increasing arousal, thus favoring cognitive impairment, even in acute level.

FUNDING

The study protocol was conformed to the recommendations of the Declaration of Helsinki. An informed and written consent was obtained prior to testing from all participants, in accordance with the approval by the Ethics Committee of the Research Centre for Sport Sciences, Health and Human Development, based at Vila Real, Portugal (UID/DTP/04045/2018).

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Sex Difference in Triathlon Performance

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This brief review investigates how sex influences triathlon performance. Performance time for both Olympic distance and Ironman distance triathlons, and physiological considerations are discussed for both elite and non-elite male and female triathletes. The relative participation of female athletes in triathlon has increased over the last three decades, and currently represents 25–40% of the total field. Overall, the sex difference in both Olympic and Ironman distance triathlon performance has narrowed across the years. Sex difference differed with exercise mode and exercise duration. For non-elite Ironman triathletes, the sex difference in swimming time (≈12%) is lower than that which was evidenced for cycling (≈15%) and running (≈18%). For elite triathletes, sex difference in running performance is greater for Olympic triathlon (≈14%) than it is for Ironman distance triathlon (≈7%). Elite Ironman female triathletes have reduced the gap to their male counterparts to less than 10% for the marathon. The sex difference in triathlon performance is likely to be due to physiological (e.g., VO_{2max}) and morphological (e.g., % body fat) factors but hormonal, psychological and societal (e.g., lower participation rate) differences should also be considered. Future studies should address the limited evidence relating sex difference in physiological characteristics such as lactate threshold, exercise economy or peak fat oxidation.

Keywords: gender difference, swimming, cycling, running, Ironman, human physiology

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INTRODUCTION

Triathlon is a unique endurance sport that combines swimming, cycling and running over a variety of distances (Bentley et al., 2002). Top male triathletes can nowadays finish an Olympic distance triathlon (1.5 km swim, 40 km cycle, and 10 km run) in less than 2 h and an Ironman (3.8 km swim, 180 km cycle, and 42 km run) distance triathlon in less than 8 h and 30 min (Rüst et al., 2013; Gallmann et al., 2014).

The number of females who compete in triathlon has increased since the 1990s but the rate of participation in triathlon events remains lower for females compared to males, with the female rate varying between 25 and 40% of the total field (Lepers, 2008; Lepers et al., 2013b; Wonerow et al., 2017). Nowadays, female triathletes have similar opportunities to train and compete than males in most parts of the world, but female participation rates remain lower than those of males, and particularly so in the case of long distance triathlons.

Females have progressively reduced the gap between their triathlon performance and that of their male counterparts over time (Lepers, 2008; Rüst et al., 2012b, 2013; Lepers et al., 2013a; Meili et al., 2013; Gallmann et al., 2014). The number of female triathletes who finish an Ironman distance triathlon in under 9 h has increased yearly, from 1 in 1991 to 23 in 2017[1]. In 2018, the Swiss woman Daniela Ryf won the Ironman Triathlon World Championship for the fourth time in a row, in a time of 8 h and 26 min, and placed 25th overall. She reduced the gap to the male winner (who finished the race in 7 h and 52 min) to 7.1% of total time[2] which is much less than the 10–12% sex difference that is typically evidenced by elite endurance athletes (Joyner, 2017).

Although the sex difference in endurance performance has received considerable research attention, most studies have focused on running (Joyner, 2017). Previous investigations have, however, pointed out some male-female differences in selected physiological, biomechanical, nutritional, training and medical aspects of triathlon performance (O'Toole and Douglas, 1995; Hausswirth and Lehénaff, 2001; Laursen and Rhodes, 2001; Jeukendrup et al., 2005; Hausswirth and Brisswalter, 2008; Vleck et al., 2014). This brief review investigates how sex influences triathlon performance. Performance time for Olympic distance and Ironman distance triathlons, and physiological characteristics between female and male triathletes are discussed.

SEX DIFFERENCE IN PERFORMANCE

The sex differences in triathlon performance have been described for both elite and non-elite triathletes but more data are available for Ironman distance than for sprint or Olympic distance triathlons (Lepers, 2008; Lepers and Maffiuletti, 2011; Rüst et al., 2012a,b, 2013; Etter et al., 2013; Lepers et al., 2013a,b; Gallmann et al., 2014; Wonerow et al., 2017). The sex difference in total triathlon performance has decreased over the last three decades and currently varies between 12 and 18%, depending on both event distance and athlete ability level (Lepers et al., 2013a). With the exception of the Ironman distance triathlon World Championship, which takes place in Hawaii every year, the other World triathlon Championships take place in different towns, with different course topographies, and climatic conditions, making year-to-year absolute comparisons difficult. In Hawaii, the climatic conditions could also differ, affecting the performances. Despite these limitations, it still possible to compare males and females in terms of relative performances. Moreover, in contrast to Ironman triathlons, the international level Olympic distance triathlons have all been draft legal since 1997. It is consequently difficult to compare sex differences in overall performance between Olympic and Ironman distance triathlons.

Sex Difference in Ironman Triathlon Performance

The Ironman distance triathlon World Championships, which have been held in Kona (HI, United States) since 1982 with only a few changes in the course, have been frequently used as a model to analyze the sex difference in Ironman performance (Lepers, 2008; Lepers and Maffiuletti, 2011; Rüst et al., 2012b; Lepers et al., 2013b).

By analyzing the Hawaii Ironman triathlon performances of the top 10 non-elite triathletes from the age groups between 18 and 64 years old, Lepers and Maffiuletti (2011) showed that the sex differences in 3.8 km swim, 180 km cycle, and 42 km run and total times were 12, 15, 18, and 16%, respectively. Independent of age, the sex difference in swimming time was lower than that which was evidenced for cycling and running. The sex difference in cycling time was lower than that for running. The lower sex difference in swimming performance may be explained by higher economy and mechanical efficiency of swimming in females compared to males (Zamparo et al., 2005). However, the lower sex difference in cycling performance as compared to running performance remains difficult to explain. In the literature, the sex difference in performance is usually lower in elite athletes than it is in non-elite athletes (Joyner, 2017). A confounding factor in non-elite athletes is age; indeed some studies have pooled data from different age groups when they have analyzed sex differences in performance of non-elite athletes (Lepers and Maffiuletti, 2011; Lepers et al., 2013a).

For elite athletes (i.e., top 10 male and female finishers), the sex difference in total performance has decreased over the last few decades, from 15% in the 1990s to 11% in 2012 (Lepers, 2008; Rüst et al., 2012b). During the period from 1983–2012, the sex differences in performance remained relatively stable at around 12.5% for swimming and cycling, whilst the sex difference in running performance decreased from 13.5 to 8% (Rüst et al., 2012b). The reasons for a greater improvement in females' running performance at the Ironman during the 1983–2012 period are not clear because both males and females had the opportunities to use new training methods. One explanation could be a sex difference in race strategy. Females, using a more constant pacing strategy and not a fast-starting pacing strategy during the bike, may save energy for the marathon running. However, given the contrast previous findings (Wu et al., 2014; Angehrn et al., 2016), this hypothesis needs to be confirmed with further studies examining Ironman pacing strategy for both males and females.

In 2018, the weather conditions at the Ironman World Championship were favorable, with a light tail wind during the second part of the bike course. It was less hot than usual during the marathon. Both the elite male and elite female course records were broken (see footnote 2). **Table 1** shows the sex differences in the Ironman World Championship records in 2018. The female Ironman record holder, thanks to a strong bike performance, was only 4% slower on the bike than the male record holder, lowering the sex difference in total Ironman performance to 7.1% between sexes. However, the performances of both male and female winners are not representative of the rest of the elite field. In contrast to Daniela Ryf, who performed relatively poorly in the swim and relatively well on the bike, the top 10 female cyclists remained 10.9% slower on the bike section than the top 10 male cyclists (**Table 1**). In addition, the sex difference in marathon performance of the top 10 runners (6.6%) appears lower than the sex difference in performance for the top 10 swimmers (9.1%) and cyclists (10.9%). These observations

[1]https://www.tri247.com/triathlon-features/analysis/sub-9-hour-iron-women-triathletes

[2]http://eu.ironman.com

TABLE 1 | Split times and corresponding sex differences at the 2018 Ironman Triathlon World Championship (Hawaii) for the winners and the top 10 performers in each discipline and overall.

Hawaii Ironman triathlon (2018)		Swim 3.8 km	Cycle 180 km	Run 42 km	Total
Male winner – Patrick Lange		50:37	4:16:05	2:41:32	7:52:39
Female winner – Daniela Ryf		57:26	4:26:07	2:57:05	8:26:16
Sex difference (%)		13.5	3.9	9.6	7.1
Top 10 males	Mean	48:21	4:13:28	2:50:55	8:04:02
	SD	00:49	02:27	04:55	05:57
Top 10 females	Mean	52:47	4:41:10	3:02:08	8:48:05
	SD	01:56	05:54	04:28	10:44
Sex difference (%)	Mean	9.1	10.9	6.6	9.1
	SD	3.1	1.6	1.0	0.9

Publicly available data obtained from the Ironman Corporation's Web site at http://eu.ironman.com/triathlon/events/americas/ironman/world-championship/results.aspx#axzz5hwN1WJ9o.

suggest that nowadays elite female Ironman triathletes are able to reduce the gap with their males counterparts to less than 10% of total performance, thanks to improvement in their marathon running performance. Nevertheless, it is clear that training to improve relative weaknesses in bike performance should be a major consideration for females aiming to maximize overall performance and to minimize the gap to their male counterparts.

Sex Difference in Olympic Distance Triathlon Performance

The sex difference in Olympic distance triathlon performances has received relatively less attention than that of the Ironman format in the research literature (Etter et al., 2013; Meili et al., 2013; Wonerow et al., 2017). The sex difference in non-elite Olympic distance triathlon performance has been examined by Etter et al. (2013) at national level, and by Wonerow et al. (2017) at international level. Etter et al. (2013) analyzed the sex differences in the non-drafting Zurich (Switzerland) triathlon, for the top 5 athletes overall, within each 5-year age group between the ages of 20 and 60 years, over the period 2000–2010. The sex difference in 1.5 km swimming, 40 km cycling, 10 km running and total event times was 18.5, 15.5, 18.5, and 17.1%, respectively. Sex difference differed with exercise mode, independent of athlete age. Indeed, in this study the sex difference in performance appeared to be significantly lower for cycling than it was for swimming and running, but the reasons for this finding were unclear. Sex difference in Olympic distance triathlon has also been examined at World Championship level, during the period 2009–2014, by Wonerow et al. (2017). Unfortunately, the marked variability of results both over the 5-year period of study and across age groups did not allow for conclusions to be drawn about a possible effect of locomotion mode on the sex differences in performance. The changes in race conditions across events and the confounding effect of age make difficult to clearly elucidate the sex differences in non-elite triathlon performance.

As elite-level international Olympic distance triathlons have all been draft legal for several years, the pacing over the course, especially during the bike section, could influence the sex difference in performance (Vleck et al., 2008). Only one study has examined the sex difference in triathlon performance for elite triathletes during draft legal races (Le Meur et al., 2009). Le Meur et al. (2009) showed that both female and male elite triathletes adopt similar positive pacing strategies during the swim and run legs of draft legal races. However, compared to females males pushed the pace harder during the swim-to-cycle transition with high levels of cycling power output at the beginning of the bike session, and female triathletes were more affected by changes in slope during the triathlon cycle and run. By analyzing the performance of elite male and female triathletes in international Olympic distance triathlons from 2009 to 2012, Rüst et al. (2012b) found that the sex difference in running (14.3%) was greater than that which was evidenced for swimming (9.1%) and cycling (9.5%). In light of this observation, the relatively lower gender difference in cycling versus running may be associated with drafting, pacing and/or cadence on the bike (Bernard et al., 2003; Le Meur et al., 2009). However, the relative effects of these factors on the cycling and subsequent running performance of males as compared to females remain to be fully explored, and certainly warrant further study.

Comparison Between Olympic Distance and Ironman Distance Triathlons

Figure 1 shows the sex difference in time for swimming, cycling and running at three 2018 World Championships of the different distances. Whilst not yet established as statistically significant, sex difference in swimming performance appears to be lower for Olympic distance as compared to half- and full- Ironman distance performance. The lower sex difference in cycling performance that has been observed for Olympic distance versus half-Ironman distance events is difficult to explain and requires further investigation. It could be due to different racing strategies between males and females and/or a greater drafting benefit for females as compared to males within Olympic distance races. In contrast, sex difference in running performance appears to be greater for Olympic triathlon than it is for Ironman distance triathlon. The sex difference in running time clearly decreased with running distance from 13.7% for Olympic distance to 7.0% for Ironman distance. Similar observations were made by Lepers and Stapley (2010). Such an increase in the sex difference in running performance with a decrease in running

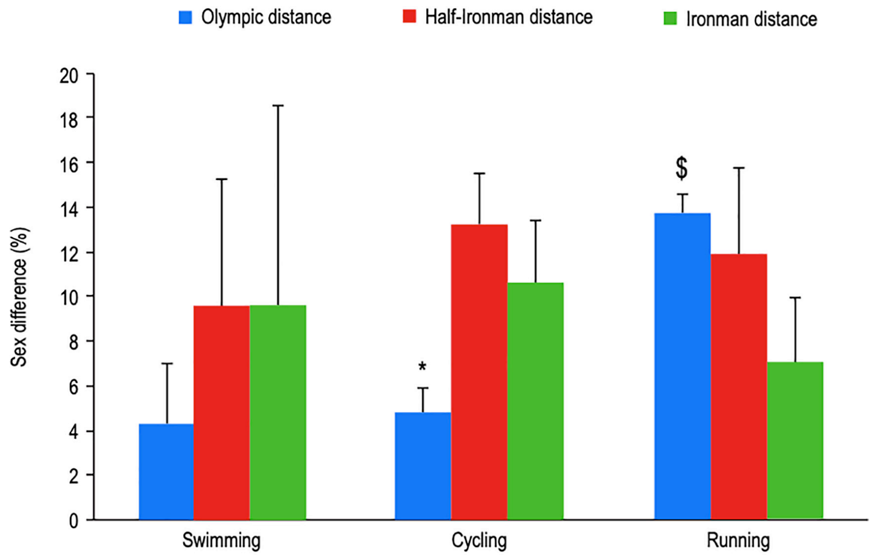

FIGURE 1 | Sex difference in time for swimming, cycling and running between the top 10 females and males at three triathlons considered as the World Championship of the distance in 2018. Olympic distance : World Triathlon Series – Grand Final (Gold Coast, Australia), Half-Ironman distance : Half-Ironman Triathlon Word Championship (Port Elizabeth, South Africa), Ironman distance : Ironman Triathlon World Championship (HI, United States). *different from Half-Ironman distance, $different from Ironman distance; $p < 0.05$.

distance is intriguing. Several hypotheses can be proposed for why this might occur. Firstly, the difference may be explained by the drafting conditions of Olympic distance triathlon. It has been shown that drafting can improve subsequent running performance (Hausswirth et al., 2001) and that fast runners likely benefit most from drafting during the triathlon cycle (Hausswirth et al., 1999). Differences between the sexes in drafting strategy can influence running performance. Male triathletes may also benefit more from drafting than females because they tend to ride in larger packs (Landers et al., 2008). The exercise duration of both the running course and the event overall could also explain the lower sex difference in Ironman marathon performance as compared to 10 km running. Given this point, and the physiological implications of differing distances (and intensities) of event, there are a number of physiological and morphological factors, which may underpin performance differences between of genders and, therefore, warrant further discussion.

PHYSIOLOGICAL CONSIDERATIONS

Sex difference in triathlon performance may be explained in part by morphological and physiological factors. Triathlon performance is related to body morphology (Ackland et al., 1998; Landers et al., 2000). Elite female athletes generally have 7–12% more body fat than males (Fleck, 1983; Heydenreich et al., 2017). As fat is buoyant in water, women are less penalized than men in swimming than they are within terrestrial events such as cycling and running. Male triathletes also possess a larger muscle mass, greater muscular strength and lower relative body fat than female triathletes (Knechtle et al., 2010a). It has been shown that both male and female triathletes' morphology has evolved since the 1990s. This may possibly be a result of changes in race distances and race tactics (Landers et al., 2013). It is worth noting that low body fat was associated with faster race times in male Ironman non-elite triathletes but not in females (Landers et al., 2000; Knechtle et al., 2010b).

The physiological characteristics of both elite and non-elite triathletes, particularly those which are considered to be the determinants of endurance performance [i.e., maximal oxygen uptake (VO_{2max}), anaerobic/ventilatory threshold and economy of motion] have been extensively studied (Millet et al., 2011). However, limited research has examined the physiological characteristics for both male and female triathletes within the same study. One of the first studies that reported physiological data for both sexes was that of O'Toole et al. (1987). For male and female Ironman triathletes, respectively, the latter authors recorded treadmill VO_{2max} values of 68.8 vs. 65.9 ml kg^{-1} min^{-1}, and cycle VO_{2max} values of 66.7 vs. 61.6 ml kg^{-1} min^{-1}. O'Toole et al. (1989) also reported VO_{2max} values for groups of triathletes during treadmill running to range from 52.4 to 72 ml kg^{-1} min^{-1} in males and from 58.7 to 65.9 ml kg^{-1} min^{-1} in females, respectively. The sex difference in VO_{2max} may depend on the level of the triathletes, the way that it is measured (i.e., whether this is done during running or cycling) or event distance specialization (e.g., between those who are focusing their training on Olympic distance vs. Ironman distance events) (Millet et al., 2011). Nevertheless, it would appear that elite females exhibit relatively lower VO_{2max} values than males, irrespective of exercise mode. Furthermore, it would seem that the discrepancy between bike and run VO_{2max} is greater for females than it is for males. This may reflect a relatively greater weakness in the bike discipline in female triathletes and a need for this to be prioritized in their development.

Bunc et al. (1996) examined the physiological profile of top 17 year old male and female triathletes and found that VO_{2max} was 20% lower for the females than it was for the males (56.1 vs. 67.9 ml kg^{-1} min^{-1}). However, in both cases, the athletes′ ventilatory threshold corresponded to 82% of VO_{2max}. Similarly, Millet and Bentley (2004) found that for elite junior and senior triathletes, the sex difference in VO_{2max} was equal to 22% (74 vs. to 61 ml kg^{-1} min^{-1} for males and females, respectively). The ventilatory threshold was similar in senior males and females and corresponded to 74–77% of VO_{2max}.

These findings corroborate data for endurance running athletes for whom both absolute and relative VO_{2max} is lower for female athletes than it is for male athletes. Sex difference in VO_{2max} still persists when it is expressed per kilogram of fat free mass (Joyner, 2017). These differences are attributed to a combination of higher body fat in females and lower red cell mass and hemoglobin for a given body weight (Schmidt and Prommer, 2010).

Whilst VO_{2max} is lower for female triathletes than it is for male triathletes, lactate threshold (the exercise intensity associated with a marked rise in blood lactate and expressed as a percentage of VO_{2max}) appears to be similar in both sexes when measured in cycling and running (Millet et al., 2011). A determinant of a high lactate threshold is the ability of the mitochondria in muscles to increase in volume in response to training (Holloszy and Coyle, 1984). An increase in the capillary density in muscles also plays a role in how long athletes might be able to sustain exercise at high intensities (Coyle et al., 1988). There is no evidence that these adaptive capacities are less in females than in males. Of the three main determinants of triathlon performance, less is known about running economy and cycling efficiency than VO_{2max} or lactate threshold. Running economy or energy cost can be defined as oxygen uptake during running at a certain speed. Energy cost is higher during the running part of a triathlon than it is during an isolated run (Hausswirth et al., 2000). The study of Millet and Bentley (2004) suggested that there was no difference between males and females in running economy. However, in the aforementioned study the absolute test speed was lower for females than it was for males. Thus, the oxygen cost relative to a certain reference speed (e.g., 15 km/h) was markedly different between sexes and represented a factor in the performance difference. Data on sex difference in cycling efficiency for triathletes is missing. Hopker et al. (2010) have examined the cycling efficiency in male and female competitive cyclists. These authors found that gross efficiency was higher in female cyclists for submaximal intensities (150 W and 180 W). Males also exhibited a higher oxygen cost of "unloaded" cycling, suggesting that in addition to work rate, leg volume/mass may be an important determinant of the observed differences in cycling efficiency between male and female well-trained cyclists. These results for competitive cyclists need to be confirmed in well-trained triathletes. In conclusion, it appears that the main physiological difference between females and males that affects triathlon performance is VO_{2max}. Lactate threshold and locomotion economy probably do not explain much of the sex difference in triathlon performance but these two factors require further investigations in male and female elite triathletes.

Other factors such as sex differences in thermoregulation and fat oxidation could conceivably play a role. Some studies suggested that females, because of their smaller body size, can better tolerate hot and humid racing conditions than males (Dennis and Noakes, 1999; Marino et al., 2000). Lighter runners produce and store less heat at the same running speed, thus females may be less susceptible than males to overheating during a long race in oppressive weather. These data leads to the prediction that females might compete against males most successfully in long distance triathlons where overheating is particularly common, such as the Hawaii Ironman triathlon. Another interesting sex difference is the fact that females appear to oxidize proportionately more lipid and less carbohydrate during endurance exercise. Indeed, studies investigating sex differences in the metabolic response to prolonged submaximal exercise have found that females have a lower respiratory exchange ratio, and attenuated muscle glycogen utilization as compared to males (Tarnopolsky et al., 1990; Carter et al., 2001). This could offer females the possibility that, in triathlons that take several hours to complete, their supply of liver and muscle glycogen will outlast that of men. However, Vest et al. (2018) found that peak fat oxidation did not predict Ironman race time independently of aerobic capacity in females. On the other hand, Frandsen et al. (2017) found that maximal fat oxidation rate exerted an independent influence on Ironman performance in males. These contradictory results suggest that additional research is required to better understand the role of fat oxidation in both male and female triathlon performance.

It has been shown that females can sometimes finish ultra-marathons in times similar to those of the males who can beat them in marathons. Similarly, when males and females with equivalent marathon times are pitted against each other in ultra-marathons, the females tend to win (Speechly et al., 1996; Bam et al., 1997). It would be interesting to verify if this finding also applies to triathlon performance, i.e., when males and females have equivalent short distance triathlon time performances, do females tend to win over the Ironman distance and longer events such as ultra-triathlon events (Knechtle et al., 2011)? We could also ask what females could do to mitigate the gap to the males if they drop down to shorter events- where they are at more of a disadvantage relative to them.

CONCLUSION AND PERSPECTIVES

The sex difference in triathlon performance, representing a difference of approximately 10–20% of total time, depends upon the disciplines, the distances and the level of competitors. The sex difference in performance is likely to be due to physiological and morphological factors but hormonal, psychological and societal differences (such as lower participation rates) should also be considered. There is a growing pool of females getting involved in the sport earlier/younger, and consequently training specifically for triathlon for a greater period. This will probably filter into the top level. Recently, elite female triathletes have reduced the gap to their male counterparts during the marathon section of Ironman distance triathlon running, with the current difference standing at less than 10%. The reasons why such running improvements in females are not observed for short-distance triathlon remains not clear. It seems that cycling is the discipline with the most potential for improved female triathlon performance, especially at Ironman distance. Future studies should address the limited evidence relating sex difference in some physiological characteristics of triathletes such as lactate threshold, exercise economy or peak fat oxidation. It is important to better understand the sex difference in triathlon performance, both to promote more female participation and to help female triathletes to achieve their maximal performance.

AUTHOR CONTRIBUTIONS

The author drafted the manuscript.

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What Motivates Successful Marathon Runners? The Role of Sex, Age, Education, and Training Experience in Polish Runners

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The aim of this study was to compare the motivations of successful marathon finishers (n = 1,243) and inexperienced runners (control group, n = 296). A total of 1,537 runners with 380 women (24.7%) and 1,157 men (75.3%) completed the motivations of marathoners scales (MOMS) questionnaire and the relationships between general motivation categories and selected demographic (e.g., gender, age, and education) and training characteristics were analyzed. Successful marathon finishers did not differ significantly in motivations from the control group ($p > 0.05$). Trivial to small correlations with age, educational level, and training characteristics were observed. Female marathon finishers exceeded men on the motivational scales for weight concern, affiliation, psychological coping, life meaning, and self-esteem and they scored lower on competitive motivation ($p < 0.05$). There was also a significant relationship of some motivational aspects with level of education, experience and training frequency. These findings confirmed that age and gender differentiate motivations in both successful female and male marathon finishers and controls.

Keywords: age, running, marathon finisher, motivation, personal achievement, gender difference

INTRODUCTION

Running is one of the world's most popular sports and recreation activities with more than 64 million participants in the United States alone in 2016 (Nikolaidis et al., 2018b). Marathon events continue to grow annually and the "New York City Marathon" has been recorded as the world's largest, with over 52,000 competitors each year (Nikolaidis et al., 2018b).

During the last decades, the popularity of marathon running has been described as a "marathon fever" especially among middle-aged, non-elite runners for whom this activity could be a way to deal with midlife crisis (Summers et al., 1982). Gorczyca et al. (2016) suggested that proving the ability to run a marathon race constituted an important life event for a person, unless this person had already completed many other comparable athletic achievements, and that it could greatly affect one's beliefs about life in general and potential future achievements.

Running has been a basic locomotion mode for more than two million years dating back to primitive societies in which land travel required walking or running to travel long distances (Bramble and Lieberman, 2004) and man also had to be prepared for long lasting strenuous hunts to run after different prey (Carrier, 1984). Modern forms of transportation decreased the need to run or walk as part of everyday life.

However, participation in active leisure is one of the most important components of healthy behavior and research has shown that physical activity improves overall psychological well-being (Lawlor and Hopker, 2001; Penedo and Dahn, 2005). Exercise is considered effective for people with mild to moderate depression, for patients who prefer non-pharmacological treatments (Kok and ReynoldsIII, 2017), and for those who prefer non-intense physical activity such as walking, which has been linked to an improved mood state (Edwards and Loprinzi, 2018).

It is especially important in the view of the growing popularity of endurance running to understand the limitations or challenges that aspiring future runners might face (Ridinger et al., 2012; Pelletier et al., 2013; Knechtle et al., 2016). Wright et al. (2005) reported that adolescents were more motivated to exercise when they had higher perceptions of their physical ability. The challenge of running a marathon is highly stimulating for many runners, providing them with an opportunity to test their physical and psychological abilities. Their feelings of deep personal awareness and positive self-perception might also be motivating (Jordalen and Lemyre, 2015).

The motivations of recreational runners training for their first marathon have been examined in several studies (Summers et al., 1982; Bandura, 1997; Havenar and Lochbaum, 2007; Scholz et al., 2008; Nikolaidis et al., 2018a). Summers et al. (1982) reported that goal achievement (i.e., personal challenge and the sense of achievement) was runners' primary motivation. Scholz et al. (2008) found that increases in self-efficacy and positive outcome expectancy were correlated with improvements in one's marathon time (Bandura, 1997). Furthermore, Havenar and Lochbaum (2007) highlighted the role of social and weight-related motivations.

Other studies have characterized marathoners' motivation in terms of "direction, intensity, and persistence" (Dishman, 2001; Ogles and Masters, 2003; Havenar and Lochbaum, 2007). Curtis and McTeer (1981a,b) used open-ended questions and found that the most prevalent motivations were goal achievement (cited by 77% of respondents), the influence of other people (20%), and psychological well-being (19%). Summers et al. (1982, 1983) applied a similar method but asked each respondent to give his or her top three motivations for participating in marathons. The leading responses, in order, were goal achievement, physical fitness, and the influence of others.

Research on marathon motivation suggests that people's capacity can be at various places on a continuum ranging from strong intrinsic motivation to no intention to act (Deci and Ryan, 1985; Boudreau and Giorgi, 2010; Jeffery and Butryn, 2012). Ryan and Deci (2000) stated that all individuals are situated on the described above continuum in relation to the level of satisfaction with three psychological needs: competence, autonomy, and relatedness.

Runners with a strong intrinsic motivation are focused on pleasure and satisfaction developed and achieved during the training process and starting activity. All extrinsically motivated behaviors are varying from the basic external demands to integrated regulation. These actions are related to outcomes that lie independently from activity itself. The purposes of activity are benefits or negative consequences avoidance (Buckworth et al., 2007). Participation in organized races involves both types of motivation while the main basis of the running embraces personal achievement, enjoyment, competition, and a sense of belonging to the runners' community, at the same time (Bell and Stephenson, 2014).

One major development in this research specialty was the creation of the motivations of marathoners scales (MOMS), a multifaceted questionnaire designed specifically to assess the motives of marathon runners. The MOMS has been used widely, and its reliability and validity have been confirmed in several studies with different populations and determining factors (Masters et al., 1993; Masters and Ogles, 1995; Ogles and Masters, 2003). The MOMS contains 56 questions grouped into nine categories: health orientation, weight concern, self-esteem, life meaning, psychological coping, affiliation, recognition, competition, and personal goal achievement (Masters et al., 1993). The scale has been adapted for the use with participants in many different sports (Ogles and Masters, 2003; LaChausse, 2006; Ruiz and Sancho, 2011). For instance, Heazlewood et al. (2012) used the MOMS to investigate the motivations of athletes competing in various sports as part of the 2010 Pan Pacific Masters Games, and Brown et al. (2018) used it for black female master triathletes.

Recently, Zach et al. (2017) tested and expanded the MOMS scale of Masters et al. (1993) and found that the best structure solution resulted in 11 factors such as psychological coping-emotional-related coping, psychological coping-everyday-life management, life meaning, self-esteem, recognition, affiliation, weight concerns, general health orientation-reduced disease prevalence and longevity, general health orientation-keep fit, competition, and personal goal achievement.

Motivation for long-distance running can be complex and influenced by internal and external factors (Baldwin and Caldwell, 2003; Shipway and Holloway, 2010). Reasons for trying to complete a race as long as 26.2 miles (42.195 km) are not necessarily obvious or intuitive and they might vary between beginners and experienced runners. Accordingly, the main aim of the present study was to compare the motivations of runners who have previously completed a marathon (referred to as "successful marathon finishers") and people training for their first one.

To the best of our knowledge, there exists very little scientific evidence on the motivations of novice runners preparing for a marathon (Jeffery, 2010; Carter et al., 2016). Little is also known about the motivation of marathoners for a specific country. For example, the attendance in marathon races in Poland is significantly smaller compared to the United States and reached ∼300,000 participants in the largest ten events in the years 2000–2017[1].

[1] www.maratonypolskie.pl

There exists also some interesting phenomenon that it is possible to observe a decrease in the number of participants in Polish marathons. In general, there is growing interest in marathon races around the world, while during last 4 years it was possible to observe an inverse dynamic in Poland[2]. A falling attendance in Polish marathons has been going on for 3 years. In 2015, the organizers of the ten largest marathons recorded 36,428 participants, a year later there were 35,912 participants, and in 2017 a total of 35,833 participants. In 2018, the balance sheet closed with a loss of 2,391 participants in relation to 2017. This means that from 2015 nearly 3,000 people less completed a marathon in Poland.

About the reasons for this trend can only be speculated[3]. However, also in another European country (i.e., Switzerland), the participation in full marathons decreased during the period 2000–2010 whereas the participation in half-marathons increased in the same period (Anthony et al., 2014).

Therefore, the aim of our study was to investigate the motivation of marathoners competing in one country (i.e., Poland) and to compare their motivation with the motivation of inexperienced runners. Our study compares the motivations of marathon finishers and inexperienced runners (control group). To facilitate this comparison, we administered the MOMS questionnaire to runners in both groups and analyzed correlations between categories of motivation and selected demographic and athletic characteristics such as age, level of education, experience, training frequency, and gender.

MATERIALS AND METHODS

Ethics Statement

All procedures were performed in accordance with Polish law and were evaluated by the Bioethical Committee at the Jerzy Kukuczka Academy of Physical Education in Katowice, which granted official approval for the research (KB/47/17). The study was conducted in conformity with the Declaration of Helsinki. As online surveys or questionnaires do not require the completion of a separate participant information sheet or consent form, completion of the survey was deemed to constitute informed consent.

Participants

The total number of respondents was 1,537 including 380 women (24.7%) and 1,157 men (75.3%). The successful marathon finishers group included 1,243 subjects and the control group 296 runners. The questionnaire was distributed – from January to March 2008 – to Polish runners through professional running websites and organizers of marathon events, who directed runners to the online survey. Participants were informed about the significance of the study and were kindly requested to provide information about their sex, age, education, training experience, training frequency and income. The control group consisted of responders who did not finish a marathon race so far, but they had the intention to do so in the near future.

We included participants in several Polish marathons (e.g., Cracow, Wrocław, Poznan, and Silesia) by using various running-related websites, including ultraroztocze.pl, biegrzeznika.pl, maratonypolskie.pl, bieganie.pl, biegologia.pl, polskabiega.pl, treningbiegacza.pl, wszystkoobieganiu.pl, biegaczki.pl, ultrabieganie.pl, and festiwalbiegowy.pl. The minimum age of study participants was 18 years, and all respondents were required to be practicing long-distance running at least once per week. We classified anyone who had previously completed at least one marathon as a "successful marathon finisher." Respondents who were training for a marathon but had not yet finished one were treated as subjects for the control group.

Questionnaire

As noted above, the MOMS contains 56 items distributed across nine scales (Masters et al., 1993). The authors of that study divided the nine motivations covered into four main categories: (1) psychological motives including maintaining or enhancing self-esteem, providing a sense of life meaning, and problem solving or coping with negative emotions; (2) social motives including the desire to affiliate with other runners and to receive recognition or approval from others; (3) physical motives for running including general health benefits and weight concern; and (4) achievement-related motives are competition with other runners and personal goal achievement (Masters et al., 1993). We used the Polish translation of the MOMS, which was adapted and the reliability of which was verified by Dybała (2013). It showed high reliability and was accepted as valid adoption (**Table 1**).

Reliability of MOMS

Answers to items on the MOMS are on a 7-point Likert-type scale, where 1 means "not a reason" and 7 represents the "most important reason." The original research exhibited

TABLE 1 | Cronbach's alpha coefficient of internal consistency estimate of reliability of MOMS' scores.

Categories	Dybała (2013)	Current study
Psychological		
Life meaning	0.85	0.87
Psychological coping	0.86	0.92
Self-esteem	0.87	0.88
Achievement		
Competition	0.90	0.87
Personal goal achievement	0.90	0.81
Social		
Affiliation	0.85	0.92
Recognition	0.89	0.89
Physical		
Health orientation	0.88	0.81
Weight concern	0.88	0.83

[2] www.maratonypolskie.pl/mp_index.php?dzial=8&action=8&code=3086

[3] http://biegowe.pl/2018/10/frekwencja-na-polskich-maratonach-ostro-pikuje-co-jest-tego-powodem.html

good statistical properties, with reliability scores from 0.80 to 0.93 and temporal stability ranging from 0.71 to 0.90 (Summers et al., 1983).

Statistical Methods

Basic descriptive statistics and Kolmogorov–Smirnov tests were performed to describe the normality of data distribution. To determine the relationships between measured variables, the Mann–Whitney *U* test was used and Spearman rank correlation coefficients were calculated. The significance of the association (contingency) between the two kinds of classification was examined using Fisher's *z*. The effect sizes of Pearson correlation coefficients were estimated according to Cohen's guidelines for the social sciences (Cohen, 1988). All statistical calculations were performed with IBM SPSS version 24.

RESULTS

Reliability of Results

To evaluate the reliability of the collected data, Cronbach's alpha coefficients of internal consistency were calculated (**Table 1**). The resulting coefficients were at "good" (0.8 to 0.9) or "excellent" (above 0.9) levels.

General Characteristics of Participants

The participants were distributed in relatively balanced age groups. Participants aged 18–30 years stated 23.5% of the researched population, 35.4% were aged 31–40 years, 30.5% between 41 and 50 years and 11.6% was above 50 years. The running history showed that 296 had not competed in any marathon run, 646 had started in 1–3 marathons, 397

TABLE 2 | General characteristics of marathon finishers and control group.

	Marathon finisher		**Control group**	
	N	**%**	***N***	**%**
<18	–	–	5	1,7
18–30	237	19,1	124	41,9
31–40	455	36,6	91	30,7
41–50	406	32,7	64	21,6
51–65	131	10,5	12	4,1
>65	9	0,7	–	–
No data	5	0,4	–	–
Sex				
Women	280	22,5	101	34,1
Men	961	77,3	195	65,9
No data	2	0,2	–	–
Education				
Elementary	9	0,7	6	2
High School	319	25,7	84	28,4
University	915	73,6	206	69,6
Training experience				
Less than 1 year	19	1,5	43	14,5
1–3 years	386	31,1	165	55,7
3–10 years	667	53,7	80	27
More than 10 years	171	13,8	8	2,7
Training frequency				
1–3 times per week	419	33,7	165	55,7
4–6 times per week	744	59,9	123	41,6
Everyday	79	6,4	8	2,7
Material status				
I satisfy my needs to the minimum extent	74	6,0	23	7,8
I am dealing, but I often have financial problems	155	12,4	42	14,2
I satisfy my needs to a satisfactory degree	962	78,0	223	75,3
I can afford everything I dream of	45	3,7	8	2,7
Attitude to material needs				
They are completely irrelevant to me	32	2,6	2	0,7
I notice them, but I do not attach much importance	620	49,9	150	50,7
They are important to me	582	46,8	142	48
Material matters are priority for me	8	0,6	2	0,7
No data	1	0,1	–	–

in 4–10 marathons, 146 in 11–30 marathons and 51 in more than 30 marathons.

The responses to the question on training session frequency indicated that 37.9% trained 1 to 3 days a week, 55.6% worked out 4 to 6 days per week, and 6.5% ran every day. As for the length of training experience, only 3.9% had been in training for less than 1 year, 35.7% for 1 to 3 years, 48.5% for between 4 and 10 years, and 11.6% for more than 10 years. With regard to the educational level, 72.8% had completed a higher education, 26.2% had completed only high school, and 1% had not completed high school. General characteristics of marathon finishers and runners from the control group are presented in **Table 2**.

As a first step, along with calculating basic descriptive statistics for the quantitative variables, we used the Kolmogorov–Smirnov test to check the normality of the distribution of these variables. This test showed that the distributions of the variables tested were different from the normal distribution (**Table 3**). In such a situation, it is important to analyze the skewness values of these variables. Skewness of tested variables was fit between values equal +2 and −2. All samples fulfilled all the necessary additional requirements and the use of parametric tests was selected (George and Mallery, 2010).

The Mann–Whitney *U* test was used because of a difference in the number of runners in each category, and the results showed no significant difference in any evaluated category (**Table 4**).

Age

We examined the relationship between age and each of the nine motivations contained in the MOMS for both groups of subjects (**Table 5**). For the successful marathon finishers, age was positively correlated with health orientation ($r = 0.074$, $p = 0.009$) and affiliation ($r = 0.064$, $p = 0.025$), whereas weight concern ($r = -0.074$, $p = 0.009$), personal goal achievement ($r = -0.211$, $p < 0.001$), competition ($r = -0.108$, $p < 0.001$), recognition

TABLE 3 | Basic descriptive statistics of all participants.

	M	*Me*	*SD*	*Sk.*	*Kurt.*	*K-S*	*p*
Psychological							
Life meaning	4.07	4.14	1.43	−0.13	−0.61	0.05	<0.001
Psychological coping	4.37	4.44	1.49	−0.26	−0.68	0.05	<0.001
Self-esteem	4.61	4.75	1.38	−0.44	−0.39	0.06	<0.001
Achievement							
Competition	3.35	3.25	1.65	0.36	−0.79	0.08	<0.001
Personal goal achievement	5.32	5.50	1.19	−0.87	0.62	0.09	<0.001
Social							
Affiliation	3.40	3.33	1.62	0.26	−0.87	0.07	<0.001
Recognition	2.70	2.40	1.43	0.71	−0.32	0.12	<0.001
Physical							
Health orientation	4.63	4.83	1.15	−0.58	−0.11	0.08	<0.001
Weight concern	4.55	4.67	1.66	−0.39	−0.75	0.10	<0.001

M, mean; Me, median; SD, standard deviation; Sk., skewness; Kurt., kurtosis; K-S, Kolmogorov–Smirnov test; p, significance.

TABLE 4 | Motivations of marathoners scales and participation in marathons.

Category	Control group (*n* = 296)		Marathon finishers (*n* = 1243)		Test results			
	M	*SD*	*M*	*SD*	*U*	*Z*	*p*	*r*
Psychological								
Life meaning	3.98	1.50	4.09	1.41	176691.0	−1.06	0.290	0.03
Psychological coping	4.32	1.58	4.38	1.46	179925.5	−0.59	0.557	0.01
Self esteem	4.67	1.45	4.60	1.36	178250.0	−0.83	0.405	0.02
Achievement								
Competition	3.33	1.68	3.36	1.65	180696.5	−0.48	0.634	0.01
Personal goal achievement	5.44	1.17	5.30	1.20	170716.0	−1.93	0.054	0.05
Social								
Affiliation	3.26	1.61	3.43	1.62	172678.0	−1.64	0.100	0.04
Recognition	2.77	1.48	2.69	1.42	179516.0	−0.65	0.516	0.02
Physical								
Health orientation	4.62	1.19	4.63	1.14	182467.5	−0.22	0.827	0.01
Weight concern	4.44	1.66	4.58	1.66	174445.5	−1.39	0.165	0.04

M, mean; SD, standard deviation; U, Mann–Whitney U test; Z, standardized value; p, statistical significance; r, effect strength.

TABLE 5 | Pearson correlation coefficients between MOMS variables and chosen personal characteristics of control group (*n* = 296) and marathon finishers (*n* = 1,243).

Category	Age			Education			Training experience			Frequency of trainings			
	CG	MF	Z	CG	MF	Z	CG	MF	Z	CG	MF	Z	
Psychological													
Life meaning	−0.05	−0.091**	0.63	−0.101	−0.081*	−0.31	0.037	0.02	0.26	0.139*	0.013	1.95	0.018
Psychological coping	−0.082	−0.143**	0.95	0.044	−0.022	1.02	0.036	−0.029	1	0.06	−0.053	1.74	−0.093**
Self esteem	−0.109	−0.188**	1.24	−0.05	−0.066*	0.25	−0.043	−0.118**	1.16	0.104	−0.009	1.75	−0.138**
Achievement													
Competition	−0.106	−0.108**	0.03	−0.027	−0.031	0.06	0.093	0.01	1.28	0.301**	0.128**	2.8	0.013
Personal goal achievement	−0.211**	−0.216**	0.08	−0.081	−0.025	−0.86	0.013	−0.137	2.32*	0.211**	0.145**	1.05	−0.127**
Social													
Affiliation	0.111	0.064	0.73	0.028	−0.125**	2.37*	0.045	0.001	0.68	0.093	−0.027	1.85	0.048
Recognition	−0.036	−0.117**	1.26	−0.028	−0.042	0.22	−0.067	−0.051	0.25	0.114	0.003	1.72	−0.034
Physical													
Weight concern	0.154*	−0.074*	3.53	0.055	−0.019	1.14	−0.052	−0.059	0.11	−0.081	−0.002	−1.22	−0.095**
Health orientation	0.231**	0.074*	2.48*	−0.007	−0.034	0.42	0.076	0.007	1.06	−0.034	−0.012	−0.34	−0.02

*CG, control group; MF, marathon finishers; Z, Fisher test. *p < 0.05, **P < 0.001.*

($r = -0.117$, $p < 0.001$), psychological coping ($r = -0.143$, $p < 0.001$), life meaning ($r = -0.091$, $p = 0.001$), and self-esteem ($r = -0.188$, $p < 0.001$) were all negatively correlated with age. The effect size was small for the correlations with health orientation, affiliation, weight concern, and life meaning; it was medium for the other variables.

In the control group, two motivations showed a significant and positive relationship with age and had a medium effect size: health orientation ($r = 0.231$, $p < 0.001$) and weight concern ($r = 0.154$, $p = 0.008$). On the other hand, personal goal achievement had a significant and negative relation with age ($r = -0.211$, $p < 0.001$). Calculating Fisher's z identified two significant differences: the correlations between age and health orientation ($Z = 2.48$, $p = 0.013$) and between age and weight concern ($Z = 3.53$, $p < 0.001$) were significantly stronger for the control group than for successful marathon finishers (**Figure 1**).

Level of Education

Only three motivational scales showed a significant correlation with level of education among the successful marathon finishers. With increasing education level, psychological coping ($r = -0.125$, $p < 0.001$), life meaning ($r = -0.081$, $p = 0.004$), and self-esteem ($r = -0.066$, $p = 0.020$) motivation levels all decreased. The effect size was small for the correlations with life meaning and self-esteem; it was medium for the correlation with psychological coping. Fisher's z showed a significant difference between groups only in the case of affiliation ($Z = 2.37$, $p = 0.018$), as the correlation between education level and affiliation was significantly stronger (and negative) among successful marathon finishers.

Experience and Training Frequency

Two training factors, running experience and frequency of training sessions, were analyzed for both groups. For the successful marathon finishers, there were only two statistically significant correlations with running experience, both negative and with a medium effect size: personal goal achievement ($r = -0.137$, $p < 0.001$) and self-esteem ($r = -0.118$, $p < 0.001$). The correlation between running experience and personal goal achievement was significantly stronger ($Z = 2.32$, $p = 0.020$) among successful marathon finishers than in the control group, according to Fisher's z.

As for frequency of training sessions, there was a significant positive correlation with personal goal achievement motivation in both the control group ($r = 0.211$, $p < 0.001$) and the successful marathon finishers ($r = 0.145$, $p < 0.001$). Similarly, both groups showed positive correlations between frequency of training and competitive motivation ($r = 0.301$, $p < 0.001$ for the control group; $r = 0.128$, $p < 0.001$ for successful marathon finishers). The effect sizes in all four cases were medium. Fisher's z showed that the control group had a significantly stronger correlation with competitive motivation than the successful marathon finishers ($Z = 2.80$, $p = 0.005$). In the control group, life meaning also had a positive correlation, at medium effect size, with frequent of training ($r = 0.139$, $p = 0.016$).

The questionnaire asked successful marathon finishers how many prior marathons they had run. This variable was significantly and negatively correlated to weight concern ($r = -0.095$, $p = 0.001$), psychological coping ($r = -0.093$, $p = 0.001$), personal goal achievement ($r = -0.127$, $p < 0.001$), and self-esteem ($r = -0.138$, $p < 0.001$). The effect size was small for the correlations with weight concern and psychological coping, and it was medium for the correlations with personal goal achievement and self-esteem.

Gender

The Mann–Whitney U test (**Tables 6**, **7**) was used here because of the large difference in the number of runners between genders. In the control group, there were four statistically significant differences, as men indicated higher motivation for competition ($Z = -2.80$; $p = 0.005$; $r = 0.16$) and were lower on psychological coping ($Z = -4.81$; $p < 0.001$;

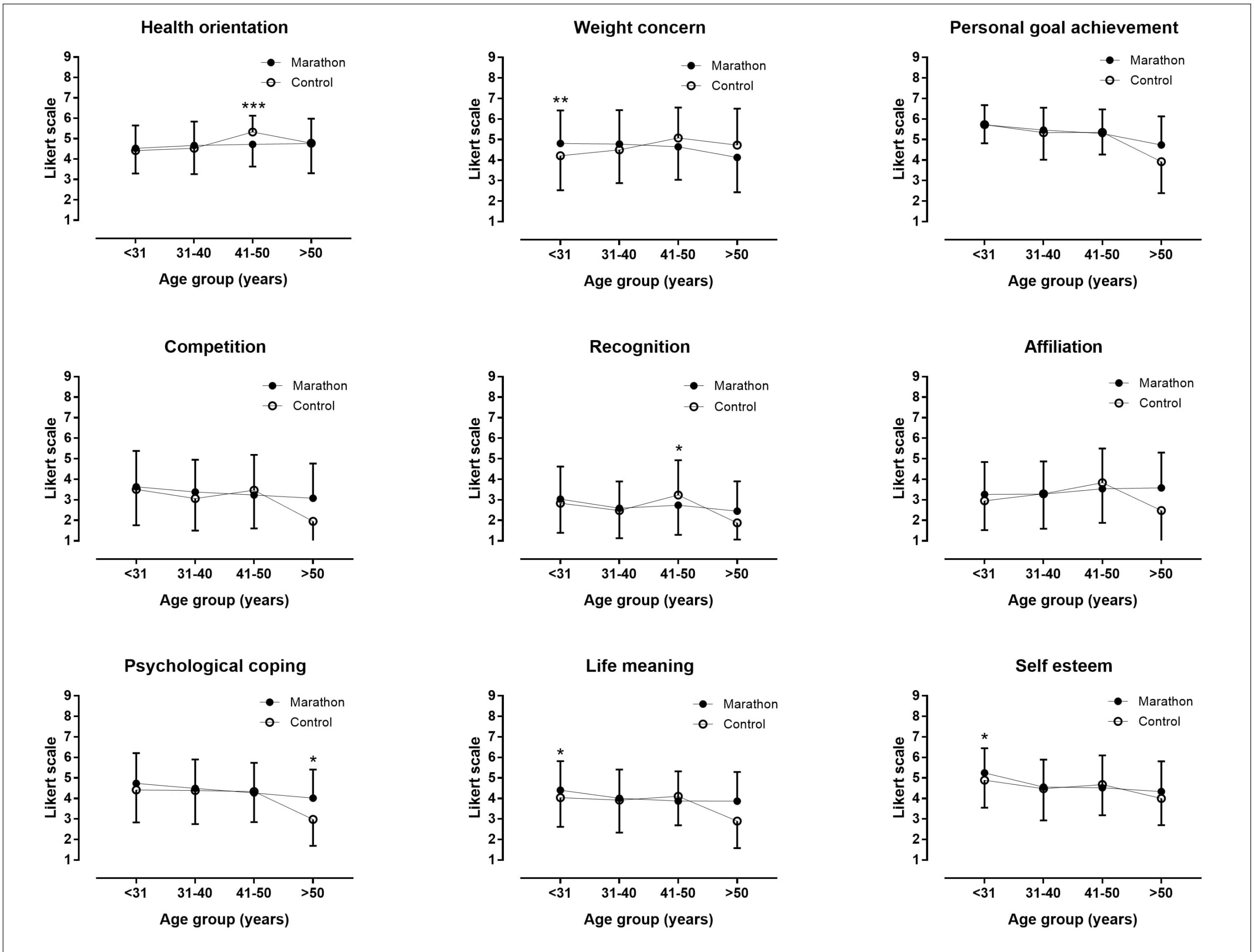

FIGURE 1 | Differences in motivations between marathon runners and control group by age. *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

$r = 0.28$), life meaning ($Z = -3.41$; $p = 0.001$; $r = 0.20$), and self-esteem ($Z = -2.66$; $p = 0.008$; $r = 0.15$). Among successful marathon finishers, women had higher values for weight concern ($Z = -3.91$; $p < 0.001$; $r = 0.11$), affiliation ($Z = -2.31$; $p = 0.021$; $r = 0.09$), psychological coping ($Z = -6.56$; $p < 0.001$; $r = 0.19$), life meaning ($Z = -3.91$; $p < 0.001$; $r = 0.11$), and self-esteem ($Z = -6.09$; $p < 0.001$; $r = 0.17$); they were lower than men in competitive motivation ($Z = -4.69$; $p < 0.001$; $r = 0.13$). The effect size was medium for the two correlations with psychological coping and small for all others.

DISCUSSION

The main finding of the present study was that successful marathon finishers did not differ in motivation from runners intending to compete in their first marathon. Further important findings were that (*i*) personal goal achievement was the strongest motivation and recognition the weakest; (*ii*) trivial to small correlations were observed between the motivation scales and age, educational level, and training characteristics; and (*iii*) female marathon finishers were more motivated than men by weight concern, affiliation, psychological coping, life meaning, and self-esteem, but less motivated by competition.

Personal Goal Achievement Was the Strongest Motivation and Recognition the Weakest

The most important finding in this study was that personal goal achievement was the strongest motivation in these successful marathoners. On the other hand, recognition was the weakest motivation which was in contrast to recent findings where recognition was reported as more important (Zarauz et al., 2016). Furthermore, it had been observed that self-esteem, health and finding meaning in life were strong motivations in many runners, especially in women (Zarauz et al., 2016). Also, it was shown that general health orientation and psychological coping were the strongest

TABLE 6 | Motivations of marathoners scales of marathon runners in the control group in relation to gender.

	Women (n = 101)		Men (n = 195)					
	M	*SD*	*M*	*SD*	*U*	*Z*	*p*	*r*
Psychological								
Life meaning	4.37	1.40	3.78	1.52	7469.0	−3.41	0.001	0.20
Psychological coping	4.93	1.49	4.00	1.54	6488.0	−4.81	<0.001	0.28
Self esteem	4.96	1.40	4.51	1.45	7994.5	−2.66	0.008	0.15
Achievement								
Competition	2.94	1.58	3.53	1.70	7894.5	−2.80	0.005	0.16
Personal goal achievement	5.33	1.22	5.49	1.14	9115.0	−1.05	0.293	0.06
Social								
Recognition	2.68	1.42	2.81	1.51	9401.5	−0.64	0.522	0.04
Affiliation	3.50	1.68	3.13	1.57	8596.5	−1.79	0.073	0.10
Physical								
Health orientation	4.67	1.13	4.59	1.22	9520.0	−0.47	0.639	0.03
Weight concern	4.60	1.54	4.36	1.72	9112.0	−1.06	0.291	0.06

M, mean; SD, standard deviation; U, Mann–Whitney U test; Z, standardized value; p, statistical significance; r, effect strength.

motivations for female ultra-marathoners in a study adopting different methodological approach to evaluate motivation (Krouse et al., 2011).

With regards to the assessment tool of motivation, Zach et al. (2017) examined the psychometric soundness of the traditional MOMS model and found a novel 11-factor model solution that introduced several changes to the original model. A canonical factor analysis indicated that psychological coping was split into two new factors, which Zach et al. (2017) termed emotion-related coping and everyday life management. In the same study, self-esteem failed to be defined as a distinct factor, since the original self-esteem items were distributed into other factors. There was also another interesting split, where health orientation was divided into reduction in disease prevalence and staying fit. The abovementioned authors underscored that the new model was conceptually similar to the original MOMS but psychologically sounder and stated that runners' motivation was not hierarchically oriented, but that all factors should be treated as independent factors.

As the number of successful marathon runners increased over recent years (Nikolaidis et al., 2018b) and the average race times became slower (Hammer and Podlog, 2016), a shift in motivation was observed among successful marathon finishers. Carter et al. (2016) stated that beginners in marathon running exhibited positive attitudes toward marathon preparations and were well motivated. However, they were often unprepared for the mental and emotional demands of training and competing in a marathon. Carter et al. (2016) recommended multimodal mental skills training as a complementary activity to help novices prepare for the challenges they might face in completing a

TABLE 7 | Motivations of marathoners scales of marathon runners in relation to gender.

	Women (n = 280)		Men (n = 961)					
Category	*M*	*SD*	*M*	*SD*	*U*	*Z*	*p*	*r*
Psychological								
Life meaning	4.38	1.48	4.01	1.39	113923.5	−3.91	<0.001	0.11
Psychological coping	4.88	1.48	4.24	1.43	99923.5	−6.56	<0.001	0.19
Self esteem	4.99	1.40	4.48	1.33	102419.0	−6.09	<0.001	0.17
Achievement								
Competition	2.97	1.61	3.48	1.64	109834.0	−4.69	<0.001	0.13
Personal goal achievement	5.15	1.36	5.34	1.14	126887.0	−1.45	0.147	0.04
Social								
Affiliation	3.66	1.72	3.37	1.58	122344.5	−2.31	0.021	0.07
Recognition	2.62	1.49	2.71	1.40	126426.5	−1.54	0.123	0.04
Physical								
Health orientation	4.55	1.24	4.66	1.11	130083.0	−0.85	0.398	0.02
Weight concern	4.91	1.65	4.48	1.65	113929.0	−3.91	<0.001	0.11

M, mean; SD, standard deviation; U, Mann–Whitney U test; Z, standardized value; p, statistical significance; r, effect strength.

full marathon. Analyzing and strengthening the factors such as competition, health improvement and achieving personal goals that were driving people to run a full marathon enabled athletes to increase their internal sense of motivation to manage the physical, emotional, and psychological obstacles that can arise during a marathon run.

Successful Marathon Finishers Did Not Differ in Motivation From Novice Marathoners

The similarity in motivations between successful marathon finishers and s the control group was surprising. One possible explanation might be that runners in the control group were more interested in the marathon than the total population of novices, as the recruitment of all participants in this study occurred through professional running websites and organizers of marathon events. No major differences in stated motivations to run marathons between experienced runners and novices were reported in previous research (Goodsell et al., 2013).

Differences Between Female and Male Marathoners

A further important finding was that female marathon finishers were more motivated than men by weight concern, affiliation, psychological coping, life meaning, and self-esteem, but less motivated by the competition. There were no previous research data on gender differences in the Polish running population. According to surveys, 39% of Polish runners are women (National Runners Register, 2014; Polska Biega and Gazeta Wyborcza, 2014). Thirty percent of Polish runners ran at least three times a week and 20% more ran at least once a week. Among all runners, only 7% indicated their intention to compete in mass distance running events, and most of these were of the age from 25 to 39 years (Activity of Poles, TNS Kantar, 2017). In our study, all athletes were focused on a future marathon race, so they clearly did not proportionally represent the general running population.

The gender differences in motivations —namely, that women exhibited a higher motivation on the weight concern, affiliation, psychological coping, life meaning, and self-esteem measures and lower interest in competition than men— were in agreement with previous findings. For instance, in one earlier study, male intercollegiate distance runners reported greater competitiveness than females (Deaner et al., 2015).

It is known that long-distance runners tend to have a specific body anthropometry, as a small stature and little body fat are generally considered better for this type of event (Legaz and Eston, 2005). Perfectionism in female runners has sometimes led to eating disorders, whereas male athletes did not account for a significant variance (Galli et al., 2014). It has also been shown that dissatisfaction with one's body due to its appearance or race performance was more prevalent in women than in men (Anderson et al., 2016).

The results obtained in our study with regard to affiliation, psychological coping, life meaning, and self-esteem seemed to differ from previous research. According to Ziegler (1991), women reported more than men that running had a positive effect on their self-image and indicated that life was much richer as a result of running. On the other hand, males were more likely to indicate that running allowed them to decrease anxiety, strengthened their sense of identity, made them feel less shy, or increased their perseverance. In another study, women reported greater benefits from running than men in terms of opportunities to meet people, relief from depression, and feeling less shy. Females also scored higher in the affiliation category and rated having company while training as more important than males did (Summers et al., 1983).

Gender differences among marathoners have also been described recently with regard to motivations, perceived control, and mental toughness based on the administration of the MOMS and the Sports Mental Toughness Questionnaire (Samson et al., 2015).

Limitations and Strengths of the Study

One limitation of this study involved the use of an online survey to obtain the data. We must be cautious in comparing these findings with those of studies that used paper and pencil questionnaires or interviews. However, recent studies reported that web-based surveys obtained nearly the same results as those administered using paper and pencil (Van De Looij-Jansen and De Wilde, 2008; Hohwu et al., 2013). A further limitation is that the MOMS was designed to specifically to assess the motives of marathon runners, but not of runners intending to compete in their first marathon. However, no other validated tool exists to investigate the motivations of potential marathon runners.

On the other hand, a key strength of the study is the large sample size and the novel study design, which compared experienced marathon runners with first-timers. In view of the enormous increase in marathon runners during recent decades (e.g., from 143,000 in 1980 to over 550,000 in 2014 in the United States) (Hammer and Podlog, 2016), the findings of the present study are of great practical relevance for strength and conditioning coaches working with runners.

CONCLUSION

The present study has contributed to our understanding of the factors motivating athletes who participate regularly in marathons and those training for their first marathon. It showed a significant influence of age and sex as well as the importance of the level of education, experience and training frequency. This knowledge can help us to grasp more clearly how the differing motivations of men and women affect their ability to sustain a long-term training commitment. However, our knowledge of the physical and social factors as well as the psychological motives of both recreational runners and experienced marathon finishers indicates that motivation is probably a fluid process. Observing patterns of inconsistency in motivation, along with the qualitative factors that characterize the daily training process and race preparations, may give coaches and physiotherapists better insight about their people and athletes. In long-distance and ultra-running, one of the most important challenges is to better understand how psychological support can best be provided to improve competitors' performance. Coaches should use their current knowledge to plan and implement training schedules and workloads. The findings confirmed that age and gender differentiate motivations in marathon finishers and control group. There was also significant relationship of some motivations with level of education, experience and training frequency which was a novel finding, suggesting that sport psychologists and strength and conditioning coaches should consider these factors when motivating their runners.

DATA AVAILABILITY

The datasets for this manuscript are not publicly available. Requests to access the datasets should be directed to Zbigniew Waskiewicz: z.waskiewicz@awf.katowice.pl.

ETHICS STATEMENT

All procedures were performed in accordance with the Polish law and were evaluated by the Bioethical Committee at the Jerzy Kukuczka Academy of Physical Education in Katowice, which granted official approval for the research (KB/47/17). The study was conducted in conformity with the Declaration of Helsinki. As online surveys or questionnaires do not require the completion of a separate participant information sheet or consent form, completion of the survey was deemed to constitute informed consent.

AUTHOR CONTRIBUTIONS

ZW, PN, DG, and BK contributed and conceived the study. ZW, ZB, DG, PN, and BK designed the study and drafted the manuscript. ZW collected, analyzed, and interpreted the data. PN, DG, TR, and BK revised the manuscript and approved the final version.

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Quality of Life, Depression, Anxiety Symptoms and Mood State of Wheelchair Athletes and Non-athletes: A Preliminary Study

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The present study aims to compare quality of life, depression, anxiety symptoms, and profile of mood state of wheelchair athletes and non-athletes. Thirty-nine basketball and rugby wheelchair athletes (n = 23, nine women, age 36.0 ± 10.0 years; body mass 66.2 ± 13.8 kg; height 170.0 ± 8.5 cm) and non-athletes (n = 16, 4 women, 39.0 ± 14.2 years; body mass 79.6 ± 17.2 kg; height 170.0 ± 6.4 cm) were recruited. Quality of life, anxiety and depressive symptoms and mood disorders were evaluated by the Medical Outcomes Short-Form Health Survey (SF-36), State-Trait Anxiety Inventory, Beck Depression Inventory and Profile of Mood State questionnaire, respectively. Comparison between groups (non-athletes vs. athletes) was performed using Student's t-test for independent samples. No differences ($p > 0.05$) were found between non-athletes vs. athletes regards to quality of life, depressive and anxiety symptoms and profile of mood state. Overall, non-athletes and athletes presented medium anxiety symptoms and mild to moderate depressive symptoms. In conclusion, the wheelchair athletes and non-athletes presented similar quality of life, depressive and anxiety symptoms, and profile of mood state.

Keywords: quality of life, depression, anxiety, mood state, wheelchair, athletes

INTRODUCTION

There is a growing number of people with disabilities (including wheelchair users) who participate in regular physical activity/sports programs with ludic and rehabilitation purposes as well as with elite sport performance purposes (Bhambhani, 2002; De Lira et al., 2010; Lee and Uihlein, 2019). Indeed, the participation of people with disabilities in sports is desirable, because it has a positive impact on social, psychological and physical aspects (Côté-Leclerc et al., 2017). Moreover, it is considered as a complementary strategy for physical, social and emotional rehabilitation, and consequently, could improve the quality of life (Blauwet and Willick, 2012; Lee and Uihlein, 2019). Furthermore, wheelchair sports consist a favorable opportunity for people with disabilities by increasing the possibility of social integration and physical, motor, psychological, and neurological rehabilitation (Lee and Uihlein, 2019).

Despite of indisputable benefits of exercise and sports for people with disabilities, there are some barriers that prevent the participation of people with disabilities (including wheelchair users) in adapted sports. These barriers could be divided into psychological, physical, physiologic, and environmental factors (Côté-Leclerc et al., 2017). For instance, Côté-Leclerc et al. (2017) pointed that physical and mobility limitations might restrict opportunities to perform sports and physical activity, which may affect quality of life. Regarding to psychological factors, in general, people with disabilities have low self-esteem and confidence, decreased motivation, increased depression and pain, and high stress level which affect negatively quality of life (Lee and Uihlein, 2019).

Previous meta-analysis showed that exercise can improve mental health (Ochentel et al., 2018; Rodriguez-Ayllon et al., 2019) and quality of life (Conn et al., 2009; Gillison et al., 2009; Sweegers et al., 2018) in healthy and clinical population. For example, Schuch et al. (2018) showed that exercise can confer protection against the emergence of depression regardless of age and geographical region. Conn et al. (2009) conducted a meta-analysis to investigate the effects of interventions to increase physical activity among adults with chronic illness in quality of life outcomes and found that, despite considerable heterogeneity in the magnitude of the effect, participants improved quality of life from exposure to interventions designed to increase physical activity. However, there are, so far as we are aware, few studies that investigated whether participation in adapted sports (particularly wheelchairs sports) affects the quality of life and emotional status of people with disabilities. For example, Muraki et al. (2000) demonstrated that sports activity can improve the psychological status in both tetraplegics and paraplegics with spinal cord injury, and the psychological benefits are emphasized by sports activity at high frequency.

Considering that about 10% of worldwide population (∼650 million people) have disabilities and that about 10% of people with disabilities require a wheelchair, studies that investigated the effects of exercise on mental health and quality of life of wheelchair are warranted (World Health Organization, 2011). Thus, the aim of the present study was to compare the quality of life, depressive and anxiety symptoms, and profile of mood state between wheelchair users practicing sports or not. The research hypothesis is that people with disabilities, especially those wheelchair users that not practicing sports, would present poor levels of quality of life, anxiety and depressive symptoms, a negative profile of mood state as compared with wheelchair users practicing sports.

MATERIALS AND METHODS

Participants

Basketball and rugby wheelchair athletes and non-athletes participated in this study. Due to difficulties in recruiting and assessing wheelchair users (sports and/or non-sports practitioners), the sample consisted of people of both sexes with different types of affections (the most commons were spinal cord injury and neurological diseases).

Initially, 50 wheelchair users (25 athletes and 25 non-athletes) were invited to participate. However, two athletes and nine non-athletes did not accept or gave up participation in the study. Thus, the final sample was constituted by 39 participants (26 men and 13 women), 23 in the athlete group (14 men and nine women) and 16 in the non-athlete group (12 men and four women). The athlete group were recruited from the teams (basketball and rugby wheelchair) of the *Physical Rehabilitation Center of Espírito Santo (Espírito Santo, Brazil)*. Regarding to physical training characteristics of athletes group, 11 (47.8%) trained 3 h and 3 days/week, 2 (8.7%) trained 3 h and 6 days/week, 6 (26.1%) trained 4 h and 3 days/week, 3 (13%) trained 5 h and 3 days/week, and 1 (4.3%) trained 6 h and 3 days/week. Relative to participation in competitions, 19 (82.6%) had participated and 4 (17.4%) had not participated. Participants in the non-athlete group did not practice sports.

The participants of the non-athlete group were recruited from several places, such as therapeutic centers, rehabilitation clinics, universities and private companies. Age, body mass and height were self-reported by the participants at the interview time application (**Table 1**). Concerning the athletes, 23 people were interviewed being: 9 (39.1%) practitioners of wheelchair rugby and 14 of wheelchair basketball (60.9%); 9 were women (39.1%) and 14 (60.9%) were men; 12 (52.2%) were unmarried, 6 (26.1%) married, 3 (13%) divorced and 2 (8.7%) maintained a stable union; 5 (21.7%) had work and 18 (78.3%) were unemployed/retired; and 4 (17.4%) had incomplete elementary education, 3 (13%) had only completed elementary education, 1 (4.3%) had incomplete secondary education, 12 (53.2%) had high school and 3 (13%) were either attending or had completed higher education.

For the non-athletes, 16 people were interviewed, being: 12 (75%) males and 4 (25%) females; 11 (68.8%) were unmarried, 4 (25%) were married and 1 (6.3%) were divorced; 4 (25%) worked and 12 (75%) were unemployed/retired; and 1 (6.3%) had incomplete elementary education, 2 (12.5%) had completed elementary education, 6 (37.5%) had completed high school, 4 (25.5%) had incomplete 1 (6.3%) had completed higher education. Both groups (non-athletes and athletes) presented similar socio-demographic characteristics (**Table 2**).

All participants were informed about the aims, procedures, possible discomforts, risks and benefits of the study, and signed the informed consent form. All the experimental procedures were submitted and approved by the Ethics Committee of the Federal

TABLE 1 | General characteristics of the non-athlete and athlete groups.

	Non-athlete group (*n* = 16)			Athlete group (*n* = 23)			*p*-value
	Mean ± SD	**Median [q1-q3]**	**Min-Max**	**Mean ± SD**	**Median [q1-q3]**	**Min-Max**	
Age (years)	39.0 ± 14.2	33 [30–51]	20–67	36.0 ± 10.0	35 [30–38]	19–57	0.461
Body mass (kg)	79.6 ± 17.2	76 [65–90]	53–115	66.2 ± 13.8*	66 [56–72]	38–106	0.014
Height (cm)	170.0 ± 6.4	170 [165–175]	162–182	170.0 ± 8.5	170 [165–174]	148–181	0.564

*SD, standard deviation. *Significant different from non-athlete group.*

TABLE 2 | Socio-demographic characteristics of non-athlete and athlete groups.

	Non-athlete group (*n* = 16)	Athlete group (*n* = 23)	Statistics	*p*-value
Sex				
Men (*n* = 26)	12(46.2%)	14(53.8%)	$X^2(1) = 0.848$	0.357
Women (*n* = 13)	4(30.8%)	9(69.2%)		
Marital status				
Single (*n* = 23)	11(47.8%)	12(52.2%)		0.520
Married (*n* = 10)	4(40%)	6(60%)	$X^2(3) = 2.260$	
Divorced (*n* = 4)	1(25%)	3(75%)		
Stable union (*n* = 2)	0(0%)	2(100%)		
Work				
Yes (*n* = 9)	4(44.4%)	5(55.6%)	$X^2(1) = 0.057$	0.812
No (*n* = 30)	12(40%)	18(60%)		
Education level				
Elementary school (*n* = 11)	3(27.3%)	8(72.7%)		0.538
High school (*n* = 22)	10(45.5%)	12(54.5%)	$X^2(2) = 1.238$	
Higher education (*n* = 6)	3(50%)	3(50%)		

University of Espírito Santo (CAAE: 70119817.3.0000.5542 and protocol number: 2.182.183) and are in accordance with the Declaration of Helsinki.

Research Procedures

This was a cross-sectional study conducted in 1 day. Both groups (athletes and non-athletes groups) answered the following questionnaires in this order: (i) a questionnaire for collecting demographic and exercise characteristics data; (ii) Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36); (iii) State-Trait Anxiety Inventory (STAI); (iv) Beck Depression Inventory (BDI); and (v) Profile of Mood State questionnaire (POMS) in order to evaluate demographic and exercise characteristics (weekly frequency, duration and workload), health-related quality of life, anxiety symptoms, depressive symptoms, and profile of mood state, respectively.

Quality of Life Assessment

The perception of quality of life was evaluated using the SF-36, translated and validated for Brazilian Portuguese by Ciconelli et al. (1999). The SF-36 is a widely used, generic questionnaire that comprises eight subscales: functioning capacity (10 items), role limitations due to physical problems (four items), pain (two items), general health perceptions (five items), vitality (four items), social functioning (two items), role limitations due to emotional problems (three items), and mental health (five items). In addition, a single item provides an indication of perceived change in health (Ware and Sherbourne, 1992). Subscale scores range from 0 to 100, with 100 being the best, most positive, quality of life on the subscale measured and 0 the worst. The questionnaire was conducted as an interview. Internal consistency of the SF-36 is good, with Cronbach's alpha ranging from 0.76 to 0.90 for all subscales of the questionnaire (Jenkinson et al., 1994). Froehlich-Grobe et al. (2008) showed that the SF-36 successfully measures (good fit) health-related quality of life among mobility-impaired individuals, including wheelchair users.

Assessment of Anxiety and Depressive Symptoms

To assess the anxiety symptoms, the STAI, translated and adapted into Brazilian Portuguese by Biaggio et al. (1977), was used. Briefly, the questionnaire consists of two different scales of anxiety, one that evaluates state and another that evaluates trait. The trait-scale consists of 20 statements related to how the participant usually feels, and state-scale consists of 20 statements regarding the current situation of the participant. Both scales classify the participant as having low, medium or high levels of anxiety. Scores can vary from of 20 to 80. A score $\leq$ 30 indicates a low level of anxiety, a score between 31 and 49 a medium level, and a score equal to or greater than 50 a high level of anxiety. Internal consistency coefficients for the scale range from 0.86 to 0.95; and test-retest reliability coefficients range from 0.65 to 0.75 over a 2-month interval (Spielberger et al., 1983).

To assess the depressive symptoms, the BDI, translated and adapted to Brazilian Portuguese by Gorenstein and Andrade (1996), was used. BDI is one of the most frequently used questionnaires to evaluate the severity of depressive symptoms. This instrument has 21 questions about symptoms of depression that cover affective, behavioral, somatic and interpersonal aspects. Each item consists of a series of four statements scaled to indicate increasing depressive symptomatology. The classification of the score ranges from normal to mild, mild to moderate and moderate to severe depressive symptoms. Scores below 9 are considered normal, whereas scores between 10 and 18 indicate mild to moderate depressive symptoms, 19 to 29 indicate moderate to severe depressive symptoms, and 30 to 63 severe depressive symptoms. Internal consistency of BDI ranges from 0.81 (for students) to 0.88 (for depressed patients) (Beck et al., 1979; Gorenstein and Andrade, 1996).

Profile of Mood State Evaluation

Mood state was assessed by the POMS (Morgan et al., 1987, 1988; Peluso and Guerra de Andrade, 2005), which is a self-report, global mood measure comprising 65 items across six categories: anxiety-tension, depression, anger-hostility, vigor, fatigue, and confusion and scored from 1 to 4 according to severity. The questionnaire yields a global measure of mood. The global score is computed by subtracting the positive category (vigor) from the sum of the five negative categories (tension, depression, anger, fatigue, and confusion). The number 100 was added to the final TMD score to avoid negative results (Legey et al., 2016).

Statistical Analysis

Data was presented as mean, median, interquartile range, standard deviation, minimum, and maximum. The normality was evaluated by the Shapiro–Wilk test. As the data presented normal distribution, comparison between groups (non-athletes vs. athletes) was performed using Student's t-test for independent samples. Chi-square tests were performed on categorical variables (socio-demographic characteristics and signs and symptoms of depression and anxiety) to determine differences in proportion between the non-athletes vs. athletes. The level of significance adopted in all analyzes was 5% with the 95% confidence interval. The Statistical Package for the Social Sciences (SPSS) version 21.0 (IBM Corp., Armonk, NY, United States) was used for all statistical analysis.

RESULTS

Regarding to the evaluation of quality of life, depressive and anxiety symptoms and profile of mood state, no significant differences were found between the mean scores of the non-athlete and athlete groups (**Tables 3**, **4**). Nevertheless, the values of the domains of quality of life evaluated, in general, were numerically higher for the athlete group. However, this pattern was not repeated for depressive and anxiety symptoms and profile of mood state.

Regarding to non-athlete group, 37.5% (n = 6), 25.0% (n = 4), 18.8% (n = 3), and 18.8% (n = 3) presented normal, slight, slight to moderate, and moderate to severe depressive symptoms, respectively. For anxiety-Trait and State of the non-athlete group, 12.5% (n = 2) and 25.0% (n = 4), 81.3% (n = 13) and 68.8% (n = 11), and 6.3% (n = 1) and 6.3% (n = 1) presented low, mild and high levels, respectively. Relative to athlete group, 39.1% (n = 9), 30.4% (n = 7), 21.7% (n = 5), and 8.7% (n = 2) presented normal, slight, slight to moderate and moderate to severe depressive symptoms, respectively. Concerning to anxiety-trait of the athlete group, 21.7% (n = 5), 65.2% (n = 15), and 13.0% (n = 3) presented low, medium and high levels, respectively. For anxiety-State of the athlete group, 95.7% (n = 22) and 4.3% (n = 1) presented mild and high levels, respectively.

Chi-square test revealed a significant difference in the proportion between the non-athletes vs. athletes with low, medium and high anxiety-State (**Table 5**); however, no significant differences were found between non-athletes and athletes in anxiety-Trait, depressive symptoms (**Table 5**) or socio-demographic characteristics (**Table 2**).

DISCUSSION

The aim of the present study was to evaluate the quality of life, depression and anxiety symptoms and profile of mood state of wheelchair users that practicing sports or not. The research hypothesis is that people with disabilities, especially those wheelchair users that not practicing sports, would present poor levels of quality of life, anxiety and depressive symptoms, and a negative profile of mood state as compared with wheelchair users practicing sports. However, we did not find significant differences between the non-athlete and athlete groups. Despite this, it is important to briefly describe the characteristics of our sample. We observed that athlete group had a statistically significant lower body mass than non-athlete group, which is a positive feature.

Concerning quality of life, the athlete group, in general, presented higher values in almost all factors evaluated. We can highlight the factors functional capacity and limitations by physical aspects. Regarding the anxiety-Trait and State levels, by the general mean of the non-athlete and athlete groups, we can observe that both groups present medium levels. With regard to depressive symptoms, by the general mean of the non-athlete and athlete groups, both groups present mild to moderate depression levels. Finally, with respect to the profile of mood state the athlete and non-athlete groups presented similar levels of vigor.

The participation in sports by people with disabilities can positively impact health status, levels of quality of life, physical fitness and psychological and emotional state (Bhambhani, 2002; De Lira et al., 2010; Blauwet and Willick, 2012; Côté-Leclerc et al., 2017; Lee and Uihlein, 2019). Kawanishi and Greguol (2013) performed a systematic review with the aim to study the influence of physical activity on the quality of life and functional independence of adult individuals with spinal cord

TABLE 3 | Quality of life profile (SF-36) of non-athlete and athlete groups.

SF-36 domains	Non-athlete group (*n* = 16)			Athlete group (*n* = 23)			*p*-value
	Mean ± SD	Median [q1-q3]	min-max	Mean ± SD	Median [q1-q3]	min-max	
Functional capacity	44.4 ± 28.1	47 [13–71]	0–80	56.3 ± 23.6	55 [45–70]	5–100	0.160
Limitations by physical aspects	54.6 ± 34.4	62 [25–75]	0–100	65.2 ± 39.7	75 [25–100]	0–100	0.396
Pain	71.1 ± 25.2	73 [51–96]	22–100	72.0 ± 19.5	72 [51–80]	51–80	0.591
General health status	73.1 ± 22.9	77 [52–95]	27–100	77.0 ± 22.7	87 [62–97]	20–100	0.607
Vitality	68.4 ± 18.3	75 [55–80]	35–100	69.3 ± 18.6	75 [65–80]	20–95	0.881
Social aspects	72.6 ± 22.9	62 [50–100]	37–100	80.0 ± 25.2	87 [75–100]	12–100	0.332
Limitations due to emotional problems	66.7 ± 34.4	66 [50–100]	0–100	73.9 ± 46.2	100 [33–100]	0–100	0.537
Mental health	79.5 ± 12.3	78 [72–91]	60–100	79.4 ± 16.0	84 [76–88]	20–100	0.996

SF-36: short form 36 questionnaire. SD, standard deviation.

TABLE 4 | Profile of mood state (POMS) and depressive and anxiety symptoms of non-athlete and athlete groups.

	Non-athlete group (*n* = 16)			Athlete group (*n* = 23)			*p*-value
	Mean ± SD	Median [q1-q3]	min-max	Mean ± SD	Median [q1-q3]	min-max	
POMS							
Tension-anxiety	4.8 ± 4.5	5[2 – 6]	–2–15	4.0 ± 6.6	2[0 – 5]	–3–26	0.675
Depression	2.6 ± 2.9	2[0.25 – 4]	0–9	5.3 ± 10.5	1[0 – 4]	0–45	0.332
Anger-hostility	6.5 ± 4.3	6[3 – 11]	0–14	7.4 ± 9.8	4[1 – 11]	0–44	0.712
Vigor	18.7 ± 5.0	20[15 – 21]	0–10	19.2 ± 5.3	20[18 – 24]	7–29	0.786
Fatigue	4.1 ± 2.7	4[2 – 5]	0–10	4.7 ± 5.4	3[1 – 7]	0–22	0.660
Confusion	1.1 ± 2.6	1[0.75 – 2]	–3–6	2.0 ± 5.0	0[-1-5]	–4–17	0.528
Disturbance mood total score	100.5 ± 13.2	102[94 – 111]	73–118	104.4 ± 38.3	92[80 – 110]	74–247	0.656
Anxiety-Trait	40.0 ± 7.3	41[35 – 45]	25–51	37.8 ± 10.3	36[31 – 43]	23–71	0.476
Anxiety-State	36.6 ± 7.8	35[30 – 41]	24–57	37.5 ± 6.8	35[33 – 39]	31–60	0.706
Depressive symptoms	12.8 ± 6.4	11[7 – 18]	4–23	13.3 ± 7.3	13[9 – 16]	3–36	0.821

SD, standard deviation.

TABLE 5 | Classification of signs and symptoms of depression and anxiety of non-athlete and athlete groups.

	Non-athlete group (*n* = 16)	Athlete group (*n* = 23)	Statistics	*p*-value
Depressive symptoms				
Normal (*n* = 15)	6 (40.0%)	9 (60.0%)		
Slight (*n* = 11)	4 (36.4%)	7 (63.6%)	$X^2(3) = 0.890$	0.828
Slight to moderate (*n* = 8)	3 (37.5%)	5 (62.5%)		
Moderate to severe (*n* = 5)	3 (60.0%)	2 (40.0%)		
Anxiety-Trait				
Low (*n* = 7)	2 (28.6%)	5 (71.4%)		
Medium (*n* = 28)	13 (46,4%)	15 (53.6%)	$X^2(2) = 1.211$	0.546
High (*n* = 4)	1 (25.0%)	3 (75.0%)		
Anxiety-State				
Low (*n* = 4)	4 (100%)	0 (0%)		
Medium (*n* = 33)	11 (33.3%)	22 (66.7%)	$X^2(2) = 6.624$	0.036
High (*n* = 2)	1 (50.0%)	1 (50.0%)		

injury (including wheelchair users). They found that this strategy has an important influence on social relationships, functional independence, psychological factors, and physical aspects, which can enhance quality of life and independence in the performance of daily activities.

In our study, although we found no significant differences between the groups that practiced and did not practice sports, this does not mean that the practice of sports has no beneficial effect on the quality of life and emotional well-being of wheelchair users. Richardson et al. (2017)

demonstrated that sports participation in wheelchair tennis players may be a viable means to promote and enhance psychosocial well-being. These authors pointed out that skills learnt "on court" are transferrable to everyday life potentially improving independence and quality of life.

de Groot et al. (2013) showed that wheelchair users with a spinal cord injury (which, although not controlled, was the expressive part of our sample) generally had a relatively inactive lifestyle and they demonstrated that this situation was associated with a lower fitness level, poorer health, reduced social participation and a lower quality of life. However, an active lifestyle often requires a change in attitude or behavior and general practitioners, other primary healthcare providers and rehabilitation professionals can help in this respect.

Côté-Leclerc et al. (2017) showed that people with mobility limitations (9 women and 25 men with paraplegia, the majority of whom worked and played an individual adapted sport such as athletics, tennis or rugby at an international or national level, playing adapted sports and people without limitations had a similar quality of life. The authors demonstrated that participation in adapted sports was identified as having positive effects on self-esteem, self-efficacy, sense of belonging, participation in meaningful activities, society's attitude toward people with mobility limitations, and physical well-being.

Although it was not possible to fully control the affections of the participants of the present study, a large part of the sample consisted of spinal cord injuries (i.e., tetraplegic and paraplegic). In this sense, Tweedy et al. (2017) showed that traumatic spinal cord injury may cause tetraplegia (i.e., motor and/or sensory nervous system impairment of the arms, trunk, and legs) or paraplegia (i.e., motor and/or sensory impairment of the trunk and/or legs only), which can lead to large negative effects on health, fitness and functioning and consequently to the sedentary behavior. In this sense, the benefits of practicing sport and physical exercise including reduced risk of depression and improvement of quality of life and functional independence which in a way we observed in our study despite the fact that it did not find statistical significance between groups of wheelchair users who practiced sports or not.

Finally, Muraki et al. (2000) examined whether the psychological benefits of sports activity differ between tetraplegics (i.e., poor mobility) and paraplegics with spinal cord injury. No significant difference was found for any psychological measurements between tetraplegics and paraplegics. However, they concluded that sports activity can improve the psychological status, irrespective of tetraplegics and paraplegics, and that the psychological benefits are emphasized by sports activity at high frequency.

Study Limitations

Our study is not without limitations. Firstly, a factor that may have influenced the results is that the population of wheelchair used is very heterogeneous (both groups were composed of men and women) in terms of the causes and type and time of injury (which could not be controlled). Thus, studies with more homogeneous samples and group people by type of injury/affections are need. Also, the athlete wheelchairs were recruited from several places, such as therapeutic centers, rehabilitation clinics, universities and private companies. These are spaces of inclusion and social/health attention as well as the scenarios of the practice of sport. Nevertheless, all these limitations could consider non-fatal, since these are inherent difficulties in studies in this area.

CONCLUSION

In conclusion, the wheelchair athletes and non-athletes presented similar quality of life, depressive and anxiety symptoms and profile of mood state.

DATA AVAILABILITY

The datasets for this manuscript are not publicly available because the data are available on request from RLV. Requests to access the datasets should be directed to rodrigoluizvancini@gmail.com.

ETHICS STATEMENT

All participants were informed about the aims, procedures, possible discomforts, risks, and benefits of the study, and signed the informed consent form. All the experimental procedures were submitted and approved by the Ethics Committee of the Federal University of Espírito Santo (CAAE: 70119817.3.0000.5542 and protocol number: 2.182.183) and are in accordance with the Declaration of Helsinki.

AUTHOR CONTRIBUTIONS

RLV, AG, HdPO, and CdL conceived and designed the study, collected the data, performed the statistical analysis, and drafted, edited, and revised the manuscript. WR-T, MA, KS, and MS collected the data, and drafted and revised the manuscript. RBV drafted, edited, and revised the manuscript. PN, TR, and BK edited and revised the manuscript.

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Training Load, Aerobic Capacity and Their Relationship With Wellness Status in Recreational Trail Runners

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The present study aimed to analyze the relationship between variables related to the internal and external loads of training and competition races as well as to athletes' perceptions of well-being measured throughout the course of a 4-week mesocycle. It also aimed to analyze the intra- and inter-week variations in terms of training load and well-being. The study included the participation of 47 male recreational athletes competing in the national championships of trail running in Portugal (age: 34.85 ± 8.88 years; height: 1.77 ± 0.58 m; body mass: 65.89 ± 3.17 kg). During the 4 weeks, subjective perception of effort (RPE), training time (min), session-RPE (sRPE), distance covered (km), and perception of well-being (Hooper's questionnaire) were monitored. Weekly RPE was greater in week 1 than in week 3 ($p = 0.001$; $d = 0.563$, small effect). Moreover, weekly sRPE was greater in week 1 than in week 2 ($p = 0.001$; $d = 0.441$, small effect). The correlations between the well-being variables and RPE that were found to be significant with small magnitudes are those between sleep and RPE ($r = 0.287$; $p = 0.001$), stress and RPE ($r = 0.217$; $p = 0.001$), fatigue and RPE ($r = 0.191$; $p = 0.001$), muscle soreness and RPE ($r = 0.240$; $p = 0.001$), and Hooper's index and RPE ($r = 0.279$; $p = 0.001$). Among the variables of the Cooper test and the competition race load, it was verified that VO_{2max} had a negative correlation of an average magnitude with pace ($r = -0.396$, $p = 0.015$). The findings of the study suggest that small variations in training stimulus during the period of analysis and increases in maximal oxygen uptake result in improvements in the performance of trail running athletes when considering the running speed in the race.

Keywords: training monitoring, session-rated of perceived exertion, global positioning system, performance, sports training

INTRODUCTION

Changes in training load – particularly in the frequency, duration, and intensity of training sessions – are associated with the principle of training stimulus variability that seeks to optimize sports performance (Halson, 2014a). Training load monitoring can be categorized into two forms: external load and internal load (Malone et al., 2015). External load is understood as the physical repercussions of training performed by an athlete, encompassing indicators such as distance, duration, and race intensity (Impellizzeri et al., 2005). Internal load is associated with the biological response of the athlete to the external load imposed by training (Bourdon et al., 2017).

In the training's prescription, it is essential that the external and internal loads be appropriate and that there is a balance between them, allowing for improvements in the performance of the athlete and for the reduction of overload or underload (Bartlett et al., 2017). The correct planning of the training load through microcycles allows an approximation of the training regarding the requirements of races (Phibbs et al., 2018), causing fundamental specific adaptations in the athlete (Manzi et al., 2010).

The monitoring of training loads requires an accurate and reliable evaluation of the determinants of the training process (Roos et al., 2013). However, the use of different methods and/or techniques is dependent on the context, namely considering the applicability and the resources. As an example, the internal load can be more objectively measured by using heart rate sensors or collecting a blood sample to determine the blood lactate (Twist and Highton, 2013). However, such methods are somehow invasive or not practical in some contexts. On the other hand, subjective scales of intensity (e.g., rated of perceived exertion) have been presenting very good levels of validity and reliability, are less invasive and more practical in realistic training scenarios (Haddad et al., 2017). Similarly, the external load quantification is also dependent on the context and will provide different information than internal load, mainly considering specific sports that require a great perception of the pace and intensity of running. For these cases, the global positioning systems are often used considering that may provide complementary information to coaches and athletes (Halson, 2014a).

Despite the unquestionable importance of quantification of the load to regulate the training process, the monitoring cycle of athletes does not finish with a simple quantification of the load. Other parameters related with the impact of the training stimulus on athletes are also a part of the monitoring process, namely considering the well-being parameters that include, among others, the perception of delayed onset muscle soreness (DOMS), fatigue, stress, or sleep quality (Hooper and Mackinnon, 1995). In this sense, the literature refers to well-being questionnaires as a good indicator of the evaluation of these variables, and the Hooper questionnaire (Hooper and Mackinnon, 1995) as being pointed out as a good tool to estimate the impact and to manage the dose of training in athletes.

Despite a great number of publications considering the training load quantification and well-being determination, the great majority of the studies are related to team sports (Roos et al., 2013; Malone et al., 2017) while just a few, to the best of our knowledge, are dedicated to individual sports (Stellingwerff, 2012; Hernández-Cruz et al., 2017). Among individual sports, the trail running practice has been increasing in the last few years and is a sport with an apparent necessity of load management considering the great distances covered by the athletes. This sport can be characterized as a mountain run (Saugy et al., 2013) with race distances that may vary according to the type of competition, ranging between 10 and 894 km (Rowlands et al., 2012). Trail running races are competitions that can last for several hours or even days because of accumulated unevenness and terrain specificity, with times varying from athlete to athlete (Easthope et al., 2014).

Due to the specificity of trail running, researches have been carried out to characterize the load and the physiological requirements derived from races (Vernillo et al., 2016). Usually, maximal oxygen uptake between 60 and 85 $ml \cdot kg^{-1} \cdot min^{-1}$ can be found in this type of athletes (Gordon et al., 2017). Therefore, it seems reasonable to assume that the training process should be adjusted to the requirements of the race and must be properly varied during the weeks aiming to fit the load with the performance expectations of the athletes. Despite this necessity, there is a lack of evidence about how athletes manage and apply the load. This is particularly important because a great number of these athletes are non-professional (recreational) and for that reason, it is important to characterize how they manage the load during the training and identify the variations of well-being parameters during the week.

To the best of our knowledge, no information has been reported about the intra- and inter-week variations of training load and well-being of trail runners. Based on that, the first purpose of our study was to characterize the training load (internal and external) and well-being parameters of trail runner athletes during a mid-season and competitive mesocycle of 4 weeks. As the second purpose of this study, we tested possible relationships (correlations) between aerobic capacity of athletes (estimated by a field-based test), performance in races (pace), and the training load variables, aiming to determine if the training process (namely intensity and volume) can be associated with the aerobic capacity and performance of these recreational athletes.

MATERIALS AND METHODS

Participants

Forty-seven Portuguese male trail running athletes (average age = 34.85 ± 8.88 years; height: 177.34 ± 5.81 cm; weight: 65.89 ± 3.17 kg; experience: 4.72 ± 2.11 years) participated in this study. On average, the athletes covered 35,159 m and trained for over 206 min per week. The absence of injuries during the study and the accomplishment of at least one and at most three races of the national championship of trail running were the criteria of inclusion. All participants provided informed consent in accordance with the recommendations of the Declaration of Helsinki for human study. The study was also approved by the local ethical committee (Polytechnic Institute of Viana do Castelo, School of Sport and Leisure) with the code number IPVC-ESDL171003.

Design

The external and internal loads and the well-being of trail running athletes were monitored throughout the month of

November 2017, during which 26 athletes participated in races of the national trail running championships. Despite participating in national trail running championships, the category of these athletes is recreational based on the fact that they are not professional and perform three sessions/week or less. However, for inclusion in this study, those reported less than three sessions per week were excluded from the analysis. From the athletes that participated in races, 65.4% competed in one race, 23.1% in two races, and 11.5% in three races. The races varied from a minimum of 10 km to a maximum of 300 km. The pace (min/km) made by the athletes during each race was collected to further correlations between aerobic capacity (as indicator of fitness level) and performance in race. In the week before the training load and well-being monitoring started, the 12-min Cooper test was implemented. During the training mesocycle, athletes were required to fill out the Hooper questionnaire before training sessions and races and to fill out the Borg scale after the end of training sessions and races. Both questionnaires were completed using an online form. External load was monitored using GPS (Global Positioning System) devices.

Data Collection: Global Positioning System

During the training sessions, the athletes used watches with GPS technology, enabling the collection of information regarding horizontal movement. The Polar V800 (37 mm × 56 mm × 12.7 mm and weight: 79 g) (Roos et al., 2017) was used based on its validity for the collection of positional information.

Hooper Index

The Hooper index (HI) questionnaire for assessing athletes' well-being was administered individually, 30 min before training sessions and races, for the variables of sleep quality, stress, fatigue, and muscle soreness. Answers were given using scales of 1–7. For the variables of fatigue, stress, and muscle soreness, 1 = very, very low, and 7 = very, very high. For sleep quality, 1 = very, very bad and 7 = very, very good (Hooper and Mackinnon, 1995).

Rated of Perceived Exertion

The rated of perceived exertion (RPE) quantified by using the CR-10 Borg's scale (Borg, 1998) was used as a measure of exercise intensity. On the CR-10 Borg's scale, the 1 = very, very easy and 10 = extremely hard. The CR-10 Borg's scale was firstly introduced to the participants aiming to familiarize them with the scale. After that, they have used the scale for 2 weeks without including the data in the study just aiming to increase the familiarization and the accuracy of the athlete's answers.

After such period, and during the data collection, the athletes scored the RPE 30 min after the end of training session in a dedicated online form built for the effect. Moreover, they reported the time of the session in minutes. Using both information (i.e., RPE score and time of the session), it was possible to determine the session-RPE (sRPE) that represents the overall internal load of the session by multiplying the RPE score for the time of the session in minutes (Foster et al., 2001). The sRPE has been used as a valid and reliable measure of internal load (Haddad et al., 2017). The data were collected in all training sessions that occurred in the period of data collection, thus the sRPE was calculated on a daily basis.

The 12-min Cooper Test

A Cooper test with a duration of 12 min was performed for the estimation of cardiorespiratory capacity and the maximal oxygen uptake (VO_{2max}). The test was performed while athletes were running or walking without interruption, and the total distance covered in the 12 min was recorded. All the participants reported previous experience and familiarization in this specific test, considering their previous participation in performance assessments.

A 5-min warm-up run was performed with a 10-min interval between the warm-up run and the test. All athletes performed the test in the same place between 10:00 a.m. and noon, with no precipitation at a temperature of 14°C and with a relative humidity of 45%. The test took place 72 h after the previous race or training session. The test was performed in an official athletic track and the distance covered by each athlete was collected immediately after the 12-min Cooper test. The distance covered (m) was one of the measures associated with the performance in the Cooper test. Moreover, using the distance on the Cooper test and the equation proposed in Bandyopadhyay (Bandyopadhyay, 2014), the maximal oxygen uptake of the athletes was estimated.

Data Analyses and Statistics

Descriptive statistics were presented in the form of mean, standard deviation, and 95% confidence intervals (presented in the **Figures 1–4**). The weekly RPE and well-being variables were treated as the average of the RPE and well-being variables in each week for each athlete and then integrated into the mean of the participants (**Figures 3, 4**). The weekly accumulated load and well-being [sum of the arbitrary units (A.U.) of all sessions of each week] were also calculated for each athlete and then integrated into the mean of the participants (**Figures 1, 2**).

Inter-week (comparisons of the weekly average of each measure between the 4 weeks) and intra-week (comparisons of the 4 weeks' average of each measure in each training session) comparisons were tested with one-way repeated-measures ANOVA after confirmation of the assumptions of normality and homogeneity of the samples. The partial eta squared (η^2) tested the effect size of the repeated-measures ANOVA. The magnitude inferences of η^2 were defined as (Ferguson, 2009): no effect ($\eta^2 < 0.04$), small effect ($0.05 < \eta^2 < 0.25$), moderate effect ($0.26 < \eta^2 < 0.64$), or strong effect ($\eta^2 > 0.65$). The Tukey HSD *post hoc* test and the Cohen's *d* tested the significances and the effect size of differences between factors. The following magnitude inferences were made for the Cohen's *d*: 0.0–0.2, trivial effect; 0.2–0.6, small effect; 0.6–1.2, moderate effect; and 1.2–2.0, large effect.

For the study of associations between well-being variables, training load; aerobic capacity; and the race performance, Pearson's r test was performed. In the particular case of correlations tested with the performance in the races, it was used a mean of the pace of each participant in the races in he has participated. According to the Hopkins classification followed for the study of the magnitude of correlations, correlation values were classified as follows (Hopkins et al., 2009): [0.0,0.1], trivial; (0.1,0.3], small; (0.3,0.5], moderate; (0.5,0.7], large; (0.7,0.9], very large; and (0.9,1.0], nearly perfect. Statistical procedures were performed in the statistical software SPSS (IBM, USA, version 23.0) for a significance level of 5%.

RESULTS

Intra- and Inter-Week Variations of Training Load and Well-Being

The descriptive statistics of accumulated (sum of the sessions of each week) training load parameters and well-being variables can be found in **Figures 1, 2**, respectively.

Inter-week (changes between weeks) differences for the weekly average of RPE (p = 0.011; η^2 = 0.078, small effect) and sRPE (p = 0.025; η^2 = 0.065, small effect) were found. Weekly RPE was greater in week 1 than in week 3 (p = 0.001; d = 0.563, small effect). Moreover, weekly sRPE was greater in week 1 than in week 2 (p = 0.001; d = 0.441, small effect). No significant changes in weekly duration (p = 0.12; η^2 = 0.40, no effect) and distance (p = 0.062; η^2 = 0.062, small effect) were found.

No significant changes were found in weekly sleep (p = 0.389; η^2 = 0.030, no effect), weekly stress (p = 0.537; η^2 = 0.022, no effect), weekly fatigue (p = 0.319; η^2 = 0.035, no effect), and weekly muscle soreness (p = 0.562; η^2 = 0.020, no effect).

Intra-week (changes within week) analysis of training load and well-being parameters can be found in **Figures 3, 4**, respectively. Repeated-measures ANOVA did not reveal significant changes between the training sessions of the week in the distance (p = 0.618; η^2 = 0.002, no effect), duration (p = 0.303; η^2 = 0.005, no effect), RPE (p = 0.751; η^2 = 0.001, no effect), and internal load (p = 0.915; η^2 = 0.001, no effect).

Intra-week comparisons of well-being variables also revealed no significant changes between training session in sleep quality (p = 0.776; η^2 = 0.001, no effect); stress (p = 0.233; η^2 = 0.006, no effect); fatigue (p = 0.557; η^2 = 0.002, no effect); muscle soreness (p = 0.852; η^2 = 0.001, no effect); and Hooper index (p = 0.733; η^2 = 0.001, no effect).

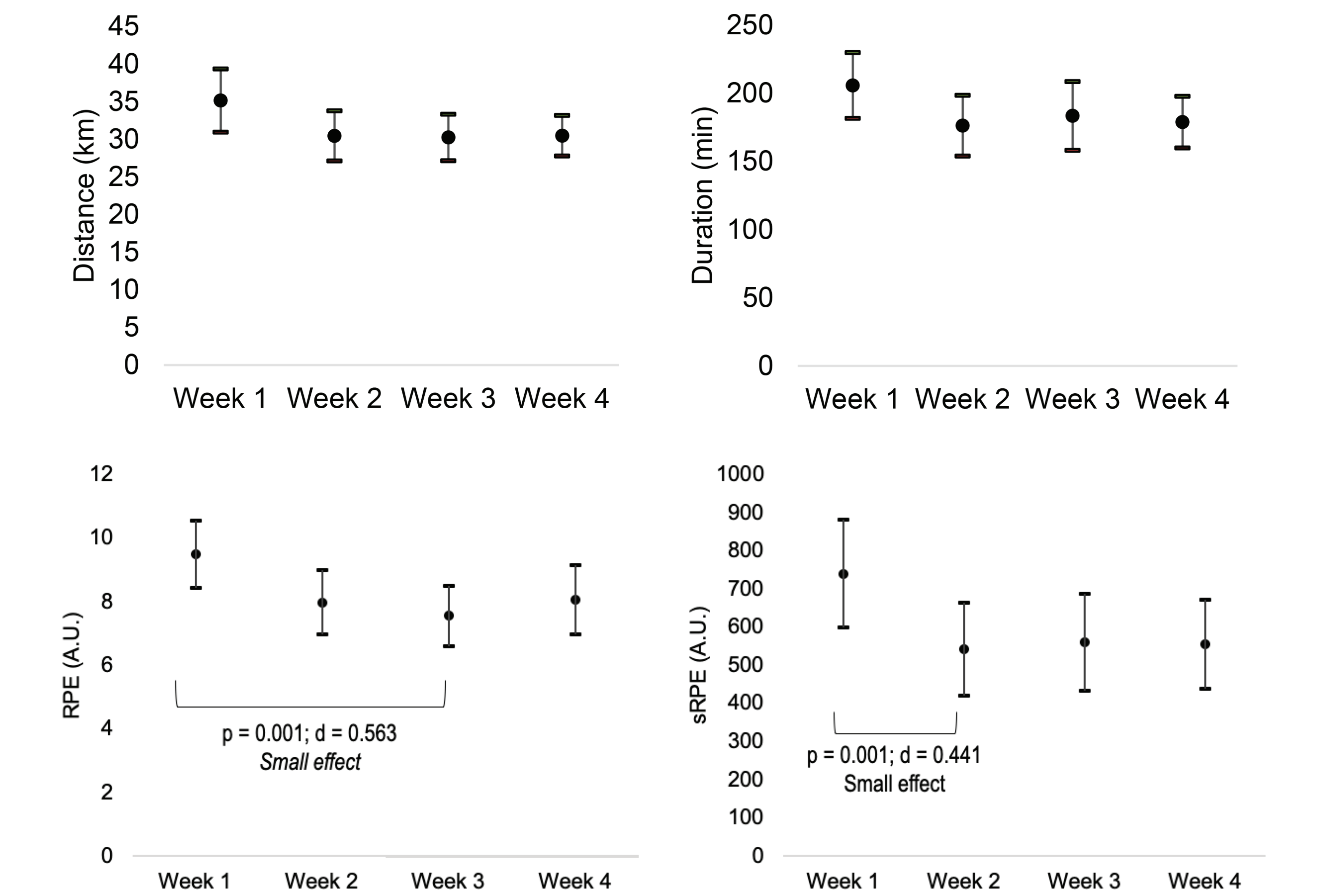

FIGURE 1 | Weekly variations of accumulated (sum of the A.U. of all sessions of each week) RPE and session-RPE (sRPE).

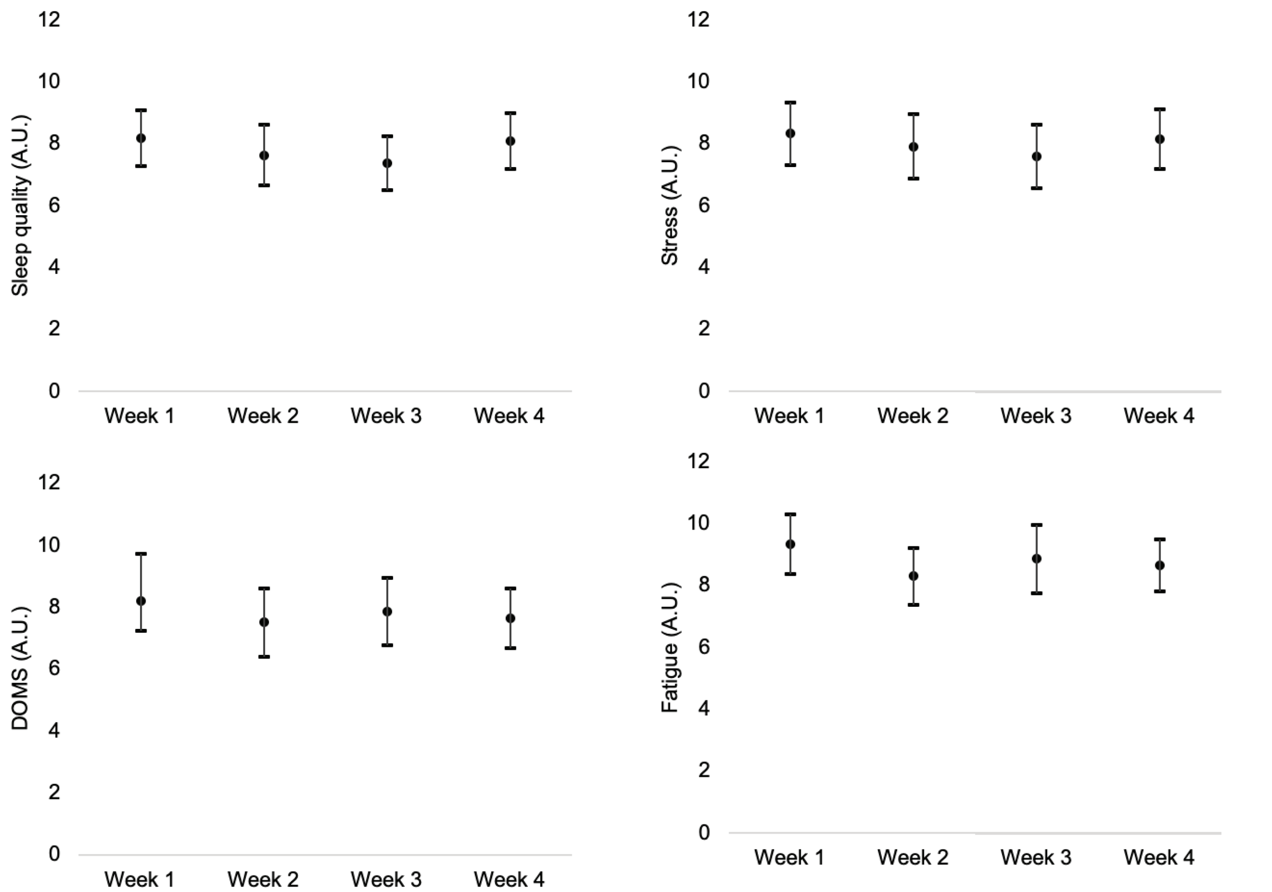

FIGURE 2 | Weekly variations of accumulated (sum of the scores of all sessions of each week) stress, fatigue, DOMS, and sleep quality.

Association Between Well-Being and Performance in Training

The mean values of the RPE, s-RPE, and well-being variables during 4 weeks of training of trail running athletes can be seen in **Table 1**.

The correlation between well-being variables and training load variables was identified in order to identify possible associations between these variables throughout the training process. The results of Pearson' correlation coefficients *r* can be found in **Table 2**.

Physical Variables and Performance in Evidence

Table 3 presents the mean values of the participants who underwent the 12-min Cooper test and the races performed during the mesocycle.

The Pearson's correlation analysis was performed between the performance variables in the Cooper test and the sports performance measured in the race (**Table 4**). Positive and significant mean values were found between Cooper 12-min (m) and RPE ($r = 0.380$, $p = 0.017$), as well as negative values with moderate magnitude between Cooper 12 -min and the pace ($r = -0.395$, $p = 0.016$). Similar results were observed between estimated VO_{2max} and RPE ($r = 0.379$, $p = 0.017$) and the pace ($r = -0.396$, $p = 0.015$).

DISCUSSION

Significant changes of RPE and s-RPE were found between the first and the third weeks and the first and the second weeks, respectively. Despite that, no more significant changes were found between weeks, possibly suggesting that there is a lack of progression in the stimulus and variability inter-week that is crucial to optimize the performance and to reduce the exposure to injuries (Gabbett, 2016). In fact a stabilization of the load may contribute to a performance plateau and, for that reason, it is interesting to identify that these athletes are not promoting (in a significative scale) the principles of variability and progression of the load based on the general absence of changes in the training load during the week and even the general comparisons between accumulated load over the weeks analyzed. One possible cause to observe such tendency can be the fact that during the period the athletes participated in races, and this may be constrained the variability within the mesocycle. As previously mentioned, the mesocycles occurred

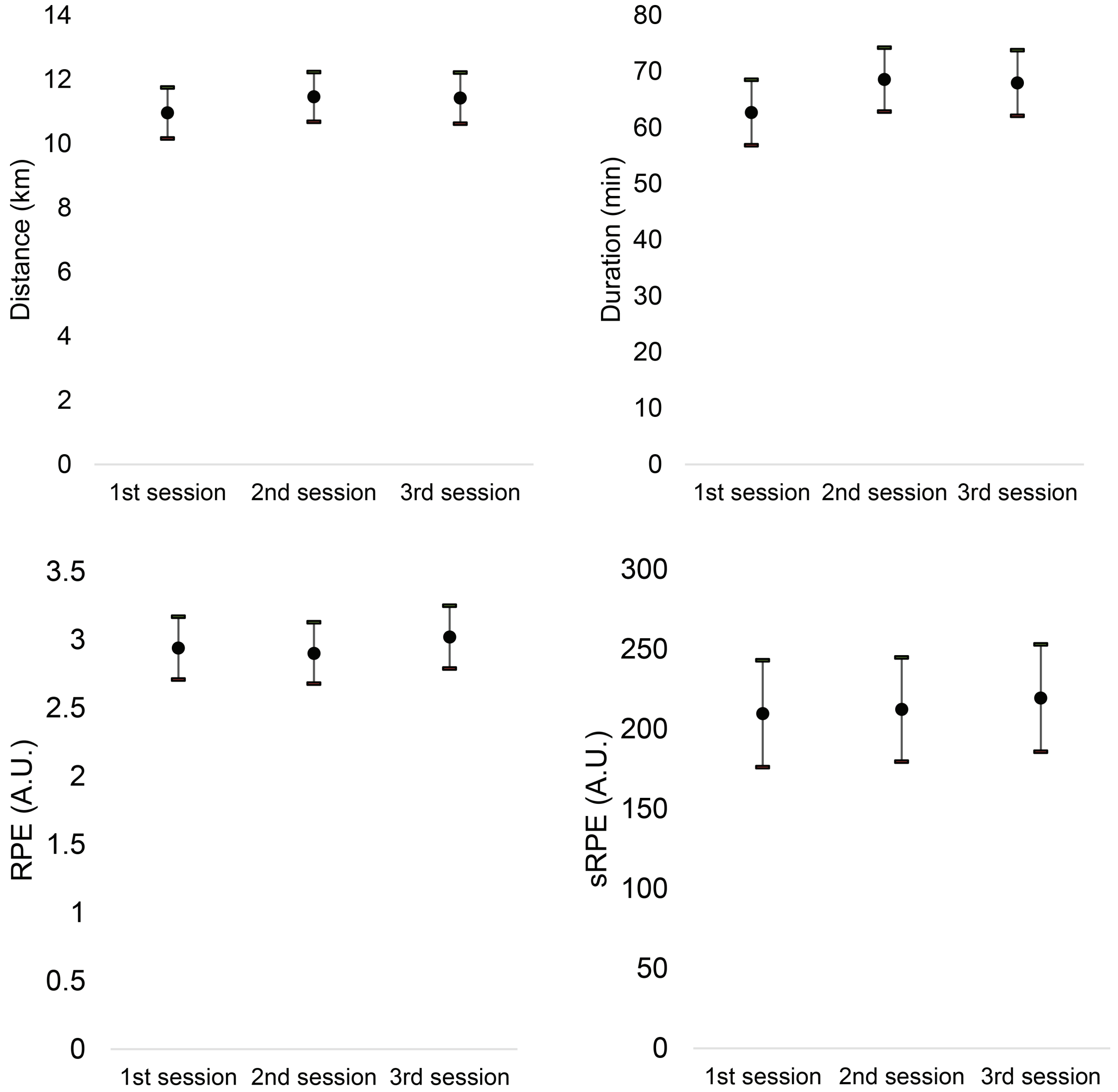

FIGURE 3 | Intra-week variations of distance, duration, RPE, and session-RPE (sRPE) (averages of 1st, 2nd, and 3rd training sessions of the week).

in mid-season during the competitive period; however, and depending on the goal of each athlete, some variability in terms of the training process may occur. This should be considered a limitation of the present study. Despite that, the descriptive statistics of the internal load revealed that the sRPE per training day was relatively similar to that of the previous reports in race athletes (Da Silva et al., 2014). Another evidence was that no intra-week changes (differences between sessions within the week) were found in training load or in well-being variables, suggesting that the training within the week is almost the same between training sessions, again revealing a lack of variability in the training stimulus.

The analysis of well-being variables and training load (**Table 1**) allowed us to observe possible associations between these two factors during the mesocycle. By analyzing **Table 2** for correlation values, it can be seen that sleep quality has a significant small magnitude with all training load variables, indicating that sleep may have consequences related to athlete performance (Halson, 2014b). The stress variable only correlates in a significant way with RPE, although with a small magnitude, which may lead to an incorrect perception of the internal load resulting from the training sessions or races, and this may provide mismatched feedback for training monitoring (Halson, 2014a). Fatigue correlates significantly at a small magnitude with RPE and internal load variables, showing that

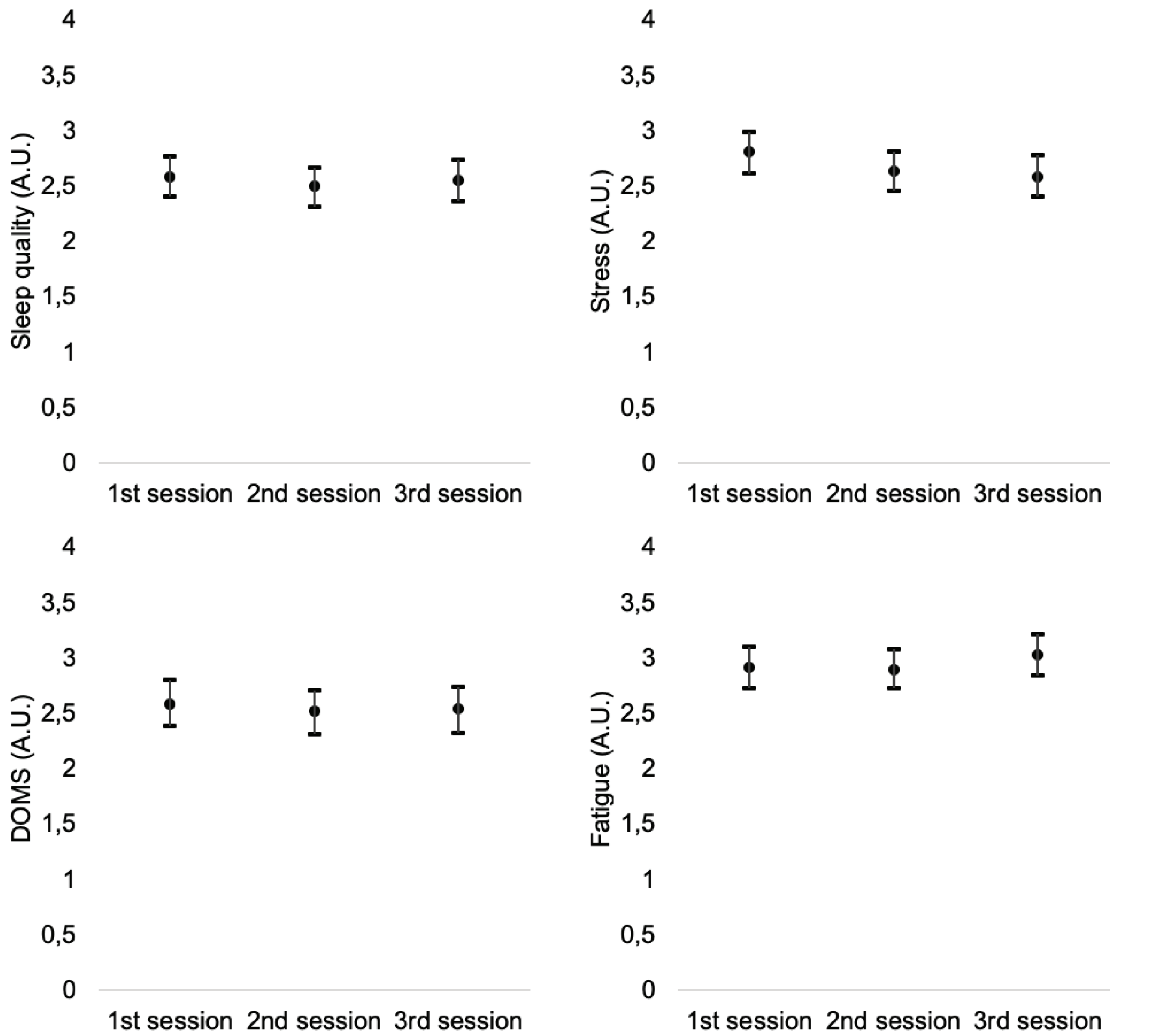

FIGURE 4 | Intra-week variations of sleep quality, stress, fatigue, and DOMS (averages of 1st, 2nd, and 3rd training sessions of the week).

TABLE 1 | Descriptive statistics (*M* ± SD) of well-being variables and training load during the mesocycle (average of the training session).

	Mean	SD
Sleep (A.U.)	2.55	1.15
Stress (A.U.)	2.68	1.16
Fatigue (A.U.)	2.95	1.16
DOMS (A.U.)	2.55	1.27
Hooper index (A.U.)	10.72	3.99
Distance (km)	11.28	5.31
Duration (min)	66.43	39.07
RPE (A.U.)	2.95	1.54
sRPE (A.U.)	213.79	223.95

DOMS, delayed onset muscle soreness; RPE, rate of perceived exertion in the CR-10 Borg's scale; sRPE, session-RPE representing the multiplication of RPE by the time in minutes; A.U., arbitrary units.

high levels of RPE indicate the presence of fatigue (Gescheit et al., 2015). DOMS had a small magnitude with distance, RPE, and internal load. This correlation suggests that an athlete's perception of muscle soreness is related to the impact of the race (Govus et al., 2017). The Hooper index scores correlate significantly, albeit with a small magnitude, with the variables of distance, RPE, and internal load. This result allows us to affirm that athletes who train or race with high Hooper index values are likely to have low levels of well-being, resulting in a reduction in performance (Gescheit et al., 2015).

Aerobic capacity of the athletes was tested to further correlations with performance in race. Our results in the 12-min Cooper test presented mean values of 3168.97 m. The values were similar with those reported by Kumar (2015). Also, mean values of 59.56 ± 6.43 ml·kg^{-1}·min^{-1} (VO_{2max}) were estimated in our recreational

TABLE 2 | Correlation values (*r*) between well-being variables and training load along the mesocycle.

	Distance (km)	Duration (min)	RPE (A.U.)	sRPE (U.A.)
Sleep (A.U.)	0.207[b]	0.153[b]	0.287[b]	0.249[b]
Stress (A.U.)	−0.007	−0.038	0.217[b]	0.079
Fatigue (A.U.)	0.068	0.012	0.191[b]	0.109[a]
DOMS (A.U.)	0.134[b]	0.098[a]	0.240[b]	0.193[b]
Hooper index (A.U.)	0.120[b]	0.068	0.279[b]	0.188[b]

RPE, rated of perceived exertion in the CR-10 Borg's scale; DOMS, delayed onset muscle soreness; sRPE, session-RPE representing the multiplication of RPE by the time in minutes. [a]Significant correlation at $p < 0.05$. [b]Significant correlation at $p < 0.01$.

TABLE 3 | Descriptive statistics (*M* ± SD) of the 12-min Cooper test and race values during the mesocycle.

	Mean	SD
Cooper test 12-min (m)	3168.97	287.57
VO_{2max} (ml/kg/min^{-1})	59.56	6.43
RPE (A.U.)	6.15	2.24
Pace (min/km)	7.38	2.04

RPE, rated of perceived exertion in the CR-10 Borg's scale.

TABLE 4 | Correlation values (*r*) between the performance variables in the 12-min Cooper test and load during the races.

	RPE (A.U.)	Pace (min/km)
Cooper test 12-min (m)	0.380[a]	−0.395[a]
VO_{2max} (ml/kg/min^{-1})	0.379[a]	−0.396[a]

RPE, rated of perceived exertion in the CR-10 Borg's scale. [a]Significant correlation at $p < 0.05$.

athletes. The correlation between the Cooper test and RPE showed positive and significant values, suggesting that a greater performance in Cooper may allow achieving higher intensities in training sessions. However, more interestingly, negative correlations were found between distance covered at Cooper test and estimated VO_{2max} with the pace in races, suggesting that greater aerobic capacity increases the intensity of running during official races. These results are in agreement with the literature regarding VO_{2max} as being the variable with the greatest effect on success in medium- and long-distance races (Bassett and Howley, 2000), being determinant to be succeeded.

The values obtained in the present recreational trail runners during races revealed a mean of perceived intensity of 6.15 ± 2.24 on the Borg scale. The pace of the athletes during races presented a mean of 7.38 ± 2.04 min/km. According to a study on running athletes by Dantas and Doria (2015), the pace was 4.05 min/km over a distance of 10 km, 4.21 min/km over the distance of a half marathon, and 4.48 min/km over the distance of a marathon. The differences between both values can be associated with the typology of long-running activities considering that trail running means to run in mountains with great variations in terms of terrain and accumulated unevenness involved.

Despite its contributions, our study had some limitations. For future studies, we recommend that heart rate during training sessions and competitions can be considered. Caloric intake should also be considered in order to determine the influence it has on the performance level. Moreover, hydration levels resulting from the excess body temperature of the athletes during a race should be also controlled. This can be also associated with the internal load in race considering that dehydration in trail running athletes causes increases in heart rate, which results in increases in fatigue levels and in an erroneous perception of effort. Finally, in the case of professional athletes, it would be important to compute some robust parameters associated with training load analysis, namely, the acute: chronic workload ratio, training monotony, and training strain.

This competitive 1-month analysis of trail running athletes demonstrated that well-being variables had small correlations between RPE and sRPE. Moreover, a negative correlation was observed between aerobic capacity measured in the Cooper test and the estimated VO_{2max} with the pace in race, demonstrating that increases in maximal oxygen consumption translate into improvements in the pace and performance of athletes.

CONCLUSIONS

It was found that, generally, there are no significant changes of training load and well-being parameters within and between weeks. Small correlations were found between training load parameters and well-being variables. A third evidence was that moderate correlations between aerobic capacity and performance in race revealed that higher levels in maximum oxygen consumption (VO_{2max}) reflect a decrease in pace (min/km) and, consequently, in performance improvements during races.

DATA AVAILABILITY

The datasets for this manuscript are not publicly available because upon request from the first author. Requests to access the datasets should be directed to Sérgio Matos: sfcmatos@gmail.com.

ETHICS STATEMENT

The study was also approved by the local ethical committee (Polytechnic Institute of Viana do Castelo, School of Sport and Leisure) with the code number IPVC-ESDL171003.

AUTHOR CONTRIBUTIONS

SM and FC conceived the study. FC and AB designed the study. SM collected data. FC analyzed and interpreted the data. SM, FC, and AB drafted the manuscript. SM, FC, AB, JP, PN, TR, and BK revised the manuscript and approved the final version.

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Mental Toughness and Associated Personality Characteristics of Marathon des Sables Athletes

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Mental toughness (MT) is commonly referred to as an important prerequisite for sustained athletic achievement. The increased research focus on MT has led to the development of a consistent debate centered around whether the construct is a unidimensional or multidimensional trait, and whether it can be differentiated from similar constructs such as hardiness. In order to move toward more clarity of MT, the present study is exploratory in nature, using athletes who have competed in the Marathon des Sables (MdS) ultra-endurance event. The MdS is a timed 250 km race in the Sahara Desert that takes place over 6 days in temperatures exceeding 40°C. Forty two British MdS competitors were recruited via the United Kingdom organizing company. Each participant completed the NEO PI-R as a measure of the five major domains of personality, as well as the six traits or facets that define each domain. Additionally, they completed the Sport Mental Toughness Questionnaire (SMTQ). The MdS sample's NEO PI-R results were compared against general population norms, and results showed a distinct ultra-endurance athlete profile characterized by significantly higher levels of extraversion and openness to experience. Additionally, the MdS sample's SMTQ scores were higher than the normed sample consisting of a collection of athletes representing multiple sports. Finally, linear regression analyses indicated a convergence between the two measures, supporting the argument that MT may in fact be measured by a general personality questionnaire such as the NEO PI-R.

Keywords: ultra-endurance, NEO PI-R, big five factor personality, sport psychology, psychometrics

INTRODUCTION

The requirement to face adversity and overcome challenges is ever-present in modern society; from businesspeople achieving their performance targets to students under the extreme pressure of final exams (Gucciardi et al., 2015). One population to experience these adversities and challenges more than others are athletes (Gucciardi et al., 2017). High-performance sport is characterized by a demand to excel at optimal levels while performing under conditions that are considered exceptionally demanding (Jones et al., 2007). Psychological attributes such as self-confidence and the ability to cope with and interpret anxiety-related symptoms as positive are now commonly accepted as being major contributors to sporting success (Hanton and Fletcher, 2005). Nonetheless, mental toughness (MT) is commonly referred to as the "defining" attribute that enables one to thrive in these situations (Weinberg, 2010). Mental toughness has come to be widely viewed as an important prerequisite for sustained athletic achievement (Sheard, 2010) and it is consistently reported that higher levels of this construct in elite athletes is related to successful performance (Mahoney et al., 2014). However, research into successful sport performance has moved beyond just the elite, exploring both collegiate and youth athlete samples. Collectively, this range of participants indicates that MT is required across many sports and many achieving sport performers, not just elite athletes (Weinberg et al., 2017). It is said that mentally tough athletes are seen to experience less intense emotions and are viewed as being able to perform effectively in situations that are stressful (Crust, 2009) – an ideal trait to possess when considering the demanding lifestyle athletes experience (Hanin, 2010). However, it is likely that there are dysfunctional outcomes associated with high levels of mental toughness. Indeed, a study by Sabouri et al. (2016) found significant associations between the "dark triad" Sabouri et al. (2016, p. 229) of personality characteristics: Machiavellianism (a manipulative, self-centered, immoral, and calculative attitude), narcissism (exaggerated self-love, dominant, self-aggrandized, egocentric), and psychopathy (lack of empathy, adventurousness, low anxiety, cold-blooded), MT and vigorous physical activity. The authors suggest that a strong goal orientation and a high level of self-confidence may mean an individual is more likely to engage in vigorous physical activity or that MT and dark triad traits are a natural result of training for competitive sports.

The consensus that MT is a crucial factor for athletic excellence has increased interest toward not only developing a comprehensive understanding of the construct, but developing appropriate instruments to assess MT. Consequently, MT has become one of the most prevalent concepts within the broader field of positive psychology (Rusk and Waters, 2013). In fact, the academic focus on MT has risen at an exponential rate since the turn of millennia (Gucciardi et al., 2015). Several studies have been conducted investigating the definition of MT (Coulter et al., 2010) the process of building MT (Weinberg and Butt, 2011) and even potential theoretical explanations for MT (Harmison, 2011). However, this has, understandably been met with rigorous scrutiny. In fact, it could be argued that MT has become a quandary with ever-present issues and deliberations embedded into the literature. This includes a consistent debate over its categorization as a unidimensional or multidimensional trait (Coulter et al., 2016). This debate, though recently favoring the former option, has still not reached a consensus and this has not been helped by a lack of an agreed conceptualization of what MT is, and what it is not, with various outsourced definitions amongst the literature (Coulter et al., 2010; Clough and Strycharczyk, 2012). This has resulted in an endless list of positive psychological characteristics being associated with mental toughness which have unfortunately been justified via anecdotal evidence and personal accounts (Jones et al., 2007). This has even raised concerns amongst academics that the likelihood of defining MT in a concise and unambiguous way is diminishing (Bauman, 2016). Unfortunately, the issues surrounding MT are not purely restricted at the conceptual level.

Further apprehension has arisen surrounding the measurement of MT (Gucciardi et al., 2017). This concern centers around the relationship between MT and another similar construct of hardiness. The prevalent concern in this respect is that the commonly used measures of MT are faulty as they fail to diverge between MT and hardiness (Brand et al., 2014). This includes the MT48, the shorter MT18 and even the revised MTQ 48 (Crust, 2008). This leads to not only scrutiny of these measures but questions over the distinctiveness of both facets. Therefore, there is a need for greater clarification of what MT consists and does not consist of, its relationship with other personality traits and a valid measurement tool that emphasizes the distinctiveness of the facet.

On the topic of the need for a valid measurement tool, the Sport Mental Toughness Questionnaire (SMTQ; Sheard et al., 2009) appears to be a significant step forward in offering a psychometrically robust measure of general sport mental toughness and most importantly triumphs where the others falter demonstrating divergent validity from hardiness (Sheard, 2010). In relation to the need for greater clarification of what MT consists and does not consist of and its relationship with other personality traits, the Marathon des Sables (MdS) presents an opportune example for this exploration. The event is a timed 250 km race completed over 6 days across the Sahara Desert in temperatures well above 40°C (Knoth et al., 2012). In focusing on extreme ultra-endurance athletes, where a significant proportion of success is likely to be due to MT (Zeiger and Zeiger, 2018) due to the lack of extrinsic reward for many competitors, a clearer and more detailed insight may be gained of the characteristics that underpin what is termed MT. This is emphasized by several accounts in the press that frequently note that individuals finish the MdS regardless of position. Additionally, measuring detailed general personality alongside MT may give a clearer insight into the characteristics that are crucial for overcoming significant challenges in sporting endeavor, as well as adding some clarity to the nature of what is perhaps an overused and equivocal term – MT.

The present study is exploratory in nature and aims to build on and add to the current body of research exploring the characteristics that enable athletes to deal with the challenges they may face in sport. In doing so this research strives to achieve three aims. The primary aim is to describe the personality characteristics, including MT, of extreme ultra-endurance athletes. A secondary aim is to gain greater insights into MT and its independence as a separate personality trait. Vicariously, a third aim is to start establishing sport-specific norms on a measure of general personality (NEO PI-R) to allow holistic assessment and development of athletes as well as continuing to establish additional construct and divergent validity of a measure of general sport MT (SMTQ). The NEO

PI-R provides a comprehensive and detailed assessment of adult personality based on the Five-Factor Model, which has been previously found to correlate with mental toughness constructs (Horsburgh et al., 2009; Delaney et al., 2015).

MATERIALS AND METHODS

Participants and Design

Participants were 42 British athletes (33 Male, 9 Female) aged between 28 and 57 years (M = 42, SD = 8.15) who had successfully completed the MdS in either 2009 or 2010, achieving race positions between 78th and 891st. A convenience self-selecting sampling approach was used in which ethical approval was acquired prior to recruitment from the ethics committee of London Metropolitan University. Participants were recruited via an open invitation to take part in the study. This was sent to the United Kingdom organizing company of the MdS, who then forwarded the invitation to all competitors. A similar invitation was also posted on the United Kingdom MdS networking site. The term mental toughness was not mentioned in either invitations to avoid preconceived bias. The design of the present study consisted of cross-sectional group differences where the participants were compared to the test norm group of the NEO PI-R (general population) and the test norm group of the SMTQ (male and female).

Materials

NEO PI-R

The NEO PI-R (McCrae and Costa, 1987) measures five factors of personality [Neuroticism (N), Extraversion (E), Openness to Experience (O), Agreeableness (A) and Conscientiousness (C)] with six traits underpinning each factor (see **Table 1**). The NEO-PIR consists of 240 items rated on a 5-point Likert scale rated from strongly agree to strongly disagree. Examples of items are as follows: 1 "I am not a worrier" and item 12 "I am dominant, forceful, and assertive." The NEO PI-R is considered psychometrically robust with alpha coefficients generally over 0.70 and ranging between 0.58 and 0.92 (Costa and McCrae, 2006).

The Sports Mental Toughness Questionnaire

The SMTQ (Sheard et al., 2009) measures General Mental Toughness (G_{MT}) and its sub-facets of Confidence (CF), Constancy (CS), and Control (CT). It consists of 14 items rated on a 4-point Likert Scale ranging from "not at all true" to "very true." An example of an item is as follows: "I am committed to completing the tasks I have to do." The measure has good internal consistency with alpha coefficients ranging from 0.7 to 0.8 (Sheard, 2010) and most importantly has been shown to have moderate divergent validity with hardiness, dispositional optimism and affect (Sheard, 2010).

Procedure

A total of 65 participants expressed a desire to take part in the study and were sent an additional email containing a consent form, a personal details (demographic) form and links to the NEO PI-R and SMTQ with instructions for completion. Specifically, the participants were instructed not to consider the questions on either measure in great depth, and to respond to the questions honestly. They were given 4 weeks to complete the measures in which reminders were sent out prior to the deadline and non-returners were contacted twice after the closing date. 42 participants completed both the NEO PI-R and SMTQ with the nine who solely completed the former excluded from analysis. The NEO PI-R results were auto-downloaded via computer whereas the SMTQ results were emailed by return and hand scored.

Data Analysis

Two independent sample *t*-tests were carried out to compare the means of two independent groups in order to determine whether there is statistical evidence that the associated population means are significantly different: the first using the mean scores of the NEO PI-R MdS group and the NEO PI-R test's general population norms; the second using the mean scores of the SMTQ sample and compared to the mean scores of the test norms (male and female). Additionally, a Pearson correlation test was conducted on the NEO PI-R (five dimensions and 30 traits) and SMTQ (G_{MT}, CF, CT, and CS) scores to determine the strongest correlations present between the two constructs. Finally, linear regressions were conducted to examine variance in SMTQ as predicated by five factors and 30 traits of NEO PI-R.

RESULTS

Descriptive Statistics and Normal Distribution

To test the normality of data, Komologorov–Smirnov (K–S), and tests of skew and kurtosis were carried out. Results indicated the NEO PI-R traits of E6 (positive emotion), O3 (feelings) and

TABLE 1 | The five factors of personality and their underpinning traits measured in the NEO-PIR.

Factors						
Neuroticism	Anxiety (N1)	Hostility (N2)	Depression (N3)	Self-consciousness (N4)	Impulsiveness (N5)	Vulnerability (N6)
Extraversion	Warmth (E1)	Gregariousness (E2)	Assertiveness (E3)	Activity (E4)	Excitement seeking (E5)	Positive emotion (E6)
Openness	Fantasy (O1)	Esthetics (O2)	Feelings (O3)	Actions (O4)	Ideas (O5)	Values (O6)
Agreeableness	Trust (A1)	Straightforwardness (A2)	Altruism (A3)	Compliance (A4)	Modesty (A5)	Tender-mindedness (A6)
Conscientiousness	Competence (C1)	Order (C2)	Dutifulness (C3)	Achievement-striving (C4)	Self-achieving (C5)	Deliberation (C6)

C2 (Order) ($p < 2.58$), and E3 (assertiveness) (z score = 2.88, $p < 3.29$) as well as C5 (self-achieving) were skewed ($p < 2.58$). Therefore, caution would be exercised in interpreting the data associated with these constructs. Means and standard deviations SMTQ variables are presented in **Table 2** and NEO PI-R variables are presented in **Table 3**.

Marathon des Sables Group Compared to Test Population Norm Groups

A series of independent sample t-tests were conducted on the mean scores of the NEO PI-R MdS group sample and the mean scores of the NEO PI-R general population norms. Significant differences were observed in two of the five factor personality traits – extraversion ($t_{(41)} = 5.16$, $p = 0.00$) and openness to experience ($t_{(41)} = 5.60$, $p = 0.00$) and in 17 out of 30 of the underpinning traits. The significant results are presented in **Table 3**. In summary, MdS athletes reported significantly lower levels of anxiety (N1), vulnerability (N6), straightforwardness (A2), order (C2), and deliberation (C6). Conversely, the MdS athletes reported significantly higher impulsiveness (N5), assertiveness (E3), activity (E4), excitement seeking (E5), positive emotions (E6), fantasy (O1), feelings (O3), actions (O4), ideas (O5), values (O6) than the general population norms (**Table 4**).

A series of independent sample t-tests were conducted on the mean scores of the SMTQ sample and compared to the means scores of the tests' norms (male and female). There were significant differences noted across the male and female MdS population in comparison with the normed data in general mental toughness (G_{MT}), confidence (CF), and Constancy (CS). See **Table 5** for the full results.

Linear Relationship of NEO-PI-R and SMTQ

A series of Pearson correlations between NEO PI-R (five traits and 30 underpinning traits) and SMTQ (total mental toughness and three sub-scales) indicated a number of significant relationships between constructs. Pearson correlations revealed moderate to strong relationships between a number of NEO PI-R and SMTQ scores for the MdS group (**Table 6**).

A series of linear multiple regressions was undertaken to examine variance in SMTQ as predicated by five factors and 30 traits of NEO PI-R-utilizing the six strongest correlations for each factor of SMTQ. Predictors were loaded into the model using forward stepwise method, outlier removal was set at casewise 2SD to reduce potential type I errors. For G_{MT}, Neuroticism, Openness, and Conscientiousness predicted 58.2% of the variance (Adj. R^2) and at underpinning trait level, C1 (Competence), O6 (Values), and N6 (Vulnerability) accounted for 66.5% of the overall variance. For Confidence (CF), Conscientiousness, and Openness explained 38.6% of the overall variance whereas at trait level, N6 (Vulnerability), O6 (Values), and A4 (Compliance) explained 56.1% of the overall variance. For Control (CT), Neuroticism explained 31.8% of the overall variance and at trait level, N2 (Hostility) and N1 (Anxiety) accounted for 41.4% of the overall variance. For Constancy (CS),

TABLE 2 | Means and standard deviations of SMTQ.

	Gender				Total	
	Male		Female			
	M	*SD*	*M*	*SD*	*M*	*SD*
Confidence	18.21	2.29	16.22	1.86	17.79	2.33
Control	11.70	2.46	10.56	2.74	11.45	2.54
Constancy	14.03	1.47	14.67	1.32	14.17	1.45
G_{MT} total	43.94	4.71	41.44	3.94	43.40	4.63

TABLE 3 | Means and standard deviations of NEO PI-R questionnaire.

Factor/Trait	*M*	*SD*
N	77.07	19.50
E	122.93	16.98
O	125.07	16.75
A	119.48	15.84
C	122.62	17.36
N1	12.40	5.06
N2	12.67	4.43
N3	12.95	5.14
N4	13.48	4.36
N5	17.24	4.60
N6	8.33	3.98
E1	22.95	3.95
E2	16.17	5.29
E3	19.07	3.97
E4	21.90	3.82
E5	20.10	4.49
E6	22.74	4.54
Trait		
O1	20.02	4.29
O2	17.79	5.50
O3	23.05	4.61
O4	19.90	3.08
O5	21.31	5.52
O6	23.00	2.54
A1	21.45	3.94
A2	18.52	4.19
A3	24.19	3.47
A4	16.60	4.14
A5	18.43	4.53
A6	20.29	2.88
C1	22.71	3.29
C2	17.55	4.51
C3	23.4	2.86
C4	21.52	4.34
C5	21.19	4.42
C6	16.24	3.68

TABLE 4 | NEO PI-R factors and trait comparisons of the MdS group with general population norm group.

Factor/Trait					99% CI of the difference	
	t	**df**	**Sig. (2-tailed)**	**Mean difference**	**Lower**	**Upper**
E	5.164	41	0.000*	13.529	6.45	20.61
O	5.598	41	0.000*	14.471	7.49	21.45
N1	−2.427	41	0.020*	−1.895	−4.00	0.21
N5	2.028	41	0.049*	1.438	−0.48	3.35
N6	−2.714	41	0.010*	−1.667	−3.33	−0.01
E3	5.346	41	0.000*	3.271	1.62	4.92
E4	7.307	41	0.000*	4.305	2.71	5.9
E5	5.337	41	0.000*	3.695	1.82	5.57
E6	3.621	41	0.001*	2.538	0.64	4.43
O1	5.178	41	0.000*	3.424	1.64	5.21
O3	3.866	41	0.000*	2.748	0.83	4.67
O4	7.368	41	0.000*	3.505	2.22	4.79
O5	2.712	41	0.010*	2.310	0.01	4.61
O6	5.874	41	0.000*	2.300	1.24	3.36
A2	−4.143	41	0.000*	−2.676	−4.42	−0.93
A4	−3.609	41	0.001*	0.41	−2.305	−0.58
C2	−2.086	41	0.043*	−1.452	−3.33	0.43
C4	3.011	41	0.004*	2.017	0.21	3.83
C6	−9.792	41	0.000*	−5.562	−7.10	−4.03

*$p < 0.05$.

TABLE 5 | Comparisons of the MdS group males and females SMTQ scores with SMTQ test norm group.

SMTQ scale					99% CI of the difference	
	t	**df**	**Sig. (2-tailed)**	**Mean difference**	**Lower**	**Upper**
Males						
G_{MT}	3.731	32	0.001*	3.059	0.81	5.30
CF	2.968	32	0.006*	1.182	0.09	2.27
CS	4.345	32	0.000*	1.110	0.41	1.81
Females						
G_{MT}	2.432	8	0.041*	3.194	−1.21	7.60
CF	2.541	8	0.035*	1.572	−0.50	3.65
CS	3.802	8	0.005*	1.677	0.20	3.16

*$p < 0.05$.

TABLE 6 | Pearson intercorrelations between SMTQ and the factors and traits of NEO PI-R.

NEO PI-R factor	SMTQ			
	Confidence	**Control**	**Constancy**	**GMT tot**
Neuroticism	−0.497***	−0.578***	−0.396**	−0.692***
Extraversion	0.348*	–	–	–
Openness	0.456**	0.338*	–	0.503***
Agreeableness	–	–	–	–
Conscientiousness	0.512***	0.336*	0.539***	0.611***
NEO PI-R Trait				
N1	−0.461**	−0.504***	−0.363*	−0.623***
N2	–	−0.583***	–	−0.470**
N3	–	−0.477***	−0.438**	−0.520***
N4	−0.498***	−0.437**	–	−0.541***
N5	–	–	–	–
N6	−0.615***	−0.438**	−0.438**	−0.687***
E1	–	–	–	–
E2	–	–	–	–
E3	0.421**	–	–	–
E4	0.436**	–	–	–
E5	–	–	–	–
E6	–	–	–	0.320*
O1	–	–	–	–
O2	0.316*	–	0.345*	0.318*
O3	0.389*	–	–	–
O4	–	–	–	–
O5	–	0.387*	–	0.453**
O6	0.622***	0.435**	0.385*	0.673***
NEO PI-R Trait				
A1				
A2				
A3				
A4	−0.365*			
A5				
A6				
C1	0.590***	0.478***	0.539***	0.728***
C2				
C3	0.431**	0.307*	0.320*	0.486***
C4	0.486***		0.408**	0.526***
C5	0.413**		0.502***	0.502***
C6			0.496***	0.421**

*All non-significant ($p > 0.05$) correlations removed. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

Conscientiousness explained 27.2% of the overall variance and at trait level, C1 (Competence) and C6 (Deliberation) explained 35.0% of the overall variance.

DISCUSSION

This study set out to achieve three aims: (1) to describe the personality characteristics of extreme ultra-endurance athletes, (2) gain a greater insight into MT and its independence as a personality trait, and (3) to establish sport-specific norms on a measure of general personality (NEO PI-R) and general sport MT (SMTQ). With this in mind, the results indicated that ultra-endurance athletes appeared to have distinct profile of personality traits compared to the general population. Additionally, their mental toughness profile was differentiated from fellow athletes. Specifically, on the big five factor personality traits, MdS athletes demonstrated a statistically significantly higher level of extraversion and openness to experience. This finding adds to the contradictory data on the differences in personality traits between athletes and non-athletes (Malinauskas et al., 2014). The equivocal findings identifying potential differences in extraversion between these two populations is supported by studies that have found no differences (e.g., Vealey, 2002; McKelvie et al., 2003), with others reporting a consistently higher level of extraversion than non-athletes (e.g., Egloff and Gruhn, 1996), albeit with a small effect size (Cohen's d = 0.33). Having said that, a more recent review suggests that athletes are characterized by higher levels of extraversion compared with non-athletes (Hughes et al., 2003). This is an important observation given that extraversion is associated with low stress reactivity (Connor-Smith and Flachsbart, 2007), coping (Nicholls and Polman, 2007), and mental toughness (Egan and Stelmack, 2003). The second big five personality factor that differentiated between MdS athletes and the general population was openness to experience. To recap, openness to experience reflects an individual's ability to seek out new experience and a general preference for an active imagination (fantasy), esthetic sensitivity, attentiveness to inner feelings, preference for variety, and intellectual curiosity (Duriez et al., 2004; Allen et al., 2013). The presence of a higher level of openness may play a greater role in predicting participation in non-traditional sports due to the level of receptiveness to ideas and opportunities for new experiences (Wilson and Dishman, 2015). Additionally, this finding may reflect a higher propensity for ultra-endurance runners tend to focus on the wonder of the external environment, driven by the preference for esthetic sensitivity (Acevedo et al., 1992; Baker et al., 2005). However, the findings regarding the differences on the openness trait differ from a recent study examining the personality profiles of athletes who have experienced most success in their career (Steca et al., 2018). This study concluded that the most successful athletes showed consistently higher scores across all big-five personality dimensions apart from Openness to Experience.

In making sense of the MT results the MdS athletes' scores on the SMTQ suggest that this population are likely to be more confident than other athletes yet surprisingly MdS athletes' confidence (CF) levels are comparable to that of the general population. This is particularly intriguing as self-confidence is commonly cited (e.g., Bull et al., 2005; Golby et al., 2007; Crust, 2008; Gucciardi and Gordon, 2009) as being the primary theme for mental toughness and therefore it would appear, based on this theoretical approach, that the MdS sample possessed no more mental toughness than their non-sporting counterparts despite the demands of their event. Remarkably, it was additionally noted that the SMTQ was not related to extraversion (E) and yet it was a characteristic that differentiated the MdS group from the general population. However, this is not the only result from the current study to question previous findings. For example, Horsburgh et al. (2009) stated that mentally tough individuals are more likely to be outgoing and sociable. In fact, social support is seen as key in developing mental toughness (Connaughton and Hanton, 2009). However, these conclusions were not supported by the findings of the current study. This could be an indication of the true uniqueness of the current sample with ultra-endurance events attracting only solitary people, but it is also a signal of the importance of utilizing in-depth personality measures as well as sport-specific norms on general measures in future research.

Another Big 5 trait to have a strong link to mental toughness is neuroticism (N) which also has relationships with both coping and hardiness (Cerin, 2004; Maddi, 2006) yet intriguingly, in the present study, there were no significant differences between the MdS sample and the general population on this higher order construct. However, the MdS athletes reported significantly lower levels of anxiety and vulnerability. However, this raises the question whether feeling free-flowing anxiety and experiencing frustration and anger states (if present) are facilitative or debilitative to performance based on the interpretation at that time. A key question for this population could be "*Do MdS athletes find ultra-endurance events stressful?*." This highlights the possibility that the demands athletes have to cope with may be so distinct that they require different dispositions to deal with them.

In regard to the second and third aim of the present study, the results provide insight into the nuances of mental toughness as well as its potential as a sole personality trait. For example, the results indicated a number of moderate to strong relationships between the SMTQ, its subscales and three of the factors and seven of the traits of NEO P-IR. The three NEO P-IR factors (N, O, C) accounted for 58.2% of the variance of SMTQ Total Mental Toughness (G_{MT}) whilst three out of the thirty NEO P-IR traits (N6, O6, C1) accounted for 66.5% of the variance of Mental Toughness (G_{MT}). This not only indicates a level of convergence between the two measures but it may also provide an argument to counter the views that mental toughness cannot be measured through a general personality measure, and that it is a separate trait (Bull et al., 2005; Gucciardi and Gordon, 2009). In terms of its relationship with the NEO PI-R, the assumed conceptual link would be between Constancy (CS) and Conscientiousness (C) given their definitions. This was supported by the results; however, closer scrutiny suggests that only two underpinning traits within Conscientiousness load onto constancy; competence (C1) and deliberation (C6). It is peculiar given the conceptualization of constancy, why it is not more strongly related to conscientiousness especially as another logically assumed trait in achievement striving (C4) did not significantly relate to constancy either. This was not the only surprising result to emerge from the SMTQ and NEO PI-R analysis. For example, Vulnerability (N6) accounted for a significant amount of variance in SMTQ mental toughness (G_{MT}) as well as confidence (CF) but surprisingly, not in control (CT). This suggests that confidence may be measuring aspects of control and control itself, is not wholly measuring what it purports to measure. In other words, its construct validity is brought into question. It is not transparent from the original SMTQ research whether control is intended to measure both perceived ability to cope and the ability to control emotions, despite both being cited within the research (Sheard et al., 2009; Sheard, 2010). Given its relationship with anxiety (N1) and angry hostility (N2) on NEO PI-R and lack of relationship with vulnerability (N6) it would appear to be the latter only. This confusion is thrown into further disrepute considering the initial item bank for the SMTQ was generated using an extremely limited sample utilizing small number of athletes from a small range of sports and therefore could explain the issues of validity. Gaining clarity over this is important especially if the SMTQ is to become influential concerning the strategies and interventions used to develop athletes.

Strengths and Limitations

There are strengths inherent within the study and some limitations that need to be considered for future research. Technically the use of a dual instrument approach (personality and mental toughness) was seen as important for the empirical rigor of investigating mental toughness. In addition, the sample choice of a mixed ability group moves mental toughness research away from being dominated by elite only studies, something that future research needs to continue to replicate. In terms of personality measures, the study has begun to build sport-specific norm bases for the NEO PI-R as well as continuing the ongoing validation of the SMTQ within a specific sport. However, it must be considered that the small, British and male dominated sample in the current study led to a restricted choice of statistical analyses and increased the need to adopt a cautious approach to it in order to minimize Type I errors, which may have increased the possibility of Type II errors. Additionally, as the study was conducted 3 or 15 months after the event, no baseline measures were taken prior to the event for comparative purposes and further analysis. Cross-comparisons between the two tests may have been less robust, as different populations (the tests' norm groups) were used as comparator groups, than if the same comparison group was used for both tests. Further limitations arise due to sole reliance on self-report questionnaires with no alternative forms of assessment or evaluations by third parties. This is particularly relevant to the NEO PI-R as its items are not sport-specific and therefore may not be suitable for athletes or in this case MdS populations. However, future research can aid in this as establishing separate norm bases on the NEO P-IR for specific sports will add to its utility and resultingly lead to a general sports norm base. This will be advantageous to the study and development of the characteristics that allow athletes to push themselves to extremes, including mental toughness.

Future Directions

An examination of the results of the present study allows for the suggestion of future directions of related research. For example, future investigation should involve a comparison of athletes from different competitive levels as literature has indicated an over-reliance on elite athletes to inform mental toughness research (Golby et al., 2007; Crust, 2008; Sheard et al., 2009). Additionally by encouraging the development of sport-specific norms, general personality measures could provide a broader and more holistic understanding of athletes as well as developing a greater awareness of athletes, which is especially important in team contexts (Beauchamp et al., 2007); In fact NEO PI-R is seen to impact on other domains like orientation to people, thinking style, operational style and emotional style (Costa and McCrae, 2006; Rust and Lord, 2006; Lord, 2007). This will not only allow greater pragmatism when working with athletes to develop the characteristics that are required for them to become successful in training and competitions but relating specifically to the current research, it will be advantageous to the study and development of the characteristics that allow athletes to push themselves to extremes. Additionally, further investigation of participants' openness scores could be addressed in future research to give an insight into the differences between those who use associative or dissociative strategies during ultra-endurance events, as this is an area of contention between authors (Acevedo et al., 1992; Baker et al., 2005).

CONCLUSION

To conclude, the MdS has provided a unique opportunity to consider the personality characteristics of ultra-endurance athletes using both the NEO PI-R and the SMTQ. The NEO PI-R appears to add insight into the MdS population's personality and mental toughness that perhaps a factor-only personality measure and the SMTQ alone could not achieve. Additionally, whilst this study has potentially added some validity to the SMTQ it has also raised some conceptual questions regarding the measure and the concept of mental toughness in general. This study has potentially supported the increasing call for sport psychology to reengage with personality research to understand how individuals deal and develop the ability to deal with the challenges they face across situations, especially competition, training and lifestyle demands (Gucciardi et al., 2008). The in-depth profile that results from completing the NEO PI-R is likely to be valuable to sport psychologists and practitioners in achieving this aim although this must coincide with the establishing of sport-specific norms through future research that acknowledges the huge variance that exists in the sporting population.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by London Metropolitan University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

KG designed and collected the data for the study and drafted the original manuscript. C-MR co-ordinated the preparation of the draft into a final version and checked and verified the statistical analysis. LA researched the most up to date literature on mental toughness, and added this to the manuscript. LW and JB-D acted as advisors and critical friends throughout the process.

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Muscle Strength and Flexibility in Male Marathon Runners: The Role of Age, Running Speed and Anthropometry

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Most studies on marathon runners have focused on physiological parameters determining performance, whereas neuromuscular aspects, such as muscle strength and flexibility, have received less attention. Thus, the aim of the present study was to examine the relationship of age, body composition, and running speed with muscle strength and flexibility of recreational marathon runners. Male marathon runners (n = 130, age 44.1 ± 8.6 years, height 176 ± 6 cm, body mass 77 ± 9 body mass index 24.7 ± 2.6 kg.m^{-2}, and race speed 10.29 ± 1.87 km/h) were separated into eight age groups (<30, 30–35, 55–60, >60 years). Four weeks before competing in a marathon, participants performed the sit-and-reach test (SAR), squat jumps (SJ), and countermovement jumps (CMJ), and four isometric muscle strength tests (right and left handgrip, lifting with knees extended and flexed), providing an index of overall isometric muscle strength in absolute (kg) relative to body mass values (kg.kg^{-1} body mass). Afterward, participants competed and finished the Athens Classic Marathon (2017), and race speed was used as an index of running performance. As an average for the whole sample, SAR was 17.6 ± 8.5 cm, SJ was 24.3 ± 4.2 cm, CMJ was 25.8 ± 4.8 cm, overall isometric muscle strength was 386 ± 59 kg in absolute values and 5.06 ± 0.78 kg/kg of body mass in relative terms. The older age groups had the lowest scores in SJ ($p < 0.001$, $\eta_p^2 = 0.298$) and CMJ ($p < 0.001$, $\eta_p^2 = 0.304$), whereas no age-related difference in SAR ($p = 0.908$, $\eta_p^2 = 0.022$), absolute ($p = 0.622$, $\eta_p^2 = 0.042$) and relative isometric muscle strength ($p = 0.435$, $\eta_p^2 = 0.055$) was shown. Race speed correlated moderately with relative isometric strength ($r = 0.42$, $p < 0.001$), but not with the other neuromuscular measures ($r < 0.13, p > 0.130$). In summary, age-related differences were shown in jumping ability, but not in flexibility and isometric muscle strength. Although these parameters - except relative strength - did not relate to running speed, they were components of health-related physical fitness. Consequently, coaches and runners should consider exercises that include stretching and strengthening in their weekly program to ensure adequate levels for all components of health-related physical fitness.

Keywords: aging, isometric muscle strength, race speed, range of motion, athlete

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INTRODUCTION

The number of annual marathon races and finishers has increased during the last few decades (Vitti et al., 2019). Along with the increase in the number of marathoners, this has raised scientific attention to the physiological needs to complete a marathon race in amateur endurance runners, because they constitute the vast majority of finishers in races held worldwide. In this context, several studies have investigated the physiological profile of marathon runners (Del Coso et al., 2017; Salinero et al., 2017). Regarding physiological characteristics of marathon runners, the interplay of maximal oxygen uptake (VO_{2max}), running velocity at lactate threshold, and running economy have been well studied, and they are traditionally considered as the limiting factors for endurance running performance. However, other aspects such as muscle strength and flexibility have received less attention (Takayama and Nabekura, 2018; Takayama et al., 2018) despite their relevance to the above mentioned limiting factors. Even if flexibility and muscle strength were not direct determinants of running performance in marathoners, they are considered as core components of health-related physical fitness (Milanović et al., 2015), and the characterization of these physical aspects through age might help coaches and runners to improve their training programs for marathon competition.

Despite muscle flexibility and muscle strength have been considered as key factors for running performance because of their effect on running economy (Boullosa et al., 2011; Drew et al., 2011), these variables have been studied in long-distance and marathon runners only in a few studies (Jones, 2002; Trehearn and Buresh, 2009; Brown et al., 2011; Nikolaidis et al., 2018a; Del Coso et al., 2019). For instance, isometric muscle strength, sit-and-reach test (SAR), and countermovement jump (CMJ) were tested in a study in female and male marathon runners, but the focus on this investigation was placed on the effects of α-actinin-3 deficiency in these variables (Del Coso et al., 2019). With regards to muscle flexibility, SAR has been negatively associated with running economy, an index of endurance performance (Jones, 2002; Trehearn and Buresh, 2009; Brown et al., 2011). This association indicated that reduced flexibility (SAR) might be advantageous for endurance performance because it might be an indicator of joint and muscle stiffness, variables positively related to running economy (Butler et al., 2003). An interpretation of this association might be reduced SAR, reflected in stiffer musculotendinous structures during the stretch-shortening cycle, which in turn increased storage and return of elastic energy, and consequently improved running economy (Drew et al., 2011).

The existing literature described above enhanced our knowledge on neuromuscular performance of male marathon runners, however, little information existed so far on the variation of muscle strength and flexibility by age, body composition, and running performance in this race distance. Such variations might have practical applications for fitness trainers and coaches in the context of training and testing of their athletes. In addition to their relevance for sport performance, muscle strength and flexibility as components of health-related physical fitness have been mortality predictors, and their optimal values would contribute to the prevention and treatment of lifestyle diseases (e.g., osteoporosis) (Milanović et al., 2019). From a health-related physical fitness perspective, flexibility was widely evaluated using SAR and muscular fitness, measured by isometric tests (e.g., handgrip and lifting) and jump tests (e.g., squat jump, SJ, and CMJ) (Heyward and Gibson, 2014; American College of Sports Medicine [ACSM], 2018). Moreover, although the beneficial role of endurance running for aerobic capacity has been well known (Milanović et al., 2015; Gomez-Molina et al., 2018), less information exists about the neuromuscular fitness levels of humans engaged in regular endurance training. Furthermore, the age of male marathon runners has shown large variation [e.g., 43 ± 10 years in the Berlin marathon (Nikolaidis et al., 2019), 42 ± 10 years in the New York City marathon (Nikolaidis et al., 2018b)], and it would be interesting to investigate the age-related differences in neuromuscular fitness. Therefore, the aim of the present study was to examine the relationship of age, running performance, and body composition with muscle strength and flexibility of recreational marathon runners. A secondary aim was to create norms of neuromuscular fitness that could be applied as a training tool in the evaluation of male recreational marathon runners.

MATERIALS AND METHODS

Study Design and Participants

A cross-sectional study design was adopted in the present study. Male marathon runners (n = 130, age 44.1 ± 8.6 years, height 176 ± 6 cm, body mass 77 ± 9 kg, body mass index 24.7 ± 2.6 $kg.m^{-2}$, and race speed 10.29 ± 1.87 km/h) were separated into eight age groups (<30, n = 7; 30–35, n = 8; 35–40, n = 25; 40–45, n = 31; 45–50, n = 30; 50–55, n = 17; 55–60, n = 6; >60 years, n = 6) and performed SAR, SJ, CMJ, and four isometric muscle strength tests (right and left handgrip, lifting with extended and bended knees), providing an index of overall isometric muscle strength in absolute (kg) and relative to body mass values ($kg.kg^{-1}$ body mass). In addition, all participants in the present study finished the Athens Classic Marathon (2017) 4 weeks after the exercise testing session and race speed was used as an index of endurance running performance. Participants were recruited mostly from Athens through advertisements in social media and local sport clubs, and provided written informed consent after having been enlightened about potential risks and benefits of the study. This study has been approved by the Institutional Review Board of the Exercise Physiology Laboratory, Nikaia, Greece, and has been assigned to the ethical approval number EPL2017/7.

Equipment and Protocols

Chronological age was estimated by a table of decimals of year (accuracy 0.01 years),considering the date (day/month/year) of exercise testing session and birthday (Ross and Marfell-Jones, 1991). A digital weighting scale (HD-351; Tanita, Arlington Heights, IL, United States) and a stadiometer (SECA, Leicester, United Kingdom) were used to measure body mass and height, respectively, with participants in minimal clothing prior to

TABLE 1 | Descriptive statistics of participants (n = 130).

Parameter	Mean	SD	Range
Age (years)	44.1	8.6	23.5–67.6
Height (cm)	176.4	5.8	163.2–196.6
Weight (kg)	76.9	9.4	56.2–108.1
BMI (kg.m^{-2})	24.7	2.6	19.1–35.0
BF (%)	17.7	4.1	7.8–27.1
FFM (kg)	63.0	6.1	48.9–79.9
CSA (cm^2)	141.5	14.1	111.2–189.3
Race speed (km.h^{-1})	10.3	1.9	6.0–15.0
SAR (cm)	17.6	8.5	−4–35.3
Right HG (kg)	48.1	5.9	31.5–62.0
Left HG (kg)	48.2	6.0	36.3–63.6
Sum of and right and left HG (kg)	96.4	11.4	68.6–125.6
Lifting with extended knees (kg)	134.8	23.1	73.5–201.5
Lifting with flexed knees (kg)	154.9	28.3	92.0–224.0
Absolute sum (kg)	386.0	58.5	247.0–523.0
Relative sum (kg.kg^{-1})	5.06	0.78	3.04–7.24
SJ (cm)	24.3	4.2	12.2–35.3
CMJ (cm)	25.8	4.8	13.7–39.1

BMI, body mass index; BF, body fat percentage; FFM, fat-free mass; CSA, total thigh muscle cross-sectional area; SAR, sit-and-reach test; HG, handgrip; SJ, squat jump; CMJ, countermovement jump. The absolute and relative sum referred to the sum of the four isometric muscle strength tests (right and left handgrip test, lifting with extended and flexed knees tests).

exercise testing. The ratio of body mass (kg) and height squared (m^2) estimated body mass index (BMI). Skinfold thickness was measured in ten anatomical sites (cheek, wattle, chest I, triceps, subscapular, abdominal, chest II, suprailiac, thigh, and calf), and their sum was considered to estimate body fat percentage (BF) (Eston and Reilly, 2001). Fat mass (FM) was calculated as "body mass × BF/100," and fat-free mass (FFM) was "body mass−FM." Total thigh muscle cross-sectional area (CSA) was estimated from the formula "(4.68 × midthigh circumference in cm)−(2.09 × anterior thigh skinfold in mm)−80.99" (Housh et al., 1995).

Low back and hamstring flexibility was assessed using SAR (Mayorga-Vega et al., 2014), where two trials were performed against a box with the score 15 cm corresponding to the touch of toes. That is, when the participant reached the toes using the fingers, he scored 15 cm. After flexibility, participants performed a 15 min warm-up including cycling and stretching exercises, jumping ability, and isometric muscle strength tests followed. Participants performed two squat jumps (SJ) and two CMJs in counter-balanced order (Aragon-Vargas, 2000); jump height was estimated by the flight time measured with a photocell beams system (Opto-jump, Microgate Engineering, Bolzano, Italy). Both SJs and CMJs were performed with hands stabilized on hips to prevent arm-swing. The two jump tests differed in their starting position, which was with hips and knees flexed in SJ and extended in CMJ. To evaluate isometric muscle strength, four tests were administered - right and left handgrip test, and lifting with extended and flexed knees tests; use of digital handgrip dynamometer (Heyward and Gibson, 2014), and back-and-leg digital dynamometer (Takei, Tokyo, Japan) (Ten Hoor et al., 2016) - and their sum provided an overall score of absolute and relative to body mass muscle strength. In the handgrip test, the grip was adjusted to the palm size and participants were asked to squeeze it in a standing position (Sterkowicz-Przybycien et al., 2019). In the lifting with extended knees, participants stood on the platform of back-and-leg dynamometer and pulled the hand bar across their thighs, whereas the lifting with flexed knees followed the same procedure but with different ankle (i.e. ∼135° instead of 180°) at the knee (Heyward and Gibson, 2014). For the abovementioned exercise tests, 1 min breaks were provided between tests and within trials, and the best of two trials was recorded. During all testing procedures, participants were instructed to perform maximally.

Statistical Analyses

All statistical analyses were performed by using IBM SPSS v.20.0 (SPSS, Chicago, IL, United States) and GraphPad Prism v. 7.0 (GraphPad Software, San Diego, CA, United States). The data were tested for normality and, thereafter, parametric statistics

TABLE 2 | Percentile values of neuromuscular fitness.

	Percentile						
Parameter	5	10	25	50	75	90	95
SAR (cm)	2.9	6.5	12.0	17.4	24.1	29.2	30.4
Right HG (kg)	38.1	39.7	44.3	48.7	52.3	55.1	57.8
Left HG (kg)	37.8	39.3	43.7	49.1	52.0	54.9	59.8
Sum of and right and left HG (kg)	76.5	81.8	88.2	98.2	103.3	110.5	115.5
Lifting with extended knees (kg)	90.1	106.0	121.1	135.0	152.0	163.3	172.3
Lifting with flexed knees (kg)	105.9	120.8	133.3	155.5	174.4	192.0	203.7
Absolute sum (kg)	282.7	307.5	344.2	387.0	425.7	461.5	479.7
Relative sum (kg)	3.62	4.09	4.60	5.05	5.55	6.10	6.37
SJ (cm)	17.0	19.1	21.7	24.5	27.1	29.6	32.5
CMJ (cm)	17.2	20.1	23.2	25.5	28.5	32.7	35.0

BMI, body mass index; SAR, sit-and-reach test; HG, handgrip; SJ, squat jump; CMJ, countermovement jump. The absolute and relative sum referred to the sum of the four isometric muscle strength tests (right and left handgrip test, lifting with extended and flexed knees tests).

were used. Mean and standard deviation were calculated for each variable. Differences in SAR, SJ, CMJ, and isometric muscle strength among age groups were examined by one-way analysis of variance (ANOVA) and subsequent Bonferroni *post hoc* tests. The magnitude of the differences was tested by partial eta square, evaluated as small ($0.010 < \eta_p^2 \leq 0.059$), medium ($0.059 < \eta_p^2 \leq 0.138$), and large ($\eta_p^2 > 0.138$) (Cohen, 1988). The relationship among variables was examined by Pearson's product moment correlation coefficient®, whose magnitude was interpreted as trivial ($r < 0.10$), small ($0.10 \leq r < 0.30$), moderate ($0.30 \leq r < 0.50$), large ($0.50 \leq r < 0.70$), very large ($0.70 \leq r < 0.90$), nearly perfect ($r \geq 0.90$), and perfect ($r = 1.00$) (Batterham and Hopkins, 2006). In addition, 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentile scores were calculated for each neuromuscular parameter. A multiple stepwise regression was run to predict race speed from anthropometric and neuromuscular variables. In addition, a multivariate analysis of covariance (MANCOVA) was performed with muscle strength (absolute and relative overall muscle strength), flexibility and jumping ability (SJ and CMJ) as the dependent variables, age group as the fixed factor, and race speed the covariate. Significance was set at alpha = 0.05, except in the case of MANCOVA, where alpha was corrected to 0.01 (Bonferroni correction) to account for multiple ANOVAs being run.

RESULTS

Table 1 depicts information about the values in all testing protocols as a whole group, including ranges. Briefly, SAR was 17.6 ± 8.5 cm, SJ was 24.3 ± 4.2 cm, CMJ was 25.8 ± 4.8 cm, absolute strength was 386 ± 59 kg and

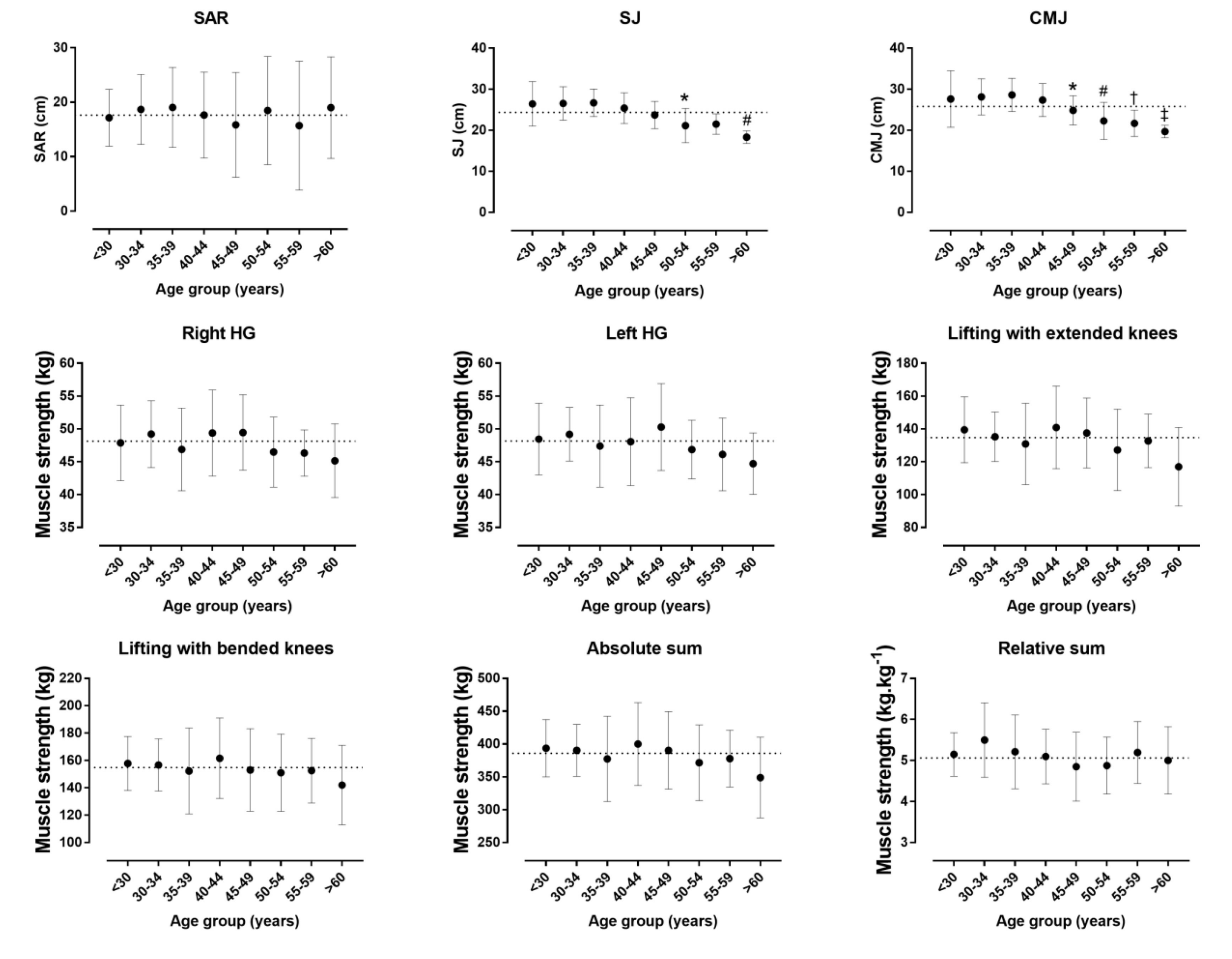

FIGURE 1 | Neuromuscular fitness by age group. SAR, sit-and-reach test; SJ, squat jump; CMJ, countermovement jump; HG, handgrip muscle strength; absolute and relative sum referred to the sum of four measures of isometric muscle strength (right and left HG, lifting with extended and bended knees tests); error bars represented standard deviations; the dashed line showed the mean score of all participants. For SJ: *, difference of 50–54 age group from <30, 30–34, 35–39, and 40–44 age groups; #, difference of >60 age group from <30, 30–34, 35–39, 40–44, and 45–49 age groups. For CMJ: *, difference of 45–49 age group from 35–39 age group; #, difference of 50–54 age group from 30–34, 35–39, and 40–44 age groups; †, difference of 55–59 age group from 35–39 age group; ‡, difference of >60 age group from <30, 30–34, 35–39, and 40–44 age groups.

relative strength was 5.06 ± 0.78 kg/kg of body mass. Percentile norms are presented in **Table 2**. The older age groups had the lowest scores in SJ ($p < 0.001$, $\eta_p^2 = 0.298$) and CMJ ($p < 0.001$, $\eta_p^2 = 0.304$), whereas no age-related difference in SAR ($p = 0.908$, $\eta_p^2 = 0.022$), absolute ($p = 0.622$, $\eta_p^2 = 0.042$) and relative isometric strength ($p = 0.435$, $\eta_p^2 = 0.055$) was shown (**Figure 1**). Age correlated moderately with SJ ($r = -0.47$, $p < 0.001$) and CMJ ($r = -0.47$, $p < 0.001$), but not with the other neuromuscular measures ($r < 0.14$, $p > 0.120$) (**Figure 2**). Race speed correlated moderately with relative isometric strength ($r = 0.42$, $p < 0.001$), but not with the other neuromuscular measures ($r < 0.13$, $p > 0.130$).

Sit-and-reach test was not related to BF, FFM, and CSA (**Figure 3**). SJ and CMJ were negatively related with small magnitude to BF, but not to FFM and CSA. The absolute muscle strength was related directly to FFM (moderate magnitude) and CSA (small magnitude), but not to BF. The relative muscle strength was negatively related to BF (large magnitude), FFM, and CSA (small magnitude).

The results of the multiple stepwise regression showed that race speed could be predicted by BF, age, BMI, and CMJ ($R^2 = 0.54$) (**Table 3**). According to MANCOVA, there was a statistically significant difference of medium magnitude in neuromuscular characteristics based on participants' age adjusted for race speed ($F_{35,482} = 2.134$, $p < 0.001$, Wilk's $\Lambda = 0.545$, $\eta_p^2 = 0.114$). There was a statistically significant effect of age group on SJ ($F_{7,118} = 6.196$, $p < 0.001$, $\eta_p^2 = 0.269$) and CMJ ($F_{7,118} = 6.448$, $p < 0.001$, $\eta_p^2 = 0.277$), but not on SAR ($F_{7,118} = 0.277$, $p = 0.962$, $\eta_p^2 = 0.016$), absolute ($F_{7,118} = 0.739$, $p = 0.640$, $\eta_p^2 = 0.042$), and relative muscle strength ($F_{7,118} = 0.382$, $p = 0.911$, $\eta_p^2 = 0.022$).

DISCUSSION

The main findings of the present study were that (a) older age groups of recreational male marathon runners had lower SJ and CMJ than their younger counterparts, (b) no difference in SAR and (absolute and relative) isometric muscle strength

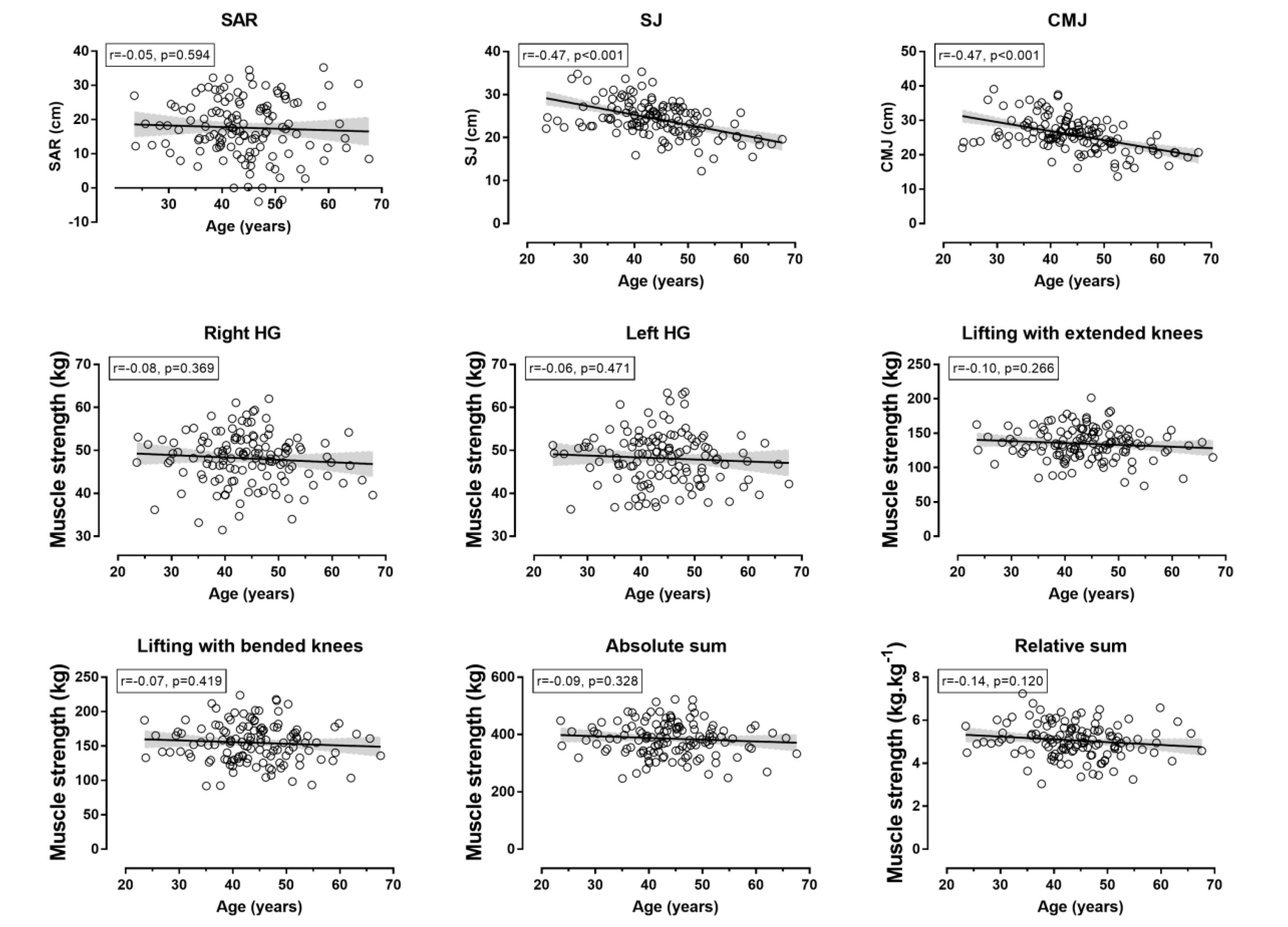

FIGURE 2 | Relationship of neuromuscular fitness with age. SAR, sit-and-reach test; SJ, squat jump; CMJ, countermovement jump; HG, handgrip muscle strength; absolute and relative sum referred to the sum of four measures of isometric muscle strength (right and left HG, lifting with extended and bended knees tests); shadowed areas represented 95% confidence intervals.

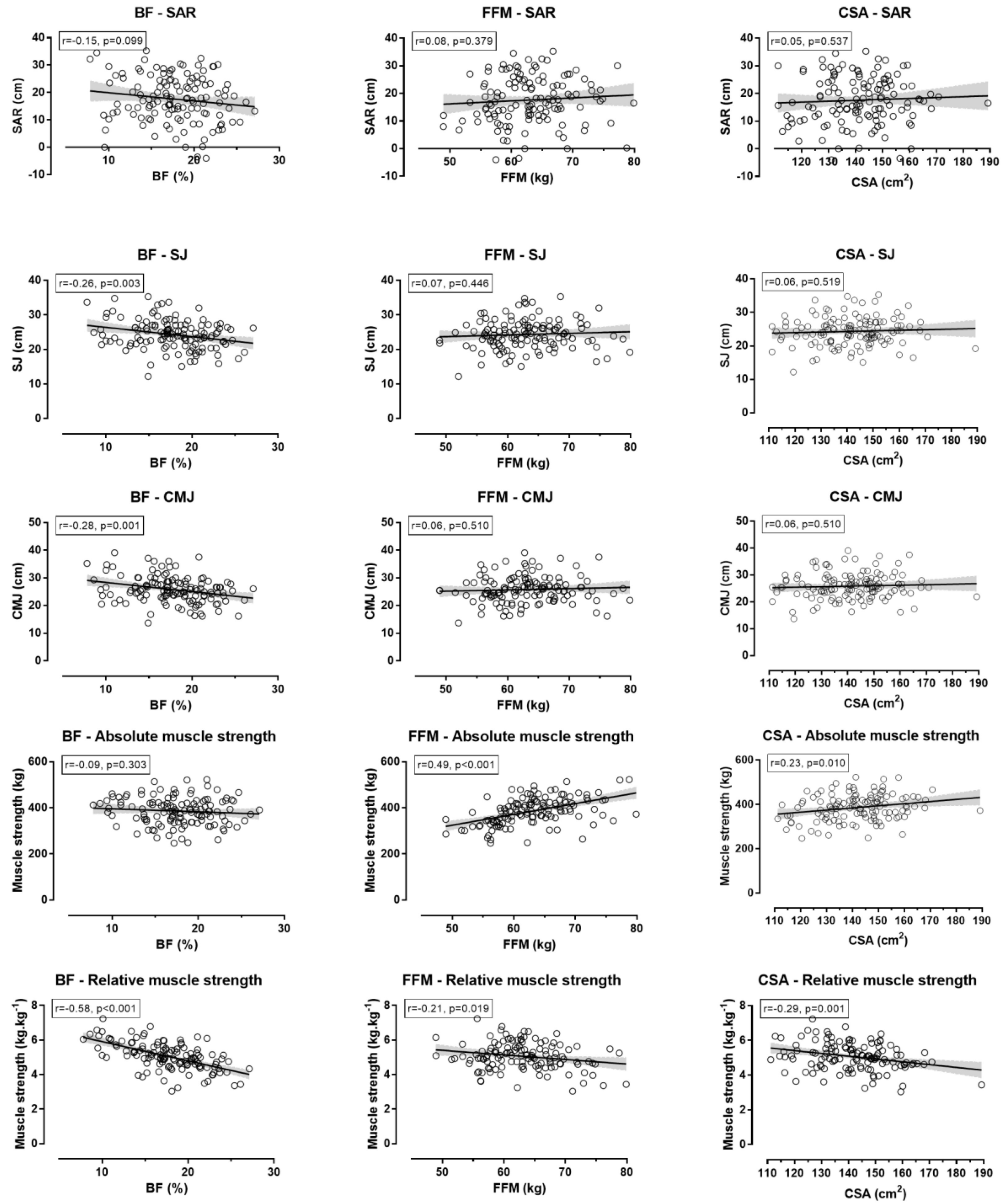

FIGURE 3 | Relationship of flexibility, jumping ability and isometric muscle strength with body fat percentage, fat-free mass and total thigh muscle cross-sectional area. Muscle strength referred to the sum of four measures (**right** and **left** handgrip test, back test, back-and-leg test); BF, body fat percentage; FFM, fat-free mass; CSA, total thigh muscle cross-sectional area; SAR, sit-and-reach test; SJ, squat jump; CMJ, countermovement jump; shadowed areas represented 95% confidence intervals.

TABLE 3 | Model summary of stepwise regression to predict race speed from anthropometric and neuromuscular characteristics.

Model	Variables	*R*	R^2	SEE	ΔR^2
1	BF[a] (−0.644)[b]	0.644	0.415	1.44	0.415
2	BF (−0.603), age[a] (−0.229)	0.683	0.466	1.38	0.051
3	BF (−0.403), age (−0.224), BMI[a] (−0.285)	0.712	0.507	1.33	0.041
4	BF (−0.446), age (−0.307), BMI (−0.277), CMJ[a] (−0.199)	0.733	0.537	1.29	0.030

BF, body fat percentage; BMI, body mass index; CMJ, countermovement jump; R, coefficient of multiple correlation; R^2, coefficient of determination; SEE, standard error of the estimate; ΔR^2, R^2 change resulting from entering a new variable, [a] denotes variable entered in each model, [b] standardized beta value was presented in brackets next to variable.

was observed among age groups, (c) race speed correlated with relative isometric muscle strength, but not with the other neuromuscular measures, and (d) BF was negatively related to SJ, CMJ, and relative muscle strength.

Comparison Among Age Groups

The lower scores in SJ and CMJ in the older compared to the younger age groups, and the absence of difference in SAR and isometric muscle strength among age groups were in agreement with the correlation analysis that identified negative relationship of SJ and CMJ - and no relationship for SAR and isometric muscle strength - with age. A negative correlation of CMJ with age was previously observed in distance runners (Michaelis et al., 2008; Nikolaidis et al., 2018a). In addition, a comparison of jumping ability, as it was reflected in jumping disciplines of athletics, among age groups showed lower performance in the older age groups than their younger peers (Kundert et al., 2019a,b). These findings together suggested a decline of SJ and CMJ with age, which should be attributed to a decline of muscle fiber type II area and fat-free mass with age (Hawkins et al., 2003). An explanation of the absence of age-related differences for SAR and isometric muscle strength, or the observation of small differences in jump performance might also be a reflection of the relatively low neuromuscular fitness of participants (Nikolaidis et al., 2016).

Relationship Between Race Speed and Neuromuscular Fitness

The moderate correlation of race speed with relative isometric muscle strength indicated that a fast marathon runner would be characterized by high muscle strength when the role of body mass was partitioned out. It has been observed previously that fast marathon runners did not differ from their slower counterparts with regards to absolute isometric muscle strength, however, when their body mass was considered, the former runners had higher relative muscle strength than the latter ones (Salinero et al., 2017). Although the application of force in leg muscles during endurance running is far from its maximal expression, high levels of relative muscle strength might be useful for marathoners in order to reduce the exercise-induced muscle damage level developed during the race (Del Coso et al., 2013) or to increase running economy (Giovanelli et al., 2017). Because muscle strength is a trainable parameter in marathoners with multiple benefits for marathoners, especially in the amateur population, concurrent resistance and endurance training should be implemented in replacement of the traditional vision of "only-endurance" training to increase overall marathon performance (Yamamoto et al., 2008).

Neuromuscular Fitness and Anthropometric Characteristics

The absence of relationships between SAR and BF, FFM, and CSA was expected, since flexibility has been a musculoskeletal attribute rather than a correlate of body composition. The negative relationship of SJ and CMJ with BF was explained from the observation that an additional FM consisted extra load that muscle strength of lower limbs should overtake (Gatterer et al., 2013). With regards to isometric muscle strength, the relationship of the absolute overall score with FFM (medium magnitude) and CSA (small magnitude) was in agreement with research demonstrating the association between muscle strength and muscle CSA (Fink et al., 2017). That is, an increased absolute overall muscle strength of participants was related to increased FFM and CSA. Interestingly, this trend was reversed when overall muscle strength was expressed relative to body mass values, since muscle strength depended on both muscular and neurological properties (McKay et al., 2017). This finding highlighted the need to assess and interpret muscle strength values in both absolute and relative to body mass values (Heyward and Gibson, 2014).

Limitations, Strength and Practical Applications

A limitation of the present study was the assessment methods of neuromuscular fitness; although popular measures of flexibility (SAR), muscle strength (isometric dynamometry), and jumping ability (SJ and CMJ) were used, caution would be needed in the consideration of methodological details to compare the findings with previous research. For instance, 8.8 cm was the SAR score of distance runners in a study, where zero was set at the toes (Jones, 2002), in contrast to the 15 cm set at the toes in the present study. Thus, to have comparable data, 15 cm should be added to the data of Jones (2002). Moreover, it was acknowledged that the existence of age groups with unequal sample sizes (most participants were in the 40–45 age group, and their number was decreasing in the younger and older groups) might be subjected to criticism from a statistical point of view. It should be highlighted that the existence of unequal sample sizes in age groups of marathon runners was ecologically valid, since it was representative of the variation in the participation rates by age group in marathon races. For instance, most male marathon runners were in the 40–44 age group in the New York City Marathon (Nikolaidis et al., 2018b) and in the Berlin marathon race (Nikolaidis et al., 2019).

In addition, the period between exercise testing session and marathon race was ∼4 weeks, and physiological characteristics could change during this period. Actually, there has been evidence that although a 3 months typical endurance running protocol (three 60 min sessions per week) improved aerobic capacity, no change in SAR, SJ, and CMJ was observed (Milanović et al., 2015). Similarly, a 2 months endurance running protocol (three ∼60 min sessions per week) improved aerobic capacity, but not SJ and CMJ (Gomez-Molina et al., 2018). Therefore, it might be assumed that neuromuscular characteristics of participants in the present study would be similar both in the exercise testing session and in the date of race.

On the other hand, the measurement of several strength variables is one of the novelties of this investigation, since it was the first study - to the best of our knowledge - presenting data on a complete battery of neuromuscular fitness tests in a large sample of marathon runners through a large age range. For practical applications, coaches and fitness trainers working with marathon runners might benefit from the novel data presented during the training and testing of their athletes.

CONCLUSION

In summary, age-related differences were shown in jumping ability, but not in flexibility and isometric muscle strength. Although these parameters - except relative strength - did not relate to marathon performance, they were components of health-related physical fitness. Consequently, coaches and runners should consider exercises including stretching and strengthening in their weekly program to ensure adequate levels for all components of health-related physical fitness.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The study has been approved by the Institutional Review Board of the Exercise Physiology Laboratory, Nikaia, Greece, and has been assigned to the ethical approval number EPL2017/7.

AUTHOR CONTRIBUTIONS

PN performed the experiments and drafted the manuscript. JD, TR, and BK helped in drafting the final manuscript.

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Perceptions of Overuse Injury Among Swedish Ultramarathon and Marathon Runners: Cross-Sectional Study Based on the Illness Perception Questionnaire Revised (IPQ-R)

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Background: Long-distance runners' understandings of overuse injuries are not well known which decreases the possibilities for prevention. The common sense model (CSM) outlines that runners' perceptions of a health problem can be described using the categories identity, consequence, timeline, personal control, and cause. The aim of this study was to use the CSM to investigate perceptions of overuse injury among long-distance runners with different exercise loads.

Methods: The study used a cross-sectional design. An adapted version of the illness perception questionnaire revised (IPQ-R) derived from the CSM was used to investigate Swedish ultramarathon and marathon runners' perceptions of overuse injuries. Cluster analysis was employed for categorizing runners into high and low exercise load categories. A Principal Component Analysis was thereafter used to group variables describing injury causes. Multiple logistic regression methods were finally applied using high exercise load as endpoint variable and CSM items representing perceptions of injury identity, consequence, timeline, personal control, and causes as explanatory variables.

Results: Complete data sets were collected from 165/443 (37.2%) runners. The symptoms most commonly associated with overuse injury were pain (80.1% of the runners), stiff muscles (54.1%), and stiff joints (42.0%). Overuse injury was perceived to be characterized by the possibility of personal control (stated by 78.7% of the runners), treatability (70.4%), and that the injury context was comprehensible (69.3%). The main injury causes highlighted were runner biomechanics (stated by 78.3%), the runner's personality (72.4%), and running surface biomechanics (70.0%). Among men, a belief in that personality contributes to overuse injury increased the likelihood of belonging to the high exercise load category [Odds ratio (OR) 2.10 (95% Confidence interval (95% CI) 1.38–3.19); *P* = 0.001], while beliefs in that running biomechanics [OR 0.56 (95% CI

0.37–0.85); P = 0.006) and mileage (OR 0.72 (95% CI 0.54–0.96); P = 0.026] causes injury decreased the likelihood. In women, a strong perception that overuse injuries can be controlled by medical interventions decreased the likelihood of high exercise load [OR 0.68 (95% CI 0.52–0.89); P = 0.005].

Conclusion: This study indicates that recognition among long-distance runners of the association between own decisions in overuse injury causation is accentuated by increased exercise loads.

Keywords: illness perceptions, long-distance running, overuse injury, exercise load, common sense model of illness, sports psychology

INTRODUCTION

Marathon and ultramarathon running are popular forms of exercise among women and men, and participation in running competitions covering distances longer than 100 km and with 24 h duration continues to increase (Knechtle and Nikolaidis, 2018; Esteve-Lanao et al., 2019; Waldvogel et al., 2019) It is today recognized that overuse injuries constitute a common problem in runners, and that psychological factors play a role in the injury causation (van der Worp et al., 2015; Kerr et al., 2016; Hulme et al., 2017). The opportunity to achieve personal goals has been identified as the main motivation among runners to compete at the longest distances, while runners competing at shorter distances commonly report self-esteem reasons and health-related reasons as equally important (Masters and Ogles, 1995; Ogles and Masters, 2000; Ogled and Masters, 2003). Regarding the psychological effects of long-distance running, already early quantitative research reported an increase in mental fatigue and a decrease in psychological tension, and anxiety (Hassmén and Blomstrand, 1991). These effects were longer lasting than the more short-term mood changes that follow briefer sessions of aerobic exercise (van Wilgen and Verhagen, 2012). As regards overuse injuries, the role of psychological and behavioral factors has been highlighted in qualitative studies (Reed and Ones, 2006; Jelvegård et al., 2016). The results point toward that sportspersons with experiences from this injury type are prone to describe a holistic view on the causal mechanisms, where biological, psychological, and social factors are seen to contribute. Strengthening this multi-factorial view on causation, ultramarathon runners were in a recent experimental study found to have higher cold pain tolerance and lower levels of pain-related anxiety than non-running controls (Roebuck et al., 2018b). The greatest difference in anxiety scores was seen for avoidance behavior, i.e., the runners were mentally less disposed to avoid activities associated with pain. This decreased psychological predisposition to avoid pain among the ultramarathon runners was found to partially mediate the elevated cold pain tolerance.

In order to master the overuse injury problem among long-distance runners, more knowledge of runners' own understanding of overuse injuries is needed. The common sense model (CSM) of illness (Leventhal et al., 2003) suggests that health problem perceptions can be divided into five main categories: (i) Identity refers to common symptoms of ill health and the extent these are considered to be related to the actual health problem; (ii) The consequence reflect the personal evaluation of the impact of the health problem on personal life; (iii) The timeline reflects the beliefs about the course of the health problem: acute or chronic; (iv) Personal control refers to beliefs about the possibilities for personal control and cure of the health problem; and (v) The cause reflects the beliefs about the causes of the problem. Together with emotional representations, these categories constitute a theoretical foundation for study of approaches to mastering overuse injury strategies also among long-distance runners. To enable comparative studies, Weinman et al. (1996) developed the Illness Perception Questionnaire (IPQ), which was elaborated by Moss-Morris et al. (2002) to the IPQ-R (R for revised). Hagger et al. (2005) introduced the IPQ-R to the sports setting, while van Wilgen et al. (2010) adjusted the instrument to injured sportspersons (IPQ-R-S). The internal consistency of the IPQ-R-S was reported to be adequate for all dimensions and attributions except for the attribution accident or chance.

Even though psychological and behavioral characteristics of long-distance runners have been investigated, several areas with relevance for prevention of overuse injuries among runners with different exercise loads have still not been explored. The aim of this study was to use the CSM to investigate perceptions of overuse injury among long-distance runners with different exercise loads and whether some perceptions distinguish runners with the highest loads.

MATERIALS AND METHODS

The study was based on a cross-sectional design. It was performed as a student project at Linköping University. According to Swedish legislation, student projects are not subject to external review by research ethics boards (Etikprövningsmyndigheten, 2019). The study was planned and conducted in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki (6th revision 2008). Informed consent was obtained in writing before interview participation, which was completely voluntary. All study data were handled without breaching the integrity of individual athletes.

Study Population

The primary study population consisted of all runners listed in the ultramarathon category at the Swedish Athletics Association or as members in the three running clubs in the Stockholm area specialized into ultramarathon and marathon distances. Runner listings with contact information were obtained from the Swedish Athletics Association and the running clubs. The runners were contacted and informed about the study by email.

IPQ-R-S

The IPQ-R instrument was designed to be adapted to the population to be examined. On the basis of an existing Dutch version adapted to injured athletes (IPQ-R-S) (van Wilgen et al., 2010), a Swedish IPQ-R version (Brink and Alsén, 2017) was adjusted to measure conceptions of overuse injury among active long-distance runners. Throughout the instrument, the word "disease" was replaced by the more specific term "overuse injury" and the wording "my injury" changed to denote "overuse injuries" (in general). The adjusted version (IPQ-R-S-Overuse injury) contains eight dimensions of injury characteristics and five groupings of injury causes.

The first IPQ-R-S-Overuse injury dimension is referred to as "Identity" and asks for perceived specific symptoms and whether these are perceived to be related to overuse injuries. Question 8 was changed from a general symptom ("Red-eyes") to address a more sports-specific issue ("Too much energy" from IPQ-R-S) and question 23 reworded from "Stiff joints" to "Stiff and/or painful joints." Two additions were specifically made with regard to the long-distance running context (questions 21 "weight gain" and 24 "stiff and/or painful muscles").

The remaining seven dimensions of injury characteristics examine the perception of overuse injury by asking to what extent on a five-point scale [1 (absolutely disagree) to 5 (absolutely agree)] the athlete agrees with statements linked to acute/chronic timeline, cyclic timeline, consequences, personal control, treatability (treatment control), the context of ill-health, and emotional representation.

Perceived causes of overuse injury are examined by the 28 in section C of the IPQ-R-S Overuse injury instrument and divided into five subgroups: (i) psychological attributes (for example, the emotional state), (ii) risk factors (for example, previous injury problems), (iii) infectious or immunological causes (for example, infection of virus or bacterium), (iv) accident or coincidence, and (v) a specific subcategory of causes, in this study related to overuse injuries (for example, poor footwear).

Collection of Data

The data collection was performed using the Briteback Survey Tool TM (Norrköping, Sweden) web-based system in January 2018. A survey was constructed that asked for basic sociodemographic information, exercise load, injury history, and data for the IPQ-R-S Overuse injury. An online version of the survey, an e-mail list, and a mailings schedule were created in the web-based system (Rönnby et al., 2018). The runners were invited to participate in the study through an email that contained study information and a link to the survey. Non-responding runners received maximum two automatic reminders by email with 10-day intervals. Automated system-generated statistics were provided for the researchers immediately after reporting of data.

Data Analysis

The first step of the data analysis grouped the participating runners with regard to exercise load. A principal component analysis (PCA) was performed to identify different components of the exercise load. The variables used for the analyses were running sessions per week, running hours per week, running miles per week, average long-distance training velocity, hours per week strength training, and hours per week alternative training. Thereafter a cluster analysis was carried out based on the exercise load components to create two (fixed number of clusters chosen as setting) exercise load categories (low, high). Separate cluster analyses were performed for each sex.

In the second step, the runners' perception of overuse injuries (recognition of, understanding of and perceived main causes of overuse injury) were described according to exercise load categories.

In the third step, a PCA was used to describe perceived compound causal components of overuse injury (variables used: the 28 variables of IPQ-R-S-Overuse-injury Section C).

In the fourth step, binary logistic regression was used to identify aspects associated with high exercise load. The endpoint variable used in the analysis was high exercise load (low/high, as generated from cluster analysis), while the explanatory variables included sex (only in analyses of all participants together), injury history, perceived characteristics of overuse injury (8 variables), and perceived compound causes of overuse injury (components from PCA in step 3). Simple models were first analyzed. Thereafter, all explanatory variables were included multiple models, where the non-significant variables were excluded by Wald's backward stepwise regression to create separate multiple models for women, men, and the total study population. All analyses were performed in the Statistical Package for the Social Sciences (SPSS version 23).

RESULTS

Study Participants

From the primary study population of 443 individuals, data were collected from 165 runners (58 women, 107 men) resulting in a response rate of 37.2%. The average age of the participants was 45.9 years (females 42.3 years, males 47.8 years) (**Table 1**). About every second runner [43.0% (females 34.0%, males 47.7%)] had suffered a significant injury the previous year (time loss from running at least 3 weeks), and 29.1% (females 37.9%, males 24.3%) had a time loss injury at the time of the study. Also about every second runner [48.6% (females 62.1%, males 41.1%)] used analgesic or anti-inflammatory medication on regular basis.

Exercise Load

The principal component analysis based on the six exercise load variables resulted in three components; running quantity (containing the variables running sessions per week, running hours per week, and running miles per week), running speed (average long-distance training velocity), and other exercise practices (hours per week strength training and hours per week alternative training). The cluster analysis based on the three

TABLE 1 | Inductively created exercise load groups (low load and high load) for female and male long-distance runners determined using cluster analysis.

	Exercise load groups								
	Female runners			Male runners			All runners		
Runner characteristics	**Low load *n* = 39**	**High load *n* = 19**	**Total *n* = 58**	**Low load *n* = 66**	**High load *n* = 41**	**Total *n* = 107**	**Low load *n* = 105**	**High load *n* = 60**	**Total *n* = 165**
Age [mean (sd)]	44.0 (9.7)	38.7 (6.8)	42.3 (9.1)	49.6 (9.4)	44.9 (9.8)	47.8 (9.8)	47.6 (9.8)	42.9 (9.3)	45.9 (9.9)
Main event									
Half-marathon [*n* (%)]	8 (20.5)	0 (0.0)	8 (13.8)	12 (18.2)	1 (2.4)	13 (12.1)	20 (19.0)	1 (1.7)	21 (12.7)
Marathon [*n* (%)]	27 (69.2)	5 (26.3)	32 (55.2)	51 (77.3)	24 (58.5)	75 (70.1)	78 (74.3)	29 (48.3)	107 (64.8)
Ultra-trail [*n* (%)]	0 (0.0)	1 (5.3)	1 (1.7)	2 (3.0)	3 (7.3)	5 (4.7)	2 (1.9)	4 (6.7)	6 (3.6)
Ultra 6 h/100 km [*n* (%)]	1 (2.6)	4 (21.1)	5 (8.6)	0 (0.0)	3 (7.3)	3 (2.8)	1 (1.0)	7 (11.7)	8 (4.8)
Ultra 12 h/100 miles [*n* (%)]	0 (0.0)	1 (5.3)	1 (1.7)	0 (0.0)	1 (2.4)	1 (0.9)	0 (0.0)	2 (3.3)	2 (1.2)
Ultra 24 h or longer [*n* (%)]	3 (7.7)	8 (42.1)	11 (19.0)	1 (1.5)	9 (22.0)	10 (9.3)	4 (3.8)	17 (28.3)	21 (12.7)
Exercise									
Running/week [sessions (sd)]	3.9 (1.0)	6.9 (2.1)	4.9 (2.1)	3.3 (1.0)	6.1 (2.7)	4.4 (2.3)	3.5 (1.0)	6.4 (2.6)	4.5 (2.2)
Running/week [h (sd)]	4.9 (1.5)	10.3 (3.5)	6.7 (3.4)	4.3 (1.5)	7.8 (2.6)	5.6 (2.6)	4.5 (1.6)	8.6 (3.1)	6.0 (3.0)
Running/week [km (sd)]	40.6 (12.9)	89.3 (30.3)	56.5 (30.6)	38.1 (13.3)	82.3 (29.9)	55.0 (30.2)	39.0 (13.2)	84.5 (30.0)	55.6 (30.2)
Running speed (min/km)	5.5 (0.4)	5.3 (0.6)	5.4 (0.5)	5.4 (0.4)	4.9 (0.5)	5.2 (0.5)	5.4 (0.4)	5.0 (0.5)	5.3 (0.5)
Strength training (min/week)	60.8 (34.9)	63.2 (61.8)	61.6 (44.9)	33.2 (29.4)	58.5 (57.1)	42.9 (43.7)	43.4 (34.1)	60.0 (58.1)	49.5 (44.9)
Alternative training [*n* (%)]	29 (74.4)	11 (57.9)	40 (69.0)	42 (63.6)	26 (63.4)	68 (63.6)	71 (67.6)	37 (61.7)	108 (65.5)
Sessions/week (*n*)	1.4 (1.2)	1.9 (2.5)	1.6 (1.7)	1.2 (1.3)	2.0 (2.4)	1.6 (1.8)	1.3 (1.2)	2.0 (2.4)	1.6 (1.8)
Injury history									
Previous serious injury [*n* (%)]	11 (28.2)	9 (47.4)	20 (34.5)	32 (48.5)	19 (46.3)	51 (47.7)	43 (41.0)	28 (46.7)	71 (43.0)
Ongoing injury [*n* (%)]	13 (33.3)	9 (47.4)	22 (37.9)	16 (24.2)	10 (24.4)	26 (24.3)	29 (27.6)	19 (31.7)	48 (29.1)
Regular use analgesics [*n* (%)]	22 (56.4)	14 (73.7)	36 (62.1)	23 (34.8)	21 (51.2)	44 (41.1)	45 (42.9)	35 (58.3)	80 (48.5)

components resulted in 105 athletes being allocated to the low exercise load category and 60 athletes allocated to the high load category (**Table 1**). Women clustered in the high load category ran more than the women clustered in the low load category in terms of distance (89.3 km vs. 40.6 km per week), time (10.3 h vs. 4.9 h per week), and sessions (6.9 vs. 3.9 sessions per week). Also the male runners clustered in the high load category ran more in terms of distance (82.3 km vs. 38.1 km per week), time (7.8 h vs. 4.3 h per week), and sessions (6.1 vs. 3.3 sessions per week).

Runners' Perceptions of Overuse Injury

The recognition of overuse injury among the runners as assessed by the Identity dimension in the IPQ-R-S-Overuse-injury symptoms was diffuse (**Table 2**). The symptom most commonly reported by the runners (80.1% of the respondents) to be associated with overuse injury was pain. Other symptoms connected with overuse injury were stiff muscles (54.1%), stiff joints (42.0%), and impaired physical ability (40.0%).

The understanding of overuse injury was among the ultramarathon and marathon runners characterized by possibility to personal control, treatability, and that the injury context was comprehensible (**Table 3**). Overuse injury was to a lesser extent distinguished by emotional representations and severe consequences for the runner, and the timeline included both cyclic and chronic representation of symptoms.

The runners perceived the main causes of overuse injury to be runner biomechanics, the runner's personality, and biomechanics associated with the running surface (**Table 3**). Less dominant causes contributing to overuse injuries were coaching, exercise overload, and alcohol, smoking and lifestyle. Individual predisposition for injury and stress and worry were perceived to be less important causes.

Compound Components Perceived to Predispose for Overuse Injury

The PCA analysis of the 28 variables in IPQ-R-S-Overuse injury section C resulted in eight causal components perceived by the runners to predispose for overuse injury (**Table 4**).

Component 1 *Stress and worry* describes the attributes stress and anxiety as explanations for overuse injury. The two variables that most strongly loaded on the component were family problems or concerns followed by the emotional state (depression, loneliness, anxiety, and emptiness).

Component 2 *Alcohol/smoking and lifestyle* describes substance use together with lifestyle as explanations of overuse injury. Alcohol and smoking were the variables with strongest loadings followed by accidents and poor general health status.

Component 3 *Exercise overload* describes exercise load that exceeds the individual's ability as explanation for overuse injury. The variables with strongest loadings were overtraining (for a longer continuous period) followed by overuse (on occasional occasions).

Component 4 *Predisposition for overuse injury* describes different forms of predisposition or susceptibility. The variables coincidence or bad luck, poor previous medical care, and heredity showed the strongest loadings.

Component 5 *Coaching* includes different aspects of coaching as possible explanation for overuse injury. The strongest loading was shown by poorly monitored exercise.

Component 6 *Biomechanics (runner)* describes various aspects of runner biomechanics. The variable with strongest loading was poor equipment (e.g., shoes) followed by poor running technique.

Component 7 *Biomechanics (surface)* includes different aspects of biomechanics associated with the running surface. The variable with the strongest loading was the transition between different surfaces.

Component 8 *The runner's personality* includes behavioral items that can explain overuse injury occurrence among long-distance runners. The correlating causal variables were own behavior followed by own personality.

Differences in Perception Between Runners With High and Low Exercise-Load

In the multiple model for men (Nagelkerke R^2 = 0.257), a strong agreement with the statement that personality contributes to overuse injury increased the likelihood of belonging to the high exercise load category [Odds ratio (OR) 2.10 [95% Confidence interval (95% CI) 1.38–3.19]; P = 0.001], while a strong perception that running biomechanics [OR 0.56 (95% CI 0.37–0.85); P = 0.006] and mileage [OR 0.72 (95% CI 0.54–0.96); P = 0.026] contributes to injury causation decreased the likelihood (**Table 5**). In the multiple model for women (Nagelkerke R^2 = 0.229), a strong perception that overuse injuries can be controlled by medical interventions decreased the likelihood of belonging to the higher load category [OR 0.68 (95% CI 0.52–0.89); P = 0.005]. In the multiple model for the total study group (Nagelkerke R^2 = 0.179), the likelihood of belonging to the higher exercise load category was increased by a strong agreement with that personality contributes to overuse injury [OR 1.57 (95% CI 1.16–2.12); P = 0.004] and that overuse injuries have serious consequences [OR 1.11 (95% CI 1.00–1.23); P = 0.043]. A strong perception that overload injuries can be controlled by medical interventions decreased the likelihood of belonging to the high-load category [OR 0.77 (95% CI 0.67–0.89); P = 0.001].

DISCUSSION

The aim of this study was to use the CSM to investigate perceptions of overuse injury among ultramarathon and marathon runners and whether some perceptions distinguish runners with the highest loads. Similar to a previous study based on the IPQ-R-S among injured athletes (van Wilgen et al., 2010), we observed that the long-distance runners associated overuse injury with a diffuse illness identity (pain was the outstanding complaint) and a high perceived manageability of the injury problem. Even though the runners related overuse injury with both chronic and cyclic timelines, a high illness coherence suggest that they still perceived they comprehended the nature of this particular threat to their health. The runners expressed trust in their possibilities

TABLE 2 | Descriptive data for the IPQ-R dimension "Identity" [mean score (standard deviation)] and frequencies of marathon and ultramarathon runners [numbers (percent)] associating IPQ-R symptoms with overuse injury displayed by runner exercise load categories and sex.

	Training load categories								
	Female runners			Male runners			All runners		
	Low load *n* = 39	**High load *n* = 19**	**Total *n* = 58**	**Low load *n* = 66**	**High load *n* = 41**	**Total *N* = 107**	**Low load *n* = 105**	**High load *n* = 60**	**Total *n* = 165**
Identity [mean (*sd*)]	18.8 (10.0)	24.7 (19.7)	20.6 (13.9)	17.7 (14.3)	19.8 (15.0)	18.5 (14.5)	18.1 (12.8)	21.3 (16.5)	19.2 (14.3)
Pain [*n* (%)]	33 (86.8)	15 (83.3)	48 (85.7)	50 (76.9)	31 (77.5)	81 (77.1)	83 (80.6)	46 (79.3)	129 (80.1)
Stiff muscles [*n* (%)]	27 (69.2)	10 (58.8)	37 (66.1)	31 (49.2)	17 (44.7)	48 (47.5)	58 (56.9)	27 (49.1)	85 (54.1)
Stiff joints [*n* (%)]	19 (48.7)	9 (52.9)	28 (50.0)	23 (35.9)	15 (40.5)	38 (37.6)	42 (40.8)	24 (44.4)	66 (42.0)
Impaired physical ability [*n* (%)]	12 (31.6)	8 (44.4)	20 (35.7)	23 (35.9)	21 (52.5)	44 (42.3)	35 (34.3)	29 (50.0)	64 (40.0)
Restlessness [*n* (%)]	9 (23.7)	4 (22.2)	13 (23.2)	8 (12.5)	12 (30.0)	20 (19.2)	17 (16.7)	16 (27.6)	33 (20.6)
Tiredness [*n* (%)]	4 (10.5)	5 (29.4)	9 (16.4)	12 (19.0)	8 (21.1)	20 (19.8)	16 (15.8)	13 (23.6)	29 (18.6)
Insomnia [*n* (%)]	3 (7.9)	4 (22.2)	7 (12.5)	8 (12.5)	7 (17.5)	15 (14.4)	11 (10.8)	11 (19.0)	22 (13.8)
Upset stomach [*n* (%)]	4 (10.5)	4 (22.2)	8 (14.5)	4 (6.3)	3 (7.5)	7 (6.7)	8 (7.9)	7 (12.1)	15 (9.4)
Breathlessness [*n* (%)]	1 (2.6)	3 (16.7)	4 (7.1)	5 (7.9)	4 (10.3)	9 (8.8)	6 (5.9)	7 (12.3)	13 (8.2)
Weight gain [*n* (%)]	0 (0.0)	3 (16.7)	3 (5.4)	6 (9.4)	2 (5.1)	8 (7.8)	6 (5.9)	5 (8.8)	11 (6.9)
Sore throat [*n* (%)]	1 (2.6)	0 (0.0)	1 (1.8)	1 (1.6)	5 (12.5)	6 (5.8)	2 (2.0)	5 (8.8)	7 (4.4)
Heavy breath [*n* (%)]	0 (0.0)	1 (5.6)	1 (1.8)	3 (4.7)	3 (7.5)	6 (5.8)	3 (2.9)	4 (6.9)	7 (4.4)
Dizziness [*n* (%)]	0 (0.0)	2 (11.8)	2 (3.7)	4 (6.3)	1 (2.6)	5 (4.9)	4 (4.0)	3 (5.4)	7 (4.5)
Headache [*n* (%)]	0 (0.0)	1 (5.6)	1 (1.8)	4 (6.3)	1 (2.5)	5 (4.8)	4 (4.0)	2 (3.4)	6 (3.8)
Nausea [*n* (%)]	3 (7.9)	1 (5.6)	4 (7.1)	1 (1.6)	0 (0.0)	1 (1.0)	4 (3.9)	1 (1.8)	5 (3.1)
Weight loss [*n* (%)]	1 (2.6)	1 (5.9)	2 (3.6)	1 (1.6)	0 (0.0)	1 (1.0)	2 (2.0)	1 (1.8)	3 (1.9)

The dimension score is standardized (to maximal score 100) using min-max normalization.

TABLE 3 | Descriptive data for the IPQ-R dimensions outlining the perceived characteristics of overuse injury and its perceived causes displayed by exercise load category and sex.

	Exercise load categories								
	Female runners			**Male runners**			**All runners**		
Mean (sd)	**Low load *n* = 39**	**High load *n* = 19**	**Total *n* = 58**	**Low load *n* = 66**	**High load *n* = 41**	**Total *n* = 107**	**Low load *n* = 105**	**High load *n* = 60**	**Total *n* = 165**
Overuse injury characteristics									
Personal control	77.6 (9.5)	77.4 (10.8)	77.5 (9.8)	79.2 (11.7)	79.6 (11.9)	79.4 (11.7)	78.6 (10.9)	78.9 (11.5)	78.7 (11.1)
Treatability	74.0 (13.1)	62.1 (12.8)	70.1 (14.1)	79.2 (12.6)	68.0 (13.5)	70.6 (13.0)	72.9 (12.8)	66.2 (13.4)	70.4 (13.4)
Comprehension of context	71.2 (14.5)	66.6 (19.7)	69.7 (16.3)	71.5 (15.7)	65.1 (17.1)	69.1 (16.5)	71.4 (15.2)	65.6 (17.8)	69.3 (16.2)
Emotional representations	59.5 (17.3)	58.8 (18.2)	59.3 (17.4)	50.6 (17.7)	54.7 (16.7)	52.1 (17.4)	53.9 (18.0)	56.0 (17.1)	54.6 (17.7)
Timeline – cyclic symptoms	51.1 (14.7)	59.2 (9.6)	53.8 (13.7)	52.2 (12.2)	48.9 (15.6)	50.9 (13.6)	51.8 (13.1)	52.2 (14.7)	51.9 (13.7)
Timeline – chronic symptoms	46.9 (15.0)	50.2 (20.6)	48.0 (16.9)	48.4 (16.9)	48.4 (15.7)	48.4 (16.4)	47.9 (16.1)	49.0 (17.3)	48.3 (16.5)
Consequences (for the runner)	46.9 (16.2)	47.1 (14.7)	47.0 (15.6)	42.9 (13.3)	49.8 (15.4)	45.6 (14.5)	44.4 (14.5)	49.0 (15.1)	46.1 (14.9)
Identity	18.8 (10.0)	24.7 (19.7)	20.6 (13.9)	17.7 (14.3)	19.8 (15.0)	18.5 (14.5)	18.1 (12.8)	21.3 (16.5)	19.2 (14.3)
Overuse injury causes									
Biomechanics (Runner)	81.4 (13.4)	78.3 (18.1)	80.4 (15.0)	79.5 (13.1)	73.2 (15.9)	77.1 (14.5)	80.2 (13.2)	74.8 (16.7)	78.3 (14.7)
Runner's personality	69.2 (16.7)	71.7 (18.6)	70.0 (17.2)	70.6 (15.3)	78.7 (14.6)	73.7 (15.4)	70.1 (15.7)	76.5 (16.1)	72.4 (16.1)
Biomechanics (Surface)	74.7 (17.1)	69.1 (16.9)	72.8 (17.1)	68.6 (17.0)	68.3 (16.8)	68.5 (16.9)	70.8 (17.2)	68.5 (16.7)	70.0 (17.0)
Coaching	67.1 (14.3)	65.4 (14.8)	66.5 (14.3)	62.2 (17.3)	58.7 (18.3)	60.9 (17.7)	64.0 (16.4)	60.8 (17.4)	62.9 (16.8)
Exercise overload	63.1 (9.7)	64.1 (11.9)	63.5 (10.4)	63.4 (9.6)	59.3 (9.7)	61.8 (9.8)	63.3 (9.6)	60.8 (10.6)	62.4 (10.0)
Alcohol, smoking, and lifestyle	63.5 (18.8)	61.5 (18.7)	62.8 (18.6)	60.8 (17.2)	60.5 (15.1)	60.7 (16.4)	61.8 (17.8)	60.8 (16.2)	61.4 (17.2)
Predisposition (uncontrollable)	57.1 (16.9)	57.2 (14.0)	57.1 (15.9)	54.7 (15.5)	50.5 (13.4)	53.1 (14.8)	55.6 (16.0)	52.6 (13.9)	54.5 (15.3)
Stress and worry	52.6 (16.5)	55.6 (19.0)	53.6 (17.3)	49.6 (18.5)	51.2 (17.0)	50.2 (17.9)	50.7 (17.8)	52.6 (17.6)	51.4 (17.7)

The dimension scores are standardized (to maximal score 100) using min-max normalization (standard deviation).

TABLE 4 | Allocation of IPQ-R-S items describing overuse injury causes (C1–C28) into preliminary components (PC1–PC8) and compound causal components (CC1–CC8).

	IPQ-R-S cause item	Preliminary components								Causal component (CC)
		PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	
C1	Stress or worry	0.73								CC 1 stress and worry
C4	Diet or eating habits	0.56	0.36							
C9	Mental attitude, e.g., negative thoughts about life	0.75								
C10	Family problems or worries cause overload damage	0.82								
C11	Too much work	0.59						0.38		
C12	Emotional state e.g., depression, loneliness, anxiety, emptiness	0.80								
C18	Changes in the immune system	0.50	0.40							
C14	Alcohol	0.36	0.77							CC 2 alcohol/smoking and lifestyle
C15	Smoking	0.31	0.76							
C16	Accident or injury		0.63							
C23	Poor health status	0.40	0.52					0.32		
C3	A bacterium or virus	0.40		−0.35						CC 3 exercise overload
C7	Environmental pollution			−0.46						
C19	Exercise overload (long continuous period)			0.83						
C20	Exercise overload (acute/short period)			0.79						
C2	Heredity, it is in the family	0.35			0.57					CC 4 predisposition for overuse injury
C5	Coincidences or bad luck				0.77					
C6	Poor past medical care				0.63					
C13	Aging			0.32	0.55					
C26	Coaching/coaches					0.71				CC 5 coaching
C27	Poorly supervised exercise					0.84				
C28	Poor preparation/warm-up		0.35	0.33		0.38	0.36			
C21	Poor/changed equipment			0.37			0.70			CC 6 biomechanics (runner)
C22	Bad material (e.g., shoes)						0.82			
C24	Transition between different surfaces/terrains							0.78		CC 7 biomechanics (surface)
C25	Poor training set-up			0.49				0.52	0.37	
C8	Own behavior			0.32					0.77	CC 8 the runner's personality
C17	Own personality	0.30			−0.31	0.42			0.47	

Principal component analysis [correlations in the rotated component matrix (correlation range −1 to 1) are shown].

to manage overuse injuries and generally associated these injuries with moderate consequences in their daily lives. Accordingly, they did not associate the injury category with strong emotional manifestations.

The overuse injury causes brought to the fore by most runners were runner biomechanics, the runner's personality, and biomechanics associated with the running surface. Previous studies have observed that ultramarathon runners and runners with high exercise loads often are people with a strong drive to explore their physical and mental limits (Masters and Ogles, 1995; Ogles and Masters, 2000; Ogled and Masters, 2003). A question is whether consistent "limits-exploring" traits exist in this category of runners (Roebuck et al., 2018a), and, if so, what impact these traits have on injury predisposition. The male runners with high exercise load in this study were less convinced than those with lower loads that running techniques were decisive for the occurrence of overuse injury. Instead, the importance of personality was highlighted. Also among women, runners with a high exercise load were more prone to indirectly highlight the importance of personal responsibility in prevention of overuse injuries, as they more than runners with a lower load submitted to that possibilities are limited for secondary prevention of overuse injuries using medical interventions. These findings can be compared to previous studies among competitive runners, which have showed that elite runners report "Ignoring pain" as a main risk factor for running injury (Johansen et al., 2017) and that the gradual onset of overuse injuries leads to behavioral responses characterized by neglect of the long-term implications of the injury (Reed and Ones, 2006). Together, these observations suggest that a characteristic of ultramarathon and marathon runners with high exercise loads is that these runners are conscious of

TABLE 5 | Associations between perceptions of overuse injury and belonging to the high exercise load category among long-distance runners displayed by sex [odds ratio (95% confidence interval)].

	High exercise load					
	Female runners (n = 58)		Male runners (n = 107)		All runners (n = 165)	
Overuse injury perceptions	**Simple models**	**Multiple model**	**Simple models**	**Multiple model**	**Simple models**	**Multiple model**
Characteristics						
Treatability	0.68 (0.52–0.89) (P = 0.005)	0.68 (0.52–0.89) (P = 0.005)	n.s.		0.82 (0.72–0.93) (P = 0.003)	0.77 (0.67–0.89) (P = 0.001)
Comprehension of context	n.s.		n.s.**		0.90 (0.81–0.99) (P = 0.031)	
Timeline – cyclic symptoms	1.39 (1.01–1.90) (P = 0.041)		n.s.		n.s.	
Severe consequences	n.s.		1.15 (1.02–1.30) (P = 0.019)		n.s.*	1.11 (1.00–1.23) (P = 0.043)
Causes						
Exercise overload	n.s.		0.76 (0.58–0.99) (P = 0.040)	0.72 (0.54–0.96) (P = 0.026)	n.s.	
Biomechanics (runner)	n.s.		0.67 (0.47–0.96) (P = 0.030)	0.56 (0.37–0.85) (P = 0.006)	0.72 (0.55–0.96) (P = 0.024)	
Runner's personality	n.s.		1.56 (1.11–2.20) (P = 0.011)	2.10 (1.38–3.19) (P = 0.001)	1.37 (1.06–1.77) (P = 0.016)	1.57 (1.16–2.12) (P = 0.004)
Nagelkerke R^2		R^2 = 0.229		R^2 = 0.257		R^2 = 0.179

**1.09 (1.00–1.20) (P = 0.060). **0.89 (0.78–1.00) (P = 0.054).*

their psychological and behavioral response to overuse injury symptoms, in particular pain. Of note, the notions of high exercise load and running experience are not synonymous. There may have been runners who had sustained overuse injuries when rapidly increasing their exercise load, and thereby had gained the insights about their own behavior during a short period of time.

The present findings have some interesting practical implications. The attention observed in this and previous studies to be paid by ultramarathon and experienced marathon runners to their psychological capacity and skills suggest that they are aware of the possibility of being harmed by a deficient inner self-critic. Mindfulness training is therefore an intervention that can relevant to supply to long-distance runners who increase their exercise load. Mindfulness is defined as a non-judgmental, purposeful and moment-to-moment awareness comprising consciousness, awareness, and attention (Kabat-Zinn, 1982). Mindfulness training differs from traditional psychological skills development such as thought control or cognitive reframing by that participants learn to act on situations thoughtfully and with an increased level of awareness and understanding, rather than acting emotionally or impulsively (Chiesa and Serretti, 2009; Lundqvist et al., 2018). It has been reported that a 4-week mindfulness-training intervention among recreational runners resulted in improvements of state mindfulness and trait awareness and decreases in sport-related worries personal standards perfectionism (De Petrillo et al., 2009), while no improvements in actual running performance were found. However, a recent systematic review of the evidence for mindfulness-training approaches in sports showed that although large effect sizes were found for improving mindfulness, flow, and performance, and lower competitive anxiety, none of the 66 studies included were rated as having a low risk of bias (Noetel et al., 2019). Further research using robust designs on mindfulness among ultramarathon and marathon runners on awareness and thoughtful management of pain and overuse injuries is therefore warranted.

This study has strengths and limitations that should be taken into consideration when interpreting the results. Studies on vulnerability in sport are generally scarce despite the topic is included in investigations of resilience and mental toughness (Sarkar and Fletcher, 2014; Uphill and Hemmings, 2016). This study used the an adapted version of the IPQ-R instrument (the IPQ-R-Overuse injury), which provides possibilities for comparisons with other populations of sportspersons suffering from overuse injuries, with perceptions of other health problems in sports, and with illness perceptions in general populations. To facilitate such comparisons, the original terminology and procedures were in the main utilized for the overuse injury adaptation. However, some notions were modified to support interpretations by sports scientists, e.g., the dimension scores were standardized. Moreover, the study population consisted of all competitive ultramarathon and marathon runners listed by the participating organizations. Although the number of invited runners (n = 443) was moderate, it represented all competitive long-distance runners in the communities involved. The overall participation rate (37.2%) is comparable to previous studies or slightly lower. Circumstances that affected the participation may have been that the data collection period comprised the pre-season and long weekends (travels abroad, etc.). Nonetheless, due to the limited number of participants, the possibility of type 1 errors occurring in the inference process should be taken into regard. It also should be taken into consideration that the study was performed among runners of Scandinavian decent and having a corresponding cultural and socioeconomic background. Generalization of the results to other populations of long-distance runners should be made with care. Finally, it should be noted that the main competition discipline (ultramarathon, marathon, etc.) was not taken into regard in the clustering of runners into high and exercise low load categories. Having the ambition to compete at ultramarathon distances may thus be associated with other psychological features than those associated with high exercise loads *per se*.

We conclude that the results of this study indicate that recognition among long-distance runners of the association between own decisions and tissue damage in overuse injury causation is accentuated by increased exercise loads.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

WW, FE, AS, VB, P-OH, ÖD, and TT conceived and designed the research project. WW and TT coordinated the study development, and made substantial contributions to drafting and writing the manuscript. FE and TT recruited the study participants. WW, ÖD, and TT were involved in data collection. AS and ÖD analyzed the data. All authors contributed to the data interpretation and provided a final approval of the version to be published. TT was the guarantor of the integrity of analysis and results.

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Cooper Test Provides Better Half-Marathon Performance Prediction in Recreational Runners Than Laboratory Tests

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This study compared the ability to predict performance in half-marathon races through physiological variables obtained in a laboratory test and performance variables obtained in the Cooper field test. Twenty-three participants (age: 41.6 ± 7.6 years, weight: 70.4 ± 8.1 kg, and height: 172.5 ± 6.3 cm) underwent body composition assessment and performed a maximum incremental graded exercise laboratory test to evaluate maximum aerobic power and associated cardiorespiratory and metabolic variables. Cooper's original protocol was performed on an athletic track and the variables recorded were covered distance, rating of perceived exertion, and maximum heart rate. The week following the Cooper test, all participants completed a half-marathon race at the maximum possible speed. The associations between the laboratory and field tests and the final time of the test were used to select the predictive variables included in a stepwise multiple regression analysis, which used the race time in the half marathon as the dependent variable and the laboratory variables or field tests as independent variables. Subsequently, a concordance analysis was carried out between the estimated and actual times through the Bland-Altman procedure. Significant correlations were found between the time in the half marathon and the distance in the Cooper test (r = −0.93; $p < 0.001$), body weight (r = 0.40; $p < 0.04$), velocity at ventilatory threshold 1, (r = −0.72; $p < 0.0001$), speed reached at maximum oxygen consumption (vVO_2max), (r = −0.84; $p < 0.0001$), oxygen consumption at ventilatory threshold 2 (VO_2VT2) (r = −0.79; $p < 0.0001$), and VO_2max (r = −0.64; $p < 0.05$). The distance covered in the Cooper test was the best predictor of time in the half-marathon, and might predicted by the equation: Race time (min) = 201.26 − 0.03433 (Cooper test in m) (R^2 = 0.873, SEE: 3.78 min). In the laboratory model, vVO2max, and body weight presented an R^2 = 0.77, SEE 5.28 min. predicted by equation: Race time (min) = 156.7177 – 4.7194 (vVO_2max) – 0.3435 (Weight). Concordance analysis showed no differences between the times predicted in the models the and actual times. The data indicated a high predictive power of half marathon race time both from the distance in the Cooper test and *v*VO2max in the laboratory. However, the variable associated with the Cooper test had better predictive ability than the treadmill test variables. Finally, it is important to note that these data may only be extrapolated to recreational male runners.

Keywords: prediction equations, comparison performance methods, long-distance runners, field test, laboratory test

INTRODUCTION

The number of half-marathon runners has increased steadily over the past ten years. As an example, in the United States the number has doubled in just a decade, reaching two million in 2013. Similarly, in Europe, it is estimated that there are around 50 million people who are regular long-distance runners (Scheerder et al., 2015). Furthermore, in Spain more than 300 half-marathon races are held annually, with an important number of runners. As a result, an increasing number of amateur runners train assiduously to finish the races and improve their personal race times. It is very helpful for them to know their ideal paces or speeds for training and competition. Accordingly, identifying these values in advance is an objective necessity, for both the athletes and their coaches.

The physiological variables related to performance have been previously described (Ramsbottom et al., 1987). In the case of long-distance runners, those variables obtained in the incremental laboratory tests, essentially maximal oxygen consumption (VO_2max) and its related variables, have been very useful for observing the adaptations produced by training (Legaz Arrese et al., 2006), and to predict performance in competition (Foster, 1983). Additional laboratory tests and associated variables have been proposed that may be determinants of long-duration aerobic performance. Thus, the finish time in cross-country races has been associated with a high percentage of oxygen consumption (Loftin et al., 2007), as well as with blood lactate accumulation (Loftin et al., 2007), lactate threshold (Mujika et al., 2000), ventilatory threshold, or race economy (speed reached for a given oxygen consumption) (Amann et al., 2004; Saunders et al., 2004; Lucia et al., 2006; Støren et al., 2008; Santos-Concejero et al., 2017). However, it appears that the maximal speed achieved in the laboratory tests is the variable most closely associated with sports performance, regardless of the duration of the test (Noakes et al., 1990; Knechtle et al., 2011a; Ronconi and Alvero-Cruz, 2011).

Despite conclusions from previous research, most of the participants in these studies were elite or high-level athletes, and studies that focus specifically on the half-marathon are lacking (Tanaka et al., 1984; Weyand et al., 1994; Roecker et al., 1998). Those studies carried out in amateur runners described the following as the main predictors of final test performance: kilometers per week, number of weeks of training for each event, body mass index, resting heart rate (Campbell, 1985), anaerobic threshold and $v$$VO_2$max (Roecker et al., 1998), anthropometric variables (Knechtle et al., 2011a,b, 2014), or fat percentage combined with average running speed during training (Knechtle et al., 2014). However, almost all the models used in these studies involve some form laboratory assessment, and are, therefore, hardly applicable in most of the amateur population.

The usefulness of field tests (Penry et al., 2011; Alvero-Cruz et al., 2017) for the assessment of the physiological construct of aerobic condition has shown great variability with respect to laboratory tests, although their validity in predicting the construct of final race performance has been poorly addressed in the literature. It should be noted that there is a paradox between the high reliability and low ecological validity of laboratory assessments and the low reliability and high validity of the methods used in field tests (Reilly et al., 2009; Galbraith et al., 2014; Llodio et al., 2016). The Cooper test, given its simplicity of application and low cost, has traditionally been widely used to estimate maximal oxygen consumption (Cooper, 1968), but its ability to predict constructs associated with sports performance in long-distance runners, such as half-marathon runners (Grant et al., 1995), has never been evaluated. Therefore, the objective of this study was to compare the predictive ability of half-marathon race time between two models derived from: (a) variables obtained in treadmill tests and (b) the Cooper test.

MATERIALS AND METHODS

Experimental Approach to the Problem

During a single visit to the laboratory, various physiological performance variables were obtained through treadmill testing and anthropometric parameters were measured with the aim of predicting half-marathon finish time. It was hypothesized that a combination of physiological variables measured during physical effort would explain half-marathon performance. Prediction equations based on the laboratory variables that best predicted performance compared with the distance covered in the Cooper Test were subsequently developed.

Participants

The laboratory study involved 23 amateur male athletes, with a mean age of 41.6 ± 7.4 years, with experience in training (8.3 ± 5.65 years) and long-distance races. The protocol was approved by the University Ethics Committee in accordance with the Declaration of Helsinki for human research. The participants were informed of the objectives, protocols and risks associated with the experiment, and signed a written informed consent to participate in the study.

Experimental Design

Laboratory assessments were performed in February 2011, in a single session and the half-marathon race was held at the beginning of March of the same year. Between 10 and 21 days before the half-marathon a treadmill tests were carried out, and 7 to 10 days before the half-marathon race, in other session the athletes performed the Cooper test. All the athletes were engaged and motivated to perform at maximal effort, using their maximum heart rate for quality control of maximal effort exerted during the test (**Figure 1**).

For collection of the independent variables (associated with the different assessments), all the participants underwent a body composition assessment using anthropometry and an incremental exercise test in the laboratory with analysis of exhaled air, on the same day and within three weeks before the race. Subsequently, they undertook a Cooper test on a track, with an analysis of blood lactate. For each assessment, both in the laboratory and in the field test, which were conducted on different days, the participants were reminded to rest the day before and to have at least one meal with a high proportion of carbohydrates the previous day (rice and pasta).

Procedures

Anthropometric Assessment

All measurements were conducted after a 12-h fast. Weight was measured on a SECA 813 electronic scale (Hamburg, Germany) with an accuracy of 0.1 kg, and height was measured using a wall mounted SECA 216 stadiometer (Hamburg, Germany) with an accuracy 0.1 cm. Skinfolds were measured in triplicate at the following sites: triceps, subscapular, biceps and iliac crest, computing the mean for their calculation. Percentage of body fat was estimated with the Durnin-Womersley equation (Durnin and Womersley, 1974). All measurements were collected under the standardized procedures of the International Society for Advancement in Kinanthropometry (Marfell-Jones et al., 2006). The technical error of measurement of the technician was less than 3% for skinfolds and 1% for the rest of the anthropometric measurements.

Laboratory Test

All participants underwent a maximum incremental exercise test to determine VO_2max, as well as respiratory and metabolic exchange variables such as carbon dioxide output (VCO_2), end-tidal oxygen tension ($PetO_2$), end-tidal carbon dioxide tension ($PetCO_2$), ventilation, and respiratory exchange ratio (RER). The expired gases were measured breath by breath and recorded in an Ultima gas analyzer system (MedGraphics, Saint Paul, MN, United States). The system was automatically calibrated before each test, according to the manufacturer's instructions. Heart rate was recorded using a telemetric electrocardiography device (X-Scribe, Mortara, Milwaukee, WI, United States) connected to the system. Aerobic (VT1) and anaerobic (VT2) ventilatory thresholds were determined using Skinner and McLellan (1980) methodology. The participants ran on a treadmill (Ms Medisoft 870, Medisoft, Italy) according to the following protocol: After a 10-min warm-up at 5 km/h, the test began at 6 km/h with a constant gradient of 1%, and increases of 1 km/h/min until volitional exhaustion. The test was considered maximum when respiratory exchange ratio $\geq$ 1.15 or there was an increase of less than 2.1 ml/kg/min in VO_2 between the two stages, or when a range $\pm$ 10 beats/min of the maximum predicted heart rate was reached, without these being excluding requirements according to ACSM Guidelines for exercise testing and prescription (American College of Sports Medicine, 2014). The velocity corresponding to VO_2max (vVO_2max), was defined as the minimum speed at which VO_2max is reached (Billat et al., 1996). All the participants received verbal encouragement from the investigators to give their maximum possible effort. The percentage with respect to the theoretical heart rate (220-age) was calculated from the heart rate values. All tests were controlled by the research team.

Cooper Test

The Cooper test (Cooper, 1968) was performed on a 400-m synthetic athletic track with the supervision of the research team. Before the test began, a 15-min warm-up of continuous running was performed at a low-moderate pace in addition to calisthenics exercises. Subsequently, the participants carried out the classic test protocol, which consisted of covering the maximum possible distance for 12 min. Immediately after completion of the test, the distance traveled was measured by means of markers placed on the track at set intervals of 50 m. During the test, the participants used a 610 Polar monitor (Polar Electro Oy, Finland). The heart rate at the end of the Cooper test was considered the maximal heart rate achieved in the test. Additionally the perceived effort

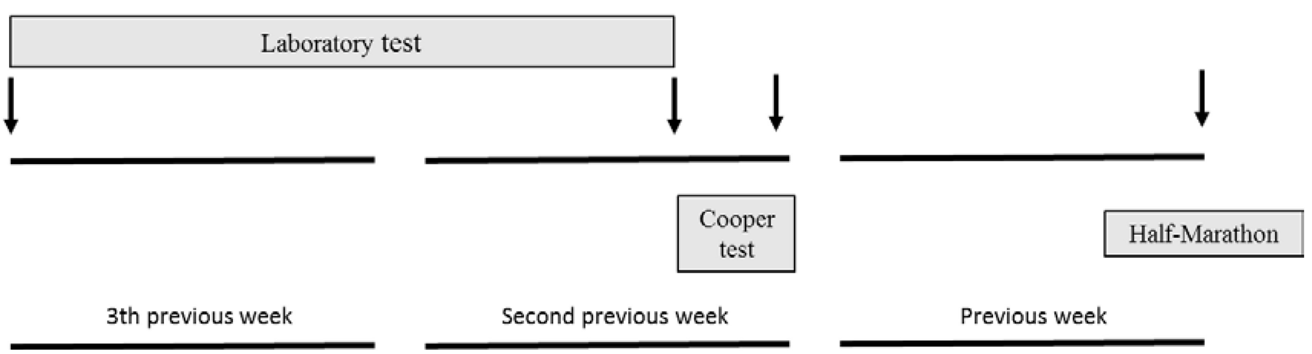

FIGURE 1 | Schedule of laboratory and Cooper tests and the half-marathon.

of the trial was recorded at the end of the test using the modified Borg visual scale (Borg, 1982).

Blood Lactate

At the end of the Cooper test and in the first minute (Cabral-Santos et al., 2017), a 0.5-μl blood sample was extracted from the earlobe for measurement of the blood lactate concentration using an enzyme electrode method (Lactate Pro LT-1710, Arkray, Japan). The objective of this analysis was to corroborate the lactate level after a steady state pace. The coefficient of variation of the analyzer used is 3%.

Weather Conditions

The weather conditions on the day of the half-marathon were cloudy, with wet soil but no rain at the time of the test. Testing took place between 10:00 a.m and 12:00 p.m, and temperatures ranged from 14 to 17°C with a relative humidity of 42% and wind less than 14 km/h.

Statistical Analyses

The data are presented as means and standard deviations. Normality was analyzed using the Shapiro-Wilk test. Since all the variables were normally distributed, an association analysis between variables was performed using the Pearson correlation coefficients. Variables significantly associated with race time in the half-marathon were included in a stepwise multiple regression analysis to estimate the predictors of race time (dependent variable) from two blocks of independent variables (from the laboratory and the Cooper test). Subsequently, a concordance analysis was carried out between the values predicted with the equations, obtained from the Cooper test and the laboratory model, and the actual race times in the half marathon, using Bland-Altman procedures (Bland and Altman, 1986). The difference between the values was tested with a Student's t-test and the bias using Kendall's tau correlation coefficient. The level of significance in all cases was set at $p < 0.05$. The statistical analysis was performed on MedCalc Statistical Software version 19.1 (MedCalc Software bv, Ostend, Belgium, 2019)[1].

RESULTS

The characteristics of the participants are shown in **Table 1**. All were older than 30 years of age, and their body mass index values and fat mass percentage indicated that they did not have excess adiposity.

Table 2 presents the data on the laboratory variables. The mean HR max at the end of the treadmill test was 181 ± 14 bpm and the heart rate of the Cooper test of 177 ± 13 bpm without significant differences ($P = 0.47$). Respiratory exchange ratio values at the end of exercise confirm maximal effort.

Cooper and Blood Lactate Test

The Cooper test values generally denote a maximal effort test in relation to mean lactate values of 8.31 ± 2.87 mmol/L and the high percentage of maximum theoretical heart rate (**Table 3**).

Half Marathon Race Time

The half-marathon race was completed by all 23 runners. The mean race time of the runners was 93.28 ± 10.28 min, range (73–117 min), (CV = 11%), at an average speed of 13.68 ± 1.57 km/h (CV = 11%).

Bivariate Correlations

Table 4 shows the correlation coefficients between the half-marathon race time and the different variables. Of note are the correlations with distance covered in the Cooper test ($P < 0.0001$), velocity at ventilatory threshold 2 (vVT2),

[1] https://www.medcalc.org

TABLE 1 | Characteristics of the sample (*n* = 23).

	Mean ± *SD*
Age (years)	41.66 ± 7.46
Weight (kg)	70.38 ± 8.15
Height (cm)	172.54 ± 6.35
Body mass index (kg/m^2)	23.60 ± 1.99
Fat mass (%)	15.73 ± 4.68

TABLE 2 | Treadmill test variables.

Variable	Mean ± *SD*
VO_2VT1 (mL/kg/min)	36.48 ± 5.77
VO_2VT2 (mL/kg/min)	48.63 ± 7.24
VO_2max (mL/kg/min)	55.73 ± 8.34
HRVT1 (ppm)	140.81 ± 14.60
HRVT2 (ppm)	165.28 ± 15.07
HRMax (ppm)	180.63 ± 14.74
HRMaxLab/HRMaxTheo (%)	101.34 ± 8.60
VelVT1 (km/h)	11.16 ± 1.20
VelVT2 (km/h)	15.31 ± 1.88
vVO_2max (km/h)	18.43 ± 1.80
RERVT1	0.85 ± 0.07
RERVT2	0.99 ± 0.08
RERMax	1.15 ± 0.11

VO_2VT1, oxygen uptake at VT1; VO_2VT2, oxygen uptake at VT2; HRVT1, heart rate at VT1; HRVT2, heart rate at VT2; HRMax, maximum heart rate; HRMaxLab/HRMaxTheo, percentage MHRLab/MHR theoretical; VelVT1, speed at VT1; VelVT2, speed at VT2; vVO2max, speed at maximal oxygen uptake; RERVT1, respiratory exchange ratio at VT1; RERVT2, respiratory exchange ratio at VT2; RERMax, maximal respiratory exchange ratio.

TABLE 3 | Test de Cooper variables.

Variable	Mean ± *SD*
Cooper distance (m)	3121.48 ± 320.04
HR Cooper (bpm)	177.93 ± 13.56
HR Cooper/HRMax (%)	94.65 ± 23.37
Lactate after Cooper (mmol/L)	8.31 ± 2.87

HR, heart rate; HRMax, maximum heart rate (220-age).

TABLE 4 | Pearson correlation coefficients between half marathon race time and treadmill variables.

Variable	*r*	*P*
HRVT1	−0.058	0.78
HRVT2	−0.215	0.3
HRMax	−0.025	0.9
*v*VT1	−0.361	0.07
*v*VT2	−0.723	< 0.0001
vVO_2max	−0.849	< 0.0001
VO_2VT1	−0.292	0.15
VO_2VT2	−0.79	< 0.0001
VO_2max	−0.645	0.0005
Cooper distance	−0.932	< 0.0001

HR, heart rate; v, speed; VT, ventilatory threshold; vVO_2max, speed at VO_2max; r, correlation coefficient.

vVO2max (both $P < 0.0001$), VO_2VT2 ($P < 0.0001$), and VO_2max ($P < 0.0005$).

Multiple Regression Analysis

Table 5 shows the two half-marathon time prediction models. In the first model, the variable of the distance covered in the Cooper test with the equation: Race time (min) = 201.26 – 0.03433 (Distance covered Cooper test) and in the model derived from the treadmill assessment, the maximum speed reached in the test together with the body weight are of note with the next equation:

$$Racetime(min) = 156.7177 - 4:7194\,(vVO_2max) + 0.3435\,(Weight).$$

Concordance Analysis

The differences between the predicted value (Cooper test model) and the actual time in the half marathon were not significant (dif = −0.08 ± 3.8 min, $P = 0.91$), or bias (Kendall's tau, $r = -0.18$) ($P = 0.40$), with concordance limits of −7.5 to 7.4 min (**Figure 2A**). The laboratory test model values also showed no significant differences with the actual time (diff: −0.17 ± 5.03) ($P = 0.83$), with concordance limits of −9.7 to 10.0 min (**Figure 2B**).

The coefficient of variation between performance subjects (CV% = 100 × SD/mean) was calculated and the mean difference between the Cooper test was 20.46 m (95% CI: −20.22–61.15) (Alvero-Cruz et al., 2017).

DISCUSSION

To the best of our knowledge, this is the only study that has evaluated and compared the ability to predict race time in the half-marathon by means of a graded exercise test in the laboratory and a Cooper test. In this work, we have identified variables associated with race time in the half-marathon through both laboratory assessment and the Cooper test. In the literature, there were several studies on different performance determinants in middle- and long-distance runners, such as anthropometric variables (Arrese and Ostáriz, 2006; Knechtle et al., 2010, 2014; Friedrich et al., 2014), variables related to training load (Ramsbottom et al., 1987; Knechtle et al., 2011a; Balsalobre-Fernández et al., 2014) as well as physiological variables (Roecker et al., 1998; Reilly et al., 2009; Rabadán et al., 2011; Ronconi and Alvero-Cruz, 2011; Gómez-Molina et al., 2017; Støa et al., 2010), which have associations with half-marathon performance.

Our results reveal that the variables from both the laboratory and the Cooper test enable significant models to be obtained for the prediction of half-marathon race time. In addition, we found that the regression model from the distance covered in the Cooper test has a better predictive value. According to results of this study, the model developed from the distance covered in the Cooper test, would explain 87.3% of the total variance of half-marathon race time in recreational runners. The laboratory model that combines *v*VO2max and body weight would explain 76.95% of the total variance. The variables included in our models find partial similarities with other published studies. With respect to anthropometric variables, the skinfolds of the lower limbs, anterior thigh and medial calf are associated with performance in runners of 1500 and 10000 m (Arrese and Ostáriz, 2006). Rüst et al. (2011) found that race time in the half marathon in amateur runners was associated with BMI and average training speed. Similar results are also found in relation to BMI (Friedrich et al., 2014) and sum of six skinfolds with race time in half-marathon (Gómez-Molina et al., 2017) in male runners. Other

TABLE 5 | Multiple regression models derived from field and laboratory tests.

Model	Dep. variable	Indep. variable	Coefficient	R^2	R^2 adj	MCC	SEE	t	P	VIF
Cooper test	Race time (min)			0.873	0.866	0.934	3.78			
		Constant	201.26							
		Distance covered Cooper test	−0.03433					−11	< 0.0001	1
Treadmill test	Race time (min)			0.769	0.75	0.877	5.28			
		Constant	156.7117							
		vVO_2max	−4.7194					−7.9	< 0.0001	1.5
		Weight	0.3435					2.25	0.0339	1.05

R^2, coefficient of determination; adj, adjusted; MCC, multiple correlation coefficient; SEE, standard error of the estimate; VIF, variance inflation factor.

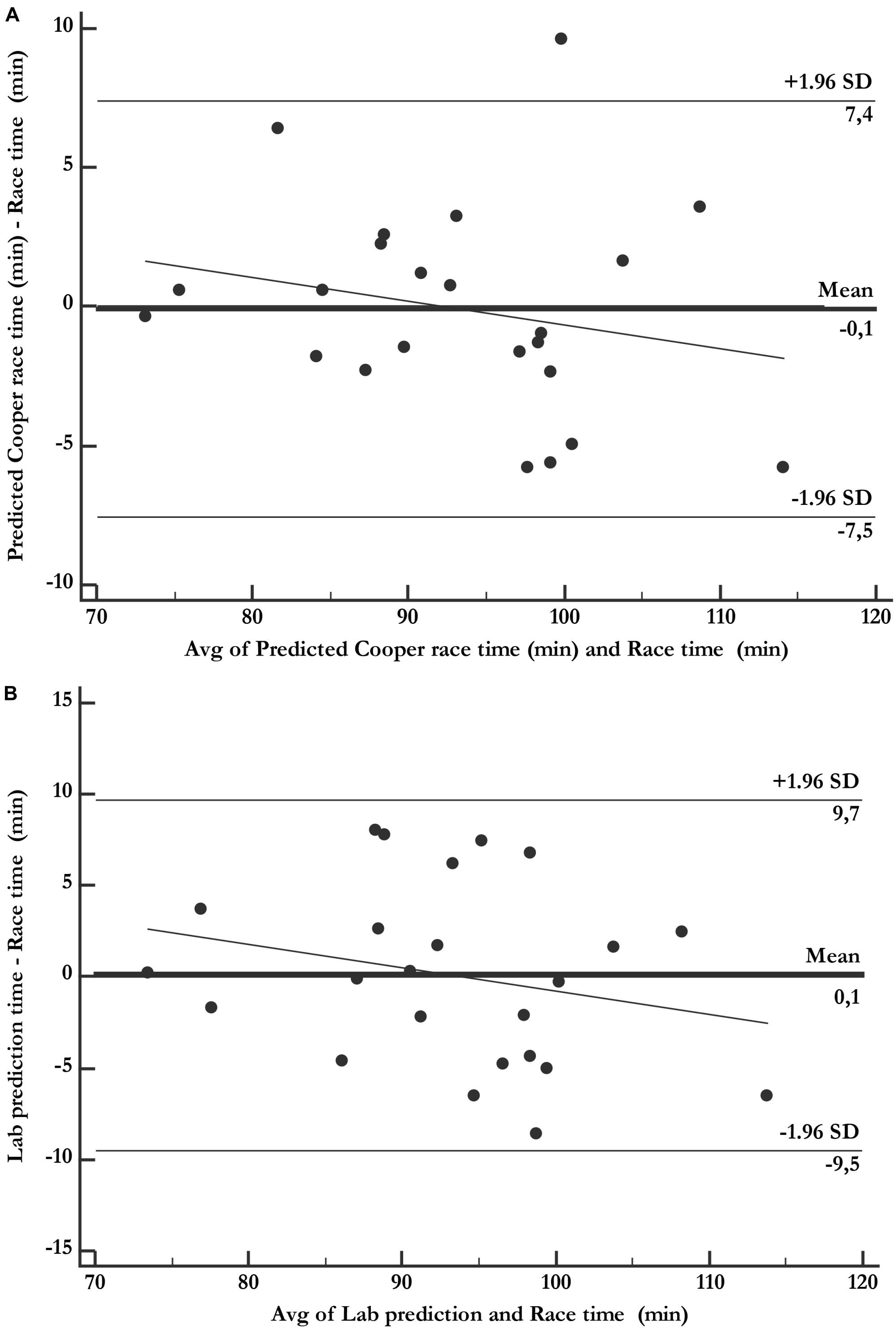

FIGURE 2 | Bland-Altman plots comparing predicted time with actual race time. **(A)** Cooper test. **(B)** Laboratory test.

authors have linked the fat mass percentage with performance in half- marathon (Knechtle et al., 2014).

The predictive model of this author explains only 44% of the race time, which can be explained by the wide limits of concordance in the prediction of race time (±25 min) and the great heterogeneity of the study sample. In our study, the only anthropometric variable that predicts race time is body weight.

Training load variables have traditionally been associated with performance in the half marathon. These include average training speed, previous experience, distance per week, hours per week, and daily training time (Friedrich et al., 2014). In the last of these studies, associations were found with the average training speed ($r = -0.77$ and $r = -0.58$, for women and men, respectively), with fat mass percentage and the average training speed as predictors. Despite the previous evidence, no training variables were introduced into our models, which must indicate the strong dependence of training on the variability of the test result.

The dependent variables in the laboratory prediction model explain 77% of the variance. *v*VO2max corresponds to around 72% and body weight to 5%. Similar aspects are those presented by Knechtle et al. (2014) who, in a recent study, found predictive models of race time in the half marathon based on body weight and average training speed as predictor variables, but explaining only 44% of the race time. The results of our research provide much more accurate equations, with a coefficient of determination of 0.873 for the equation derived from the Cooper test and 0.77 for the equation derived with body weight and *v*VO2max.

This group of researchers (Knechtle et al., 2014) sought to improve the prediction with new equations, introducing other independent variables into the model, such as the percentage of fat mass, obtaining an R^2 of only 0.42 for the men and 0.68 for women. These coefficients are still low compared to those of our study. These authors also failed to measure VO_2max and the maximum speed reached in the maximal graded test. They additionally analyze the accuracy of the prediction model using the limits of agreement (LA) between the actual value and the value predicted with the new equation. The LA of the study are very broad, between −25.6 and 24 min, with a proportional error as the race time increases. In our study, the LA for the equation derived from the distance covered in the Cooper test are from −7.4 to 7.5 min with no proportional error ($P < 0.05$).

The laboratory tests allowed us to obtain multiple variables, all of them well controlled and generally very reproducible. Maximal oxygen uptake is normally a good predictor of performance in long-distance runners (Hagan et al., 1981). However, this variable was not significant in either of our prediction models. Another factor that has frequently been associated with performance in runners is the maximum speed attained (*v*VO_2max) in the incremental exercise test in the laboratory (Roecker et al., 1998). In our study, vVO2max was also a predictor in the laboratory model. This is likely due to race intensity in the half marathon being close to maximal oxygen consumption or maximum aerobic speed. Race time in the half marathon is not always explained by the absolute value of VO_2max and is often best explained by the fractional use of VO_2max, corresponding to a running speed, usually of a submaximal character and therefore to a submaximal VO_2 value.

Nevertheless, Williams and Nute (1983) studied the physiological demands of half-marathon runners finding similarities in the physiological values of this study, in terms of the race times and VO_2max values of the athletes. This study evaluated four runners and the variables that related to performance were VO_2max and estimated speed at a concentration of 4 mmol/L of lactate, although they later verified that the average lactate values were 5.65 ± 1.42 mmol/L, which would confirm values close to VO_2max.

Other studies such as that by Rabadán (Rabadán et al., 2011) analyze in the laboratory the physiological determinants of middle- and long-distance runners, finding that VO_2max, VO_2VT2 and *v*VT2 are variables that characterize these athletes. The strength of variables such as VT2 is that they are very reproducible parameters and therefore very useful in predicting and evaluating changes based on training. They can also help differentiate the performance of middle- and long-distance runners. In the present study, these values were not found to be predictors of performance.

Limitations and Strengths of the Study

The main limitation is probably the small number of male participants and only performed in a half marathon event and therefore the results would only be applied to recreational runners between 73 and 117 min.

The main strength of this study is the comparison of prediction models in which the *v*VO_2max is found as the most frequently variable related to performance in runners (Morgan et al., 1989; Noakes et al., 1990; Muñoz et al., 2012) and an easy-to-perform field test in a training schedule.

Practical Applications

The number of long-distance runners has grown considerably in recent years. Accordingly, it is of great interest to trainers and sports science researchers to have accurate specifications regarding training and its intensities. This study enables the determination of the competition pace since an estimate of the final race time can provide greater precision in determining the different training paces, and can be assessed as often as necessary within the process. This also helps to guide the pace of the half-marathon race in amateur runners. The main application lies in the fact that a simple field test can substitute laboratory tests, offering more accurate information for the estimation of race performance, independently of physiological determinants. This undoubtedly provides a great advantage due to the simplicity of the procedure and the low economic and time cost.

CONCLUSION

The present study described the predictive ability of finish time in the half-marathon races using variables obtained in the Cooper test and in laboratory evaluations, with a higher predictive ability found in the former. In addition to the Cooper test being statistically more powerful than the treadmill laboratory test, its main strength is that it does not require laboratory technology and can be introduced into the daily training routine to provide a relatively valid prediction of race time.

The high predictive power of distance covered in Cooper test suggest that athletes and coaches should give attention to control of training paces and as a tool for selecting adequate competition strategies in half-marathon. Altogether, these results may guarantee a high degree of applicability for predicting half-marathon time in recreational male runners for its great reproducibility.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the protocol used in this study was approved by the Ethics Committee of the University of Málaga (2013-EMEFYDE-005) and was in accordance with the Declaration of Helsinki. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JA-C, MG, and EC conceived and designed the study. JA-C collected the data. JA-C, MG, EC, and FA analyzed and interpreted the data, and drafted the manuscript. JA-C, MG, EC, FA, PN, TR, and BK revised the manuscript and approved the final version.

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Do “Girls Just Wanna Have Fun?” Participation Trends and Motivational Profiles of Women in the Birkebeiner Races, Norway’s Ultimate Mass Participation Ski Event

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Mass participation sporting events (MPSEs) are viewed as encouraging regular exercise in the population, but concerns have been expressed about the extent to which they are inclusive for women. This study focuses on an iconic cross-country skiing MPSE in Norway, the Birkebeiner race (BR), which includes different variants (main, Friday, half-distance, and women-only races). In order to shed light on women’s participation in this specific MPSE, as well as add to the understanding of women’s MPSEs participation in general, this study was set up to: (i) analyze trends in women’s participation, (ii) examine the characteristics, and (iii) identify key factors characterizing the motivational profile of women in different BR races, with emphasis on the full-distance vs. the women-only races. Entries in the different races throughout the period 1996–2018 were analyzed using an autoregressive model. Information on women’s sociodemographic characteristics, sport and exercise participation, and a range of psychological variables (motives, perceptions, overall satisfaction, and future participation intention) were extracted from a market survey and analyzed using a machine learning (ML) approach (n = 1,149). Additionally, qualitative information generated through open-ended questions was analyzed thematically (n = 116). The relative prevalence of women in the main BR was generally low (< 20%). While the other variants contributed to boosting women’s participation in the overall event, a future increment of women in the main BR was predicted, with women’s ratings possibly matching the men’s by the year 2034. Across all races, most of the women were physically active, of medium-high income, and living in the most urbanized region of Norway. Satisfaction and future participation intention were relatively high, especially among the participants in the women-only races. “Exercise goal” was the predominant participation motive. The participants in women-only races assigned greater importance to social aspects, and perceived the race as a tradition, whereas those in the full-distance races were younger and gave more importance to performance aspects.

These findings corroborate known trends and challenges in MPSE participation, but also contribute to greater understanding in this under-researched field. Further research is needed in order to gain more knowledge on how to foster women's participation in MPSEs.

Keywords: cross-country skiing, machine learning, mass participation sport, physical activity, women's health

INTRODUCTION

Mass-Participation Sporting Events, a Vehicle for Health Promotion?

Mass participation sporting events (MPSEs) have been defined as sporting competitions "where the primary focus is on promoting participation and engagement rather than the significance of the sporting outcome" (Coleman and Ramchandani, 2010). In contrast with other popular sporting events that receive large coverage in the media, such as the Olympic Games and different world championships, a characteristic of MPSE is that they not only attract elite athletes but, in the spirit of "sport for all" ideals, they primarily target recreational sport practitioners. This, alongside the fact that MPSEs have experienced a large increase in popularity across the world in the last three decades, means that MPSEs have been increasingly viewed as a possible vehicle for health promotion (Murphy and Bauman, 2007; Stevinson and Hickson, 2013; Murphy et al., 2015). In particular, MPSEs can provide a motivational goal for people who intend to start exercising regularly or for those who want to enhance their exercise routines.

Some research evidence suggests that MPSEs might indeed be effective in encouraging some people to enhance their exercise habits. For example, Bowles et al. (2006) found an increased frequency of biking sessions post-event compared with pre-event among first-time participants in a mass-participation biking event in Sydney. Funk et al. (2011) argue that MPSEs might also encourage lifelong patterns of sports participation, an issue that is particularly important given the tendency for physical activity levels to decline as people age, a trend that is especially common among women (McArthur et al., 2014). Moreover, MPSEs can have a social value in that the community-oriented and celebratory nature of events can generate feelings of satisfaction and inspiration that might be important in locking people into participation (Chalip, 2006). Discussing physical activity participation more generally, Gough et al. (2018) argue that there is "a web of influences" beyond individual-level accounts that relate to the context. This suggests that the context of MPSEs and the kinds of experiences they might generate is important in understanding participation.

It should, however, be noted that to use sport as an effective vehicle for health promotion, it is essential to focus on narrowing the social gradient that characterizes sport participation. In particular, promoting sport and exercise participation in those groups that tend to be less "sporty" (e.g., women, older people, and those with low socio-economic status) has been viewed as a key strategy for improving population health (World Health Organization [WHO], 2018). In this regard, concerns about the extent to which MPSEs attract those from social groups of relevance to public health have been raised (Murphy and Bauman, 2007; Murphy et al., 2015), although it has been reported that *some* events, especially those characterized by less challenging trails and a less competitive atmosphere (e.g., the Women's Mini Marathon in Ireland), were more successful in attracting individuals with low or moderate levels of physical activity (Bauman et al., 2009). Notwithstanding the convergence in performance between men and women in recent years in specific events (see, e.g., Hausken, 2019), from a public health perspective offering variant events (such as shorter distance and women-only races) may be beneficial if those from underrepresented groups (such as relatively inexperienced women) are to be drawn in.

Understanding Why People Participate in Mass-Participation Sporting Events

When considering the issue of exercise promotion, especially in relation to encouraging people to increase their physical activity levels and/or maintain high physical activity levels over time, understanding people's motives is central. Knowledge on what motivates people to start and continue exercising, or more specifically what motivates them to participate in an MPSE, can inform promotional campaigns targeting specific groups of individuals. The act of purposefully training for and participating in an MPSE can be qualified as a goal-directed behavior (Forster et al., 2007). It is important to note, however, that different participants may perform such goal-directed behavior for varying reasons (Funk et al., 2011).

In general, studies have previously shown that participation in sports tends to be driven by different motivations compared to other forms of exercise. In particular, participation in sporting activities was found to be predominantly driven by enjoyment and mastery motives, while participating in fitness activities and other exercise forms was found to be primarily driven by appearance-related motives (Frederick and Ryan, 1993; Kilpatrick et al., 2005). Moreover, participation in organized sports has been associated with sociability motives to a larger extent than, for example, participation in gym-based and nature-based exercise such as walking or running in natural environments, the latter being more strongly associated with convenience-related motives as well as the enjoyment of being in contact with nature (Calogiuri and Elliott, 2017). More specifically in the context of MPSEs, a study among road running participants in the United States identified two major tiers depicting the participants' motivational profiles (Funk et al., 2011). A first, more common tier (reflected in 95% of the study participants), consisted of a combination of motives related to "challenge," "enjoyment," "strength and endurance," and "positive health." The second tier, less common but still largely prevalent (reflected in 75% of the participants), consisted in the combination of motives related to "competition," "weight management," "ill-health avoidance," "social affiliation," "physical appearance," and "stress management." Noticeably, both these tiers of motives were significantly related to the participants' commitment to running and future exercise intention.

In light of these findings, it is plausible to postulate that the issue of the participation motive for MPSEs is complex. Moreover, different events (and sub-events) are likely to attract participants with different performance level as well as different motivational profiles. On the other hand, individuals' motivation does not represent the only factor that explains sport participation, which is, as previously noted, often subject to a social gradient. For example, a review by Murphy et al. (2015) reports that, among MPSEs' participants, women, ethnic minorities, and people with lower previous physical activity levels are often under-represented. Moreover, a systematic review of 131 studies by Beenackers et al. (2012) found consistent evidence of the association between individuals' socio-economic status and participation in leisure-time physical activity, with the most consistent socio-economic inequalities found for vigorous activities such as sports.

Women in Mass-Participation Sporting Events

Globally, women have lower physical activity levels than their male counterparts (World Health Organization [WHO], 2010, 2018; Hallal et al., 2012). Over the past few decades, however, women's physical activity levels in many high-income countries have increased. In United Kingdom, for example, the prevalence of women meeting the minimum recommendations for physical activity is almost equal to men's (The House of Commons [THoC], 2017) and in Norway, the prevalence of sufficiently active women is slightly higher than that of men (Norwegian Directorate of Health, 2015). While women's high levels of physical activity are generally mainly driven by activities such as walking and exercising in fitness centers, their participation in other sporting activities such as running and biking tends to be lower compared to men (THoC, Statistics Norway, s.a.; 2017). In line with this pattern, in Norway, women's participation in cross-country skiing is relatively high, though lower than that of their male counterparts (Statistics Norway, s.a.).

In line with these trends, women tend to be under-represented in MPSEs (Murphy et al., 2015). A study of the characteristics of the approximately 10,000 participants in Sydney's annual Spring Cycle showed that less than 30% of them were women (Bowles et al., 2006). These figures are in line with a recent analysis of 2,195,588 recreational marathon runners across different countries, which found that, on average, women made up only 30% of total participants (Andersen, 2019). There are, however, some signs that MPSEs are, indeed, becoming increasingly attractive for women. For instance, the analyses of recreational marathon runners showed that in the past 10 years, the growth of women's participation was threefold compared with that of men's, i.e., 27% and 8%, respectively (Andersen, 2019). As a matter of fact, in some MPSE (especially running events in Northern America) women's participation ratings already match that of men. For example, in a survey conducted among road race participants in the United States, Funk et al. (2011) found that women made up 55% of overall participants, a finding that is in line with commercial reports (see, e.g., Running USA, 2014).

To boost women's participation specifically, many MPSEs offer women-only races, which typically take place on shorter and/or less challenging routes and are characterized by a less competitive atmosphere. Some studies suggest that women-only races not only catalyze women's participation in MPSEs, they also may help them maintain high physical activity levels over the years (Crofts et al., 2012; McArthur et al., 2014). While the addition of women-only races might be effective in boosting women's participation in absolute terms, enhancing the inclusiveness of women in main MPSEs may also have advantages, such as contributing to reducing gender stereotypes in sport as well as stimulating even greater amounts of exercise among female participants. Moreover, these events are likely to attract women who have different characteristics, motives, and aspirations than those who would rather enter main MPSE. In particular, it is plausible to assume that women in the main MPSEs have higher levels of physical training and are more interested in their performance, as opposed to the participants in women-only races, who may attach more importance to the social context and supportive and celebratory atmosphere of the event.

To date, there is a dearth of scientific studies and academic publications specifically investigating women's participation in MPSEs, both in terms of participation trends as well as the characteristics, motives, and aspirations of the women who attend. Furthermore, little is known about how such characteristics, motives, and aspirations may differ in different race contexts, especially with respect to female participants in *main* MPSEs or *women-only* races. Furthermore, it should be noted that the issue of women's inclusion in MPSEs is complex and presents a number of challenges. For example, it is argued that this phenomenon primarily benefits women who are already active and those from more advantaged social groups, while inactive women from more disadvantaged groups (e.g., older women, those from ethnic minorities and with lower socioeconomic status) tend to remain excluded (Murphy et al., 2015). A better understanding of this complex phenomenon is needed in order to assist initiatives in fostering a culture in MPSEs that encourages the participation of women from across these under-represented groups.

The Birkebeiner Races

In the present study, we focus on a particular MPSE, the Birkebeiner races (BRs). The BRs are an iconic Norwegian cross-country ski (classic technique) MPSE, which takes place in the region of Oppland (Inland Norway) and registers over 10,000 participants every year. The challenging 54 km trail goes through open and forest terrains, crossing two mountains (820 and 760 m above sea level). In 2018, the main BR celebrated its 80th edition; the race was launched for the first time in 1932, and since then it has been organized annually, except in the war years

1941–1945 and few other times because of adverse meteorological conditions. Alongside the main race, the event includes different variants: the Friday, the half-distance, and the women-only races. The Friday race takes place on the exact same trail two days before the main BR, and is generally characterized by fewer participants attending. Differently, the half- (28 km) and the women-only (15and 30 km) races are characterized by shorter and less challenging (relatively to the main BR) tracks. For instance, the track of the women-only 15 km race has only one major up-hill (about 550 m above sea level).

The BRs have received some research attention, especially in relation to its economic impact in the region (Stevik, 2008) as well as in relation to perspectives in sport management (Slåtten et al., 2014), sport medicine (Myrstad et al., 2014), and traumatology (see, e.g., Butcher and Brannen, 1998). On the other hand, less attention has been given to this particular event in relation to the participants' characteristics and motives, and the existing information on this particular perspective is mainly available through market reports produced by the race organizers or popular-scientific publications. In line with international literature on MPSEs (Murphy and Bauman, 2007; Murphy et al., 2015), a 2011 survey among about 900 participants in the main BR found that most lived in larger cities, were highly educated, well trained, and of male sex; women made only 19% of total participants (Rønning and Skaare, 2011). "Health" was the most common participation motive, which is generally in line with research on motives for physical activity in the Norwegian population (Norwegian Directorate of Health, 2015) as well as other Scandinavian populations (see, e.g., Aaltonen et al., 2014). Seeing the race as a personal challenge (which indicates *intrinsically* regulated motivation) was also a commonly reported participation motive. Remarkably, this motive was found to be more prevalent among men compared to women.

Purpose of the Present Study

Norway boasts relatively high sports participation rates, compared to countries beyond the Nordic region, including among women (Dalen and Holbaek-Hanssen, 2016; Green et al., 2018). This provides an interesting context to study the phenomenon of women's participation in MPSEs. Moreover, the BRs are also interesting with respect to its particular location, as the region in which it takes place (Inland Norway) has one of the worst public health profiles in Norway, including having the lowest levels of physical activity compared with the rest of the country. Specifically, in order to shed light on women's participation in the different variants of the BR event, as well as contribute knowledge of women's participation in MPSEs in general, the purpose of this study was threefold:

I Analyze trends in women's participation in the different variants of the BRs;

II descriptively examine the characteristics of women participating in different variants of the event, with an emphasis on the full-distance compared to the women-only races, in terms of: sociodemographic profile, sport and exercise participation, and a range of psychological factors (motives, self- and race-perceptions, overall satisfaction, and future participation intention); and

III by triangulating findings generated through a machine learning (ML) approach and a thematic analysis, identify key factors characterizing the motivational profile of women participating in either the full-distance or the women-only races.

MATERIALS AND METHODS

Women's Participation Trends

Design and Data

In order to analyze trends in women's participation in the different variants of the BR event (objective I), a time-series analysis of their participation rates based on entry records was undertaken. Entry records of both men and women were provided by the event organizers (Birken AS), referring to the number of participants who, in each year, signed up for the different races. Data on starters (those who actually participated in the race) were also examined but not presented in this paper as the difference between these and the starting participants was fairly constant throughout the years. For the main BR, women's entries were available for the period of 1996–2018. For the Friday, the half-distance, and the women-only races (the latter, separately for the 15 and 30 km distances), entry records were obtained from the first year the races were introduced, i.e., 2010, 2012, and 2013, respectively.

Analyses

Women's entry records were examined both as absolute numbers and as relative prevalence of women participants with respect to the overall number of participants. Autoregressive models (Wei, 2013) were created in order to forecast future participation in the main BR. The autoregressive approach allows the prediction of an event based on a weighted sum of past values reflecting the secular trend. Three time-series were analyzed for the period 1996–2018: total participants, relative prevalence of men, and relative prevalence of women. For each time series, an exponential weighted moving average (EWMA) with 6 years span was computed in order to avoid extreme frequency values that could affect the prediction of future trends. The model was trained on n-10 elements of the time series (i.e., 1996–2008) and tested on the remaining 10 waves (i.e., 2008–2018). The accuracy of the model was assessed by computing the mean squared error (MSE) between the observed and predicted values. Finally, the year in which the relative prevalence of women in the race was predicted to be equal to that of men's was based on the autoregressive function extracted from the participation frequency recorded between 1996 and 2009.

Because of the small number of observations (i.e., waves available for the analysis), it was not possible to apply the autoregression on the other races (Friday, half-distance, and women-only races). The participation trends for Friday, the half-distance, and the women-only races where thus only examined through descriptive statistics.

Characteristics of Women Participating

Design and Participants

In order to examine the characteristics of women participating in the different variants of the BR event (objective II), as well as identify distinctive characteristics of women participating in the full-distance vs. the women-only race (objective III), a secondary analysis of data based on a market survey conducted by the race organizers was carried out. In order to perform a trend analysis on the participants' characteristics (similar to that which was done with the participation ratings), we examined the series of surveys from previous years. Although the race organizers had been conducting market surveys for several years (to our knowledge, starting from 2012), they have significantly changed the questionnaire over time, as well as across the different events, with only relatively few items being consistent. In particular, starting from 2016, the race organizers changed the statistical agency that planned and delivered the survey, leading to major changes in the structure and quantity of items included. This particular survey wave had a high degree of consistency across the different races, with the exception of the half-distance race (for which a very different questionnaire, designed directly by the race organizers, was used). We have no knowledge of other survey waves being carried out after 2016. Based on this preliminary examination, it was decided to only include the survey wave from 2016 in our analyses.

The survey was administered online by an independent market research company (Differ Strategy Consulting, Oslo) about 1 month after completion of the races among participants in the main BR, Friday, and the women-only races. The race organizers performed a separate survey among the participants of the half-distance race, but because the questionnaire used was substantially different from the one used for the other races, this information was not included in the present study. All people registered for the different races were invited to participate in the survey. Only data from female respondents who confirmed their participation in either the main BR, the Friday, and the women-only races were used for the analyses (overall n = 1,187, overall response rate 35%). Details about the respondents and response rates for each individual race are presented in **Table 1**. The use of the data was approved by the Norwegian Centre for Research Data (Project No. 58439).

TABLE 1 | Race characteristics and overview of women participants and respondents to a market survey in 2016[a].

Race	Distance (km)	Participants (*N*)	Respondents (*n*)	Response rate (%)[b]
Main event	54	1546	515	33
Friday event	54	306	97	31
Half-distance[c]	28	239	96	40
Women-only 15 km	15	1,054	378	36
Women-only 30 km	30	494	197	40
All		3,639	1,283	35

[a]Based on official records available online (http://historikk.birkebeiner.no/index2.php) cross-matched with records by Birken AS. [b]The response rate was calculated on the total N of participants, who were all invited to participate in the survey. [c]Data from the market survey on the half-distance race were not included in the analyses.

Measures

The market survey included, among other things, a set of items that were primarily designed for commercial purposes (e.g., questions regarding the brand of equipment used and visibility of sponsors). These items were removed, while only items relative to the variables of interest for the study purpose were retained, based on the assumption that they were found in identical or fairly similar form across the different races. If necessary, the items were recoded to improve the consistency across the different races, or to better address the purpose of the study (see description of variables below). These items included three groups of variables: sociodemographic characteristics, sport and exercise participation, and psychological variables (motives for participating in the race, self-perception and perceptions of the race, overall satisfaction with the race, and future participation intention). Additionally, qualitative information (responses to open-ended questions) relative to the women's motivations and perceptions were also extracted for further analyses.

Sociodemographic characteristics

This included age (measured as a continuous variable), income (1 = < 200.000 NOK, 2 = 200.– 400. NOK, 3 = 400.–600 NOK, 4 = 600.–800 NOK, 5 = > 800. NOK), and region of residence. The latter was originally measured by selecting either one of the 20 Norwegian counties or the option "abroad." These were recoded into four categories: "host region" (Inland Norway, i.e., the region that hosts the races); "adjacent, most urbanized" (i.e., Oslo and Akershus; the most densely populated region, which is well connected by road and rail to the host region); "other adjacent regions" (South-Eastern Norway, the southern parts of Central Norway, which are relatively close to the host region); "farther regions" (South-Western Norway, Western Norway, the Northern parts of central Norway, Northern Norway, and abroad).

Sport and exercise participation

"Other races" was a dichotomous variable indicating whether or not the women usually participated in other sporting events, of small or large scale, either in Norway or abroad. "Ski-based exercise" was a categorical variable indicating the women's ski-based exercise levels compared with the past 5 years ("Compared with 5 years ago, do you engage in ski-based exercise . . .": 1 = In smaller amounts, 2 = More or less in equal amounts; 3 = In larger amounts). "Sum of sports" provided an indication of the variety of exercise activities in which the women were planning to engage in the spring season, and was constructed based on a multiple-choice item inquiring "What will be your main exercise activity in the next months?," to which the respondents answered by selecting one or more (or none) of six listed options: running, biking, roller-ski, team-sports, strength exercise, other. The individual exercise options were included in the analyses as dummy variables (Option selected = 0; Option non-selected = 1), and an additional variable was derived by summing the number of options selected, and ranged from 0 to 6.

Psychological variables

Eight different motives (e.g., "To measure myself against friends" and "I usually participate every time") were measured as dummy variables by asking the women to report whether or not they considered each particular motive as an important reason to enter the race. The women's self-perception during the race (seven items, such as "Challenged" and "Part of a community") and perceptions of the race (seven items, such as "Nice experience" and "Nice social setting") were measured on a 1–6 scale (1 = "It suits me very little"; 6 = "It suits me very well"). The women's overall satisfaction with the race was measured using a 1–10 scale (1 = "Absolutely dissatisfied"; 10 = "Absolutely satisfied"). Future participation intention was a dummy variable with 1 corresponding to the high intention to participate again the following year (i.e., "Extremely likely") while 0 corresponded to any lower intention.

Qualitative data

Qualitative information was collected through an optional open-ended question that allowed the participants to comment on their own motives for participating and perceptions regarding the race. This question asked: "what would you say was your main motivation for participating in the race?" Among the sample, qualitative data were available from 116 women in total (note: the open-ended items were not compulsory and respondents could choose whether or not provide more in depth information in these sections).

Analyses

Sample representativeness

In an attempt to estimate the extent to which the sample of respondents (*n*) was representative of the entire population of participants (*N*), comparisons of the frequency distributions of "age class" in the different races were carried out using a one-sample Chi-squared test. The analysis showed that the sample was broadly representative of the overall population, with some relatively small (range: 0–4%) deviations showing that older women were slightly more likely to respond than younger. These deviations were statistically significant only in the main BR, though the achievement of a statistical significance might have been facilitated by the larger sample size. Information about this comparative analysis is provided in **Table 2**.

TABLE 2 | Distribution of age and sex classification in population (*N*) vs. sample (*n*) for women participating in four Birkebeiner ski events.

Class	Main race		Women-only 15 km		Women-only 30 km	
Age group	*N* (%)	*n* (%)	*N* (%)	*n* (%)	*N* (%)	*n* (%)
<20	83 (6)	14 (3)	10 (1)	4 (1)	7 (1)	1 (1)
20–29	334 (23)	100 (20)	53 (7)	23 (6)	66 (13)	24 (13)
30–39	203 (14)	67 (13)	109 (14)	58 (16)	78 (16)	27 (14)
40–49	378 (26)	143 (28)	230 (29)	112 (31)	170 (34)	71 (38)
50–59	367 (25)	147 (29)	213 (27)	104 (29)	125 (25)	45 (24)
60–69	110 (7)	35 (7)	170 (22)	58 (16)	48 (10)	20 (11)
χ^2	*15.76; p = 008*		*8.11; p > 0.05*		*0.65; p > 0.05*	

Age classification was not available for the Friday race.

Analysis of the quantitative data

The survey data were first examined using descriptive statistics separately for each race (the main BR, Friday, and the women-only races 15 and 30 km), and then analyzed using an ML approach in order to detect the most representative variables that predict women's participation in the different races. The ML approach differs from "classical" statistical approaches in the extent to which it is not primarily theory-driven. ML is a process that enables computer systems to progressively improve performance on a specific task without being explicitly programmed, and it can be used for data analysis purposes in order to develop statistical models with a high level of precision (Jordan and Mitchell, 2015). This process makes it possible to identify more accurately the predictors that have relevant impact on the dependent variable, as well as possible confounders, and thus lead to high levels of explained variance. This approach has been previously applied to the secondary analysis of survey data, including also a study of physical activity patterns and factors associated with them in the Norwegian population (Rossi and Calogiuri, 2018).

The dependent variable in our analysis was "Race" (i.e., the race variant in which the women participated). To reduce the imbalanced class distribution of the respondent frequencies in the different ski races, a binary dependent class was created aggregating the main BR with the Friday race ("full-distance races," $n = 612$), and the two women-only races ($n = 575$). All parameters described in section "Measures" were run in the analysis. Answer alternatives "I don't know/I'm not sure" were not included in the analyses (final $n = 1{,}131$).

A recursive feature elimination with cross-validation process (RFECV) based on logistic regression performed on 50% of the dataset (Ttrain) selected the most relevant variables able to discriminate women who participated in either ski race class (i.e., full-distance or women-only races). The importance of the features was assessed by a normalized Gini coefficient (G). On the Ttrain + RFECV, the hyper-parameter of three different classifier algorithms was obtained: logistic regression, decision tree classifier, and random forest classifier. The classifiers were validated with a threefold stratified cross-validation strategy on the remaining 50% of the dataset (Ttest + RFECV). Each cross-validation fold was made by preserving the percentage of samples for each class. Each sample in the dataset was tested once, using a model that was not fitted with that sample. The goodness of the classifiers was assessed by precision, recall, and F1-score (f1). Precision indicates the fraction of examples that the classifier correctly classifies over the number of all examples that the classifier assigns to that class. Recall indicates the ratio of examples of a given class correctly classified by the classifier, while f1 is the harmonic mean of precision and recall. Additionally, in order to assess the validity of the classifiers, we compared our predictive models with two baselines. Baseline B1 randomly assigned a class to an example by respecting the distribution of classes and Baseline B2 always assigned the majority class. All statistical analyses were performed using Python version 2.6. Significance level was set at $p < 0.05$. **Table 3** shows the performance of the classifiers built on the base of the features selected in each dataset through the ML approach. Among the

TABLE 3 | Models metrics of classifiers.

Model	Dataset	Precision	Recall	f1
DT	Full-distance races (main and Friday races)	0.73	0.74	0.74
	Women-only races (women-only races 15/30 km)	0.72	0.71	0.71
RF	Full-distance races (main and Friday races)	0.76	0.76	0.76
	Women-only races (women-only races 15/30 km)	0.74	0.74	0.76
LR	Full-distance races (main and Friday races)	0.77	0.78	0.78
	Women-only races (women-only races 15/30 km)	0.77	0.76	0.76
B1	Full-distance races (main and Friday races)	0.52	1.00	0.68
	Women-only races (women-only races 15/30 km)	0.00	0.00	0.00
B2	Full-distance races (main and Friday races)	0.52	0.54	0.53
	Women-only races (women-only races 15/30 km)	0.49	0.48	0.48

DT, decision tree classifier; RF, random forest classifier; LR, logistic regression; B1, comparison with baseline randomly assigning a class to an example by respecting the distribution of classes; B2, comparison with baseline assigning the majority class.

different models, LR showed the highest level of performance. In particular, LR correctly allocated 76% of the cases with a precision of 77%.

Analysis of the qualitative data

The qualitative data was analyzed with the purpose of gaining further insight into the patterns in the quantitative data. Thus, the quantitative measurements of the women's motives for participating and perceptions of the race were used to inform the categorization of the qualitative data. Accordingly, the data was analyzed grouping the two women-only races (n = 52) and the full-distance races ("full-distance races," i.e., main BR and Friday race; n = 64). Discussion took place between two members of the team in order to arrive at a valid set of comments, which were then grouped into the categories used to present the quantitative results.

RESULTS

Women's Participation Trends

In the 17-year span between 1996 and 2013, the number of women participating in the main BR has trebled, though it dropped in the period 2015–2018 (**Figure 1**). It should be noted, however, that such fluctuation follows an overall trend in total participants. In spite of such fluctuations, the relative prevalence of women progressively increased from 13% in 1997 to 19% in 2018 (**Figure 2**). The autoregressive model confirms this trend (**Figure 3**), predicting a decrease in the percentage of male participants entries (MSE = 3.90%, residual error = 3.24 ± 2.17%) in favor of a relative increase in the women's (MSE = 4.51%, residual error = 3.70 ± 2.58%). According to the outcomes of our model, if this trend persists, it would take about 15 years for the prevalence of women in the main BR to match the men. Moreover, the model predicts an increase in the total number of participants in the main BR for future years (MSE = 2,603 participants; residual error = 1,517 ± 254 participants), indicating that the number of women in the main BR is likely to increase both in relative and in absolute terms.

The introduction of the BR variants (Friday, the half-distance, and the women-only races) seems to have contributed to boosting women's participation in the MPSE both in absolute and relative terms. In 2018, for example, the presence of the women-only races brought almost 1,600 women into the event, resulting in an increased overall prevalence of women from 20% to 30%. The presence of the women-only races also contributed to buffer the drop in women's entries during the period 2015–2018. The Friday and the half-distance also contributed to boost the total number of women as well as their relative prevalence in the event. However, the relative prevalence of women in the Friday and the half-distance reduced progressively over the years: from 31% and 43% (respectively) in their first year of introduction, to 23% in 2018 (**Figure 2**). Thus, according to the latest records, the relative prevalence of women in the Friday races and half-distance race is only slightly larger than that registered in the main BR.

Characteristics of Women Participating

Descriptive statistics for the sociodemographic characteristics, sport/exercise participation, and the psychological variables of women in the full-distance and women-only races are presented in **Table 4**. In general, most of the participants were middle-aged women with medium–high income from the most urbanized region of Norway (Oslo and Akershus). The event, however, also saw a relatively large participation of the women from the host region. A relatively large proportion of the participants (especially those in the full-distance races) reported to participate in other races, and most of them were planning to engage in at least one sporting activity in the 6 months following the race, with the most frequently reported activity being "running," followed by biking and/or strengthening exercise. A large majority of women reported to have either maintained or increased their ski-based exercise habits compared with the past 5 years.

For what concerns the psychological variables, "It's a motivational exercise goal" was the most frequently reported participation motive across all races, followed by "Because of the experience" and "It's a nice nature experience" or, for the women-only races, "My friends did it." The most highly rated perceptions relative to self were "Fit" and "Challenged," but also "Part of a community." On the other hand, the most highly rated perceptions about the race were "A nice experience," "The most important here is to complete against yourself," and "A nice nature experience." Levels of general satisfaction were remarkably high (mean value above eight for all races). Future participation intention was also relatively high, especially among the participants in the women-only races (68% reported it was very likely they will participate again the following year), while it was somewhat low among the participants in the main BR (41% reported it was very likely they will participate again the following year).

The outputs of the logistic regression identified eight features as the most relevant predictors for the women participating either in the full-distance races (BR and Friday race) or the women-only races. Of the sociodemographic characteristics, only age was found to be a significant predictor, where older women were more likely to participate in the women-only races rather than the full-distance races (G = 0.02; OR [95% CI] = 0.98 [0.97–1.00];

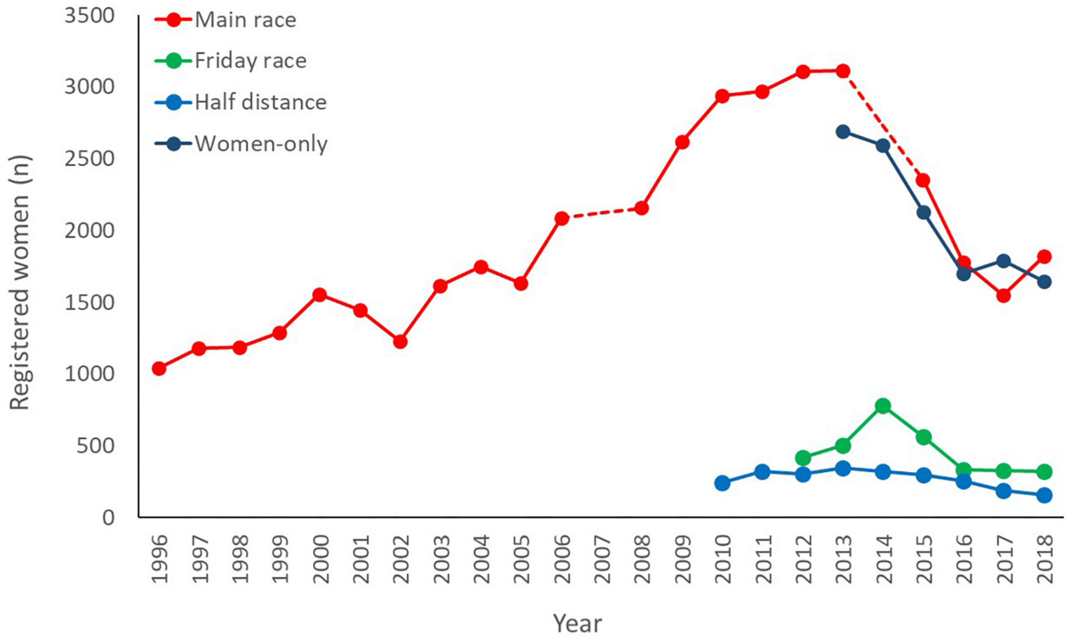

FIGURE 1 | Entries for women (*n*), expressed as registered participants, in the main ski race and other races (Friday, half-distance, and women-only). The main race was canceled in 2007 and 2014, as marked by a discontinuous line. The women-only race came under the organization of Birken AS in 2013, thought it has been taking place since 1993 (entry records before 2014 are not available).

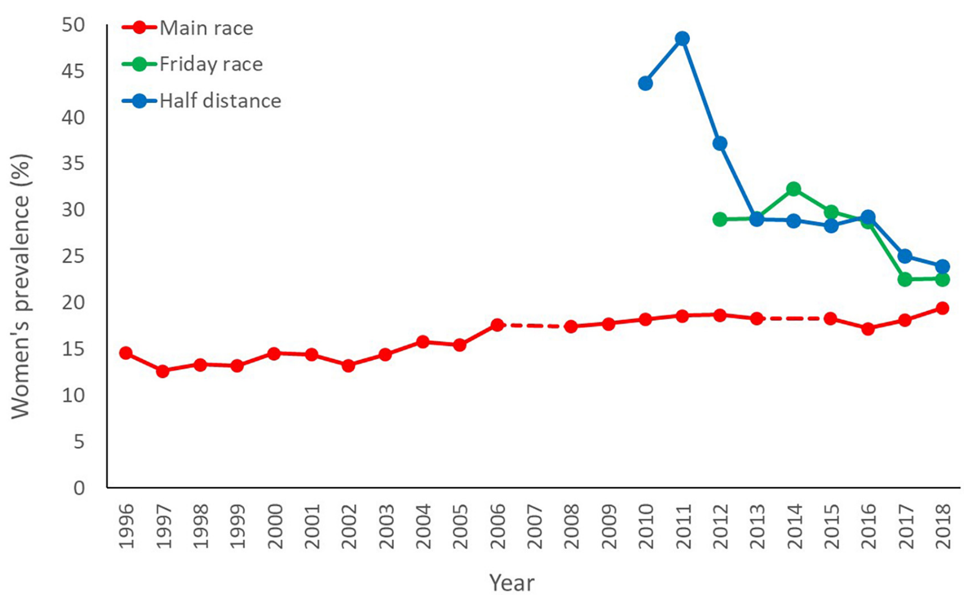

FIGURE 2 | Prevalence of women in the main ski race, Friday race, and half-distance race, expressed as a percentage (%) of total participants registered. The main ski race was canceled in 2007 and 2014, as marked by a discontinuous line.

p = 0.041). None of the sport/exercise participation variables were found to be significant predictors of women's participation in either one of the two classes of races. The psychological variables had, on the other hand, a greater weight on the overall explained variance of the model. In particular, women who rated social aspects, such as feeling "part of a community" and reporting "sociability" (i.e., "my friends did it") as an important participation motive, were more likely to participate in the women-only races rather than the full-distance races (G = 0.06 and 0.36; OR [95% CI] = 1.50 [1.18–1.90] and 5.94 [3.53–10.01]; $p < 0.001$ for both). Participation in the women-only races was also predicted by high ratings of overall satisfaction as well

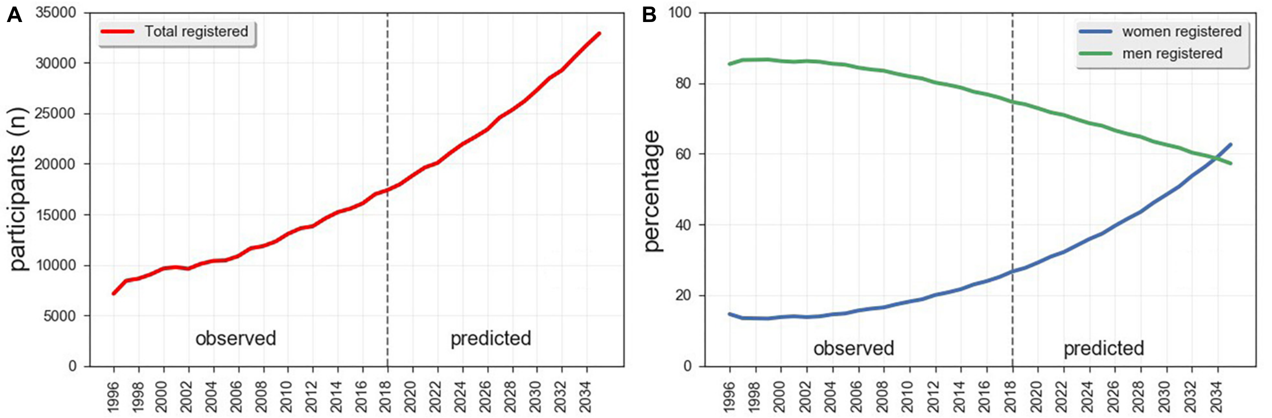

FIGURE 3 | EWMAs for observed and predicted entries of **(A)** total participants and **(B)** percentage of men and women registering in the main race. The EWMAs are computed with a span of 6 years.

as perceiving the race as a "personal tradition" (respectively, G = 0.12 and 0.09; OR [95% CI] = 1.50 [1.29–1.75] and 1.34 [1.17–1.54]; $p < 0.001$ for both). On the other hand, women with greater perception of the race as "a good exercise goal for the season" (G = 0.11; OR [95% CI] = 0.62 [0.52–0.74]; $p < 0.001$) that makes them feel "extreme" and "fit" (respectively, G = 0.24 and 0.01; OR [95% CI] = 0.59 [0.50–0.70] and 0.61 [0.47–0.79]; $p < 0.001$ for both) were more likely to participate in the full-distance races rather than in the women-only races. The features selected by the LR model are summarized in the radar chart in **Figure 4**.

In line with "exercise goal" being a significant predictor for participation in the full-distance races, the qualitative data revealed that the full-distance races provided the participants with a challenge and hence the opportunity to "experience an enormous sense of mastery" (18 y.o.). This is further elaborated by the following quotation from an older participant describing how the demanding nature of the full-distance races contributed to her feeling of mastery: "... pushing myself, breaking barriers and achieving a sense of mastery" (28 y.o.). Additionally, it seemed that within the competitive context of the full-distance races, the sense of mastery extended to a sense of mastery over others: "I was challenged by colleagues" (age). For the participants in the women-only races, however, the discourse revolved more around "having fun" (44 y.o.). This seemed to be related to the terrain of the races; "the tracks are fun, with the hilly parts first, then the flatter parts afterward" (65 y.o.). Furthermore, it seemed as if the participants in the women-only races were more in competition with themselves, rather than their peers as illustrated by the following: "It's a very 'easy' race to do without being in top shape, but you do get inspired to beat your own time!!" (54 y.o.).

While the quantitative data showed how sociability and community was a predictor for participation in the women-only races, participants of both races mentioned the general social atmosphere of the races as something that was meaningful to them. The difference between the full-distance and the women-only races was found in the kind of social connections experienced, where the full-distance races gave opportunities for the wider family to be involved and share the enjoyment of participating: "Me and my dad found we should try it out. My brother and partner joined as well, so it became a family thing" (31 y.o.). Moreover, the more challenging nature of the full-distance races seemed to provide more of an opportunity for family members to set themselves common goals: "I want to contribute to motivating my husband to get back on his feet after a serious accident in [year]" (32 y.o.). The women-only races on the other hand seemed to generate a dynamic social context for mother/daughter bonding and, in particular, for mothers to provide practical and social support: "my daughter competes, I follow as a ski waxer" (50 y.o.). The following quotation also illustrates how the women-only races provided opportunities for inter-generational sharing of enjoyable experiences with family members who were able to participate in different distances because of the way the races were organized:

> *"We have done all the women-only races, so it is tradition, and it is a nice experience that I share with my two daughters, one of which participates in the 30 km, while the other is finally enjoying the fact that she is beating her mother at 15 km" (55 y.o.).*

Indeed, one respondent felt the race arrangers should emphasis the inter-generational possibilities of participation to a greater extent: "It is a race where mothers and daughters can participate together. It's weird that there aren't more people doing this, and that [the race arrangers] don't highlight this better!"

When it comes to the significance of personal tradition, it seemed that the full-distance races mostly functioned as something of a "bucket list" thing; "A dream since the 70s" (55 y.o.). This seems especially pertinent given the iconic cultural status of the main BR in Norway. For the women-only races, the data suggest that it may have function in terms of having a life-long traditional purpose to it, locking participants into participating in the event: "I've done it all 24 times it has been arranged. So I just have to do it" (53 y.o.). In this way, participating in the race becomes a more or less embedded aspect of women's lives even as

TABLE 4 | Descriptive statistics and outcomes of the binary logistic model identifying the most important sociodemographic characteristics, exercise profile, and psychological factors that predict women participating in different Birkebeiner races in 2016.

Participants' characteristics	Full-distance races (n = 612)	Women-only races (n = 575)	Normalized Gini coefficient (%)	p	OR (95% C.I.)
Sociodemographic characteristics					
Age (years), $M \pm SD$	44.04 ± 11.75	46.21 ± 11.81	2	0.041	0.98 [0.97,1.00]
Income, n (%)			0	>0.05	–
<200.000 NOK	71 (11)	37 (6)			
200–399.000 NOK	98 (16)	116 (20)			
400–499.000 NOK	252 (41)	256 (44)			
600–799.000 NOK	105 (17)	89 (15)			
800.000 + NOK	95 (15)	42 (7)			
Region, n (%)[a]			0	>0.05	–
Host region	122 (19)	133 (23)			
Adjacent, most urbanized	261 (42)	228 (39)			
Other adjacent regions	132 (21)	162 (28)			
Farther regions	60 (9)	9 (1)			
Sport and exercise participation					
Other races, n (%)[b]	368 (60)	196 (34)	0	>0.05	–
Ski-based exercise, n (%)			0	>0.05	–
Decreased compared with 5 years ago	53 (8)	70 (12)			
Same as before	161 (26)	180 (31)			
Increased compared with 5 years ago	381 (62)	287 (49)			
Type of exercise, n (%)[b]					
Running	458 (74)	269 (46)	0	>0.05	–
Biking	264 (43)	203 (35)	0	>0.05	–
Roller-skiing	108 (17)	50 (8)	0	>0.05	–
Organize sports	14 (2)	20 (3)	0	>0.05	–
Strength exercise	211 (34)	227 (39)	0	>0.05	–
Other	70 (11)	157 (27)	0	>0.05	–
Sum of sports, $M\pm$ SD	1.78 ± 0.89	1.7 ± 0.83	0	>0.05	–
Psychological variables					
Motives for participating, n (%)[b]					
"It's a motivational exercise goal"	487 (79)	351 (61)	0	>0.05	–
"Because of the experience"	371 (60)	297 (51)	0	>0.05	–
"It's a nice nature experience"	284 (46)	227 (39)	0	>0.05	–
"My friends did it"	59 (9)	235 (40)	36	0.001	5.94 [3.53,10.01]
"To improve my time from last year"	200 (32)	182 (31)	0	>0.05	–
"I usually participate every year"	94 (15)	137 (23)	9	<0.001	1.34 [1.16,1.54]
"To measure myself against others"	96 (15)	85 (14)	0	>0.05	–
"It was a gift"	16 (2)	7 (1)	0	>0.05	–
"It's a work arrangement"	9 (1)	13 (2)	0	>0.05	–
Self-perception (1–6 scale), M ± SD					
"Fit"	5.1 ± 0.97	4.89 ± 1.01	1	<0.001	0.61 [0.47,0.79]
"Challenged"	4.95 ± 1.09	4.47 ± 1.27	0	>0.05	–
"Part of a community"	4.56 ± 1.25	4.93 ± 1.08	6	<0.001	1.50 [1.18,1.90]
"Capable"	4.34 ± 1.32	4.38 ± 1.25	0	>0.05	–
"Extreme"	3.37 ± 1.43	2.43 ± 1.29	24	<0.001	0.59 [0.51,0.70]
"Trendy"	3.14 ± 1.35	3.09 ± 1.46	0	>0.05	–
"Ordinary"	3.12 ± 1.29	3.75 ± 1.36	0	>0.05	–
Race perceptions (1–6 scale), M ± SD					
"A nice experience"	5.38 ± 0.80	5.49 ± 0.76	0	>0.05	–
"The most important here is to complete against yourself"	5.20 ± 1.03	5.10 ± 1.21	0	>0.05	–
"A nice nature experience"	5.12 ± 0.99	4.88 ± 1.16	0	>0.05	–
"A good exercise goal for the season"	4.89 ± 1.37	4.33 ± 1.62	11	<0.001	0.62 [0.52,0.74]
"A nice social atmosphere"	4.55 ± 1.38	4.88 ± 1.29	0	>0.05	–
"An opportunity to compare myself with the best in my category"	3.59 ± 1.73	3.66 ± 1.72	0	>0.05	–
"A tradition for me"	3.81 ± 1.85	4.6 ± 1.68	0	>0.05	–

(Continued)

TABLE 4 | Continued

Participants' characteristics	Full-distance races (n = 612)	Women-only races (n = 575)	Normalized Gini coefficient (%)	p	OR (95% C.I.)
Satisfaction and intention					
Overall satisfaction (1–10 scale), $M \pm$ SD	8.11 ± 1.45	8.38 ± 1.56	12	<0.001	1.50 [1.29,1.75]
Intend to participate next year, n (%)[b]	251 (41)	391 (68)	0	>0.05	–

Numeric variables are presented as means (M) and standard deviations (SD); categorical variables are presented as frequency (n) and percentage (%). [a]Regions: Host region = Inland Norway (the region that hosts the races); adjacent, most urbanized = Oslo and Akershus (the most densely populated region, which is also better connected by road and rail to the rest of Norway); other adjacent regions = South-Eastern Norway (which are relatively close to the host region); farther regions = South-Western Norway, Western Norway, the Northern parts of central Norway, Northern Norway and abroad. [b]Dummy variable or set of variables. Only the value for the "1" response alternative is shown, whereas the value for the "0" response alternative is not shown because redundant.

they age, something that is made possible by the shorter distances and less demanding courses, but also desired because of the enjoyment experienced. One woman for example described how it had "been developed into a lifestyle the last 21 years" (73 y.o.).

DISCUSSION

Women's Participation Trends and Their Significance to Women's Inclusion

In general, the findings show how women have been largely under-represented, compared to men, in the main BR as well as in the Friday and half-distance variants. This is consistent with research on MPSEs (Bowles et al., 2006; Andersen, 2019). However, some encouraging trends were observed. More specifically, in spite of some oscillations in the total number of women taking part in the main BR between 1996 and 2018, oscillations that mirror the trend of total participants in the race as well as general trends of skiing participation in Norway (Dalen and Holbaek-Hanssen, 2016; Statistics Norway, s.a.), the relative prevalence of women increased progressively. This trend is in line with analyses that indicate an increasing interest of women in major MPSEs (Andersen, 2019) as well as with trends in sports participation in the Norwegian population in general (Statistics Norway, 2015, s.a.). Moreover, our findings predict that the women's relative prevalence in the main BR will continue increase in years to come, possibly with the gender split being completely overcome in about 15 years.

In terms of the impact of the other race variants (Friday race, half-distance race, and women-only races) in boosting women's participation in this sporting event, the findings indicate that these races, and especially the women-only races, contributed to increasing the ratings of women both in absolute and relative terms. The women-only races, especially, contributed to buffering the drop among the participants in the main BR in the period 2015–2017, doubling the ratings of women's entries in that same period. However, in contrast to the trends observed in the main BR race, the relative prevalence of women in the Friday race and half-distance race has been declining since the year of their introduction. This might suggest a "shift" in interest of the women toward the main (more competitive) race, though more research is warranted in order to corroborate such an assumption.

The introduction of women-only races (such as the Women-only BR in Norway and the Women's Mini Marathon in Ireland, just to mention two) appears as an important and effective strategy to broaden the range of women participating in MPSEs. However, as Hausken (2019) notes from a physiological point of view, short distance races are unwarranted and even unethical as full-distance races suits the women's physiology just as well as men's. Thus, seen in line with the progressive increase in women's participation in the main (full-distance) races, a trend confirmed in our study, there is a need for more efforts to foster greater inclusion of women in these events as well. It is indeed encouraging to notice that, in recent years, initiatives and programs have been launched to work to increase female participation in different types and at all levels of MPSE (see, e.g., Women For Tri™ and The Women's National Runner Survey from Running USA©).

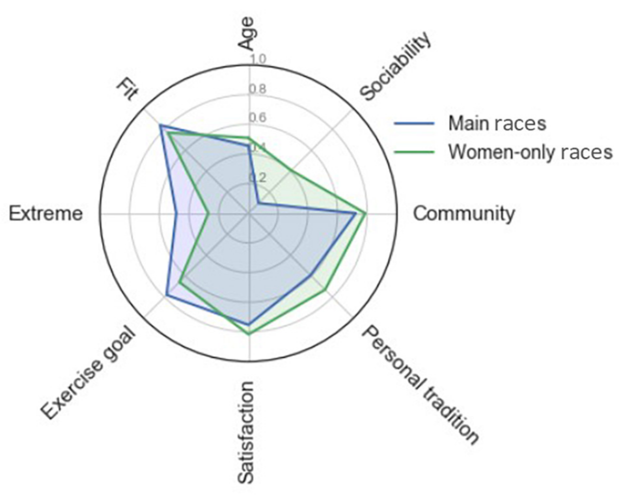

FIGURE 4 | Radar chart of the features with highest explained variance (normalized Gini coefficient) in a logistic regression model predicting women's participation in either the full-distance races (main race or Friday variant) or one of the two women-only races (15- or 30-km variants). Values expressed as the means of the questionnaire answers normalized to 0–1 range. Note: *Sociability* = "My friends did it" (participation motive); *Community* = "Part of a community" (self-perception); *Personal tradition* = "I usually participate every year" (participation motive); *Satisfaction* = Overall satisfaction with the race; *Exercise goal*: "A good exercise goal for the season" (race-perception); *Extreme* = "Extreme" (self-perception); *Fit* = "Fit" (self-perception).

Participants' Characteristics and Their Significance for Exercise Promotion

The sociodemographic profile of our sample, predominantly middle-aged women with medium–high income and living in the most urbanized region of Norway, is in line with known patterns in MPSEs participation (Murphy et al., 2015). On the other hand, the relatively large proportion of participants from the "host regions" (Inland Norway), which is remarkable especially considering the low-population density of this area, is of interest considering the poor public health profile of this area, especially in relation to low physical activity levels of its population. This finding suggests that MPSEs might have a particular beneficial impact in local communities. Arguably, this is somewhat in tension with the common approach of organizing MPSEs in major cities (see, for example, popular city marathons).

Our sample appeared to be constituted predominantly of "sporty" women, with many of them reporting their participation in similar competitions and planning to engage in at least one sporting activity during the spring season. This lends support to earlier findings indicating that MPSEs mainly reach those already adequately active (Lane et al., 2010, 2012). It is worthy of note, however, that about 60% of participants overall reported they had increased their ski-based exercise habits compared with the past 5 years, which may suggest that participation in the MPSE might have been, for some women, part of the process of increasing their physical activity levels. This interpretation is corroborated by the fact that the participation motive "It's a motivational exercise goal" was highly frequent, a finding that also emphasizes the goal-directed nature of participating in the MPSE as a health behavior. Nevertheless, none of these variables was a significant predictor of participation either in the full-distance races or the women-only races, indicating that the two groups of women had similar profiles in terms of sport and exercise participation. On the other hand, the older age of the women in the women-only races, alongside the women's reports of experiencing the race as a "tradition," suggests that the women-only races might have a greater potential than the main BR to help women maintain higher PA levels with aging. Such an assumption is in line with previous research on women-only MPSEs (Crofts et al., 2012; McArthur et al., 2014).

Worth of notice is the high importance of the participants given to *autonomous* forms of motivation (i.e., motivations driven by the intrinsic desire of pursuing an activity for its own sake, rather than for external rewards such as winning a prize or esthetic benefits). This could be noticed in the participants reporting "Because of the experience" as main participation motive, as well as perceiving the race as "A nice experience" and that "The most important here is to complete against yourself." Autonomous forms of motivations, as well as positive emotional experiences, are particularly desirable in relation to exercise (and health) promotion, as they have been previously reported to predict more stable exercise behavior in the long term (Kwan and Bryan, 2010; Teixeira et al., 2012). The importance given to nature experiences (see "it's a nice nature experience," which was highly rated both, as a participation motive and as a race-perception), which can also be seen as a factor that can elicit long-term adherence to exercise (Calogiuri and Chroni, 2014).

Taken altogether, these findings partly confirm concerns regarding the limited impact that MPSE can have in promoting health and exercise among women in the general population, although it also provides some additional insights into possible ways in which MPSEs might help *some* women to achieve and maintain their exercise goals.

Distinctive Profile of Women Participating in Different Events

Both the analysis of the quantitative and the qualitative data indicated that while participation in the women-only races was predominantly driven by the sociability motives and seeing the race as a tradition, the women in the full-distance races were predominantly driven by a performance-oriented motivation, and showed a desire to compete and feel "fit" and "pushing boundaries." Both groups of women perceived the race as enjoyable, although those in the women-only race tended to report higher ratings of satisfaction than the women in the full-distance races. Our findings are partly in line with previous research showing that sport participation, compared with other forms of exercise (e.g., exercising in the gym), is primarily driven by more autonomous forms of motivation, such as mastery, enjoyment, and sociability (Frederick and Ryan, 1993; Kilpatrick et al., 2005; Calogiuri and Elliott, 2017). These same motives were indeed found to be important for women to enter the main BR or one of its variants. At the same time, our study emphasizes how participation motives are also largely related to the specific context of sporting events, as, for example, that of the full-distance races (for which participation was predominantly characterized by mastery- and performance-oriented motives) compared to that of the women-only races (for which participation was predominantly characterized by sociability-oriented motives).

Independently of the different characteristics identified in women participating in different races (full-distances vs. women-only), it is noteworthy that the motivational profile of the women that has emerged in this study is largely in contrast with the way contemporary media tends to portray women in MPSEs. A recent critical analysis of how women are presented in sport and fitness advertising (including advertising for MPSEs) showed how most often emphasis is put on body-oriented messages, glorifying (or at times "girlifying") extreme esthetic body ideals (Drake and Radford, 2018, 2019). Based on our findings, more effective (and empowering) advertising targeting potential participants in full-distance MPSEs might instead focus on the women's performance and athletic achievements, e.g., through modeling-based messages stimulating vicarious mastery experiences. On the other hand, messages targeting potential participants in women-only events should emphasize the exhilarating social atmosphere of the race.

Strengths and Limitations of the Study

This study examined the under-researched topic of women's participation in MPSEs, with an emphasis on the characteristics that distinguish women participating in different variants of the race, thus contributing to filling a gap in the research literature. Our focus on the public health dimension of the phenomenon also contributes further understanding of the extent to which MPSEs can contribute to promoting health in the population as well as the ideal of "sports for all." Our analysis is based on novel and relatively large microdata from Norway, which had a relatively large response rate (35%), especially when compared with previous studies that used similar recruiting approaches; for example, Funk et al. (2011) had an overall response rate of 19% and Lane et al. (2010) had an average response rate of 23%. Moreover, our sample was found to be reasonably representative of the population of interest, at least in relation to age-class distribution. Finally, the inclusion of qualitative information allowed us to explore the phenomenon in more depth than hitherto.

This study has, however, a number of limitations that are worthy of note. First, in the study of participation trends, while a relatively large number of waves were available for a time-series analysis of the main BR, a relatively smaller number of waves were available for the other races (Friday race, half-distance race, and women-only races). This made the performance of a time-series analysis impossible for these races and the analysis of the participation trends less reliable.

In relation to the second part of the study, this was based on a secondary analysis of routinely collected data which may have resulted in some confounding variables being overlooked—a common limitation with secondary analysis (Cheng and Phillips, 2014). Moreover, although we performed a comparative analysis of our sample with the study population (i.e., the total participants registered), which showed a reasonable comparable distribution of age groups, the sample may not have been fully representative of the population of participants.

The instrument used in the survey was not validated. Furthermore, the inconsistency of the instruments used across years and among difference race participants made it impossible to include multiple survey waves in the analysis. This would have allowed a larger sample size as well as a better understanding of how the participants' characteristics changed alongside the changes in participation rates. Moreover, although the qualitative information in this study provided additional insight into the women's motivations and perceptions of the event context, the quality of these data was rather limited in terms of depth and richness (e.g., compared with qualitative data obtained through in-depth interviews).

Using a secondary analysis approach also limited the possibility of purposefully collecting data in line with specific theoretical frameworks, such as the *self-determination theory* (SDT), a psychological theory of motivation that has previously been used in research on sport motivation (see, e.g., Frederick and Ryan, 1993; Kilpatrick et al., 2005) as well as in the context of MPSEs (Funk et al., 2011). SDT posits that feelings of autonomy over one's behavior—the perception that one is competent enough to perform a behavior—and feelings of relatedness or personal connection, converge to support the development and enactment of motivations (Deci and Ryan, 1985). For example, "Extreme" and "Exercise goal" are both clearly related to autonomy (the former, suggesting mastery experiences, referring to satisfaction of competence needs, while the latter suggesting identified or integrated levels of autonomous motivation).

Finally, the analysis of sociodemographic, physical activity, and psychological factors only included female participants (comparing women participating in different races), while comparisons with men were not performed. The comparison with men was, in this particular paper, problematic for various reasons. First, we were primarily interested in understanding the characteristics of female participants, examining the extent to which this reflects ideals of "sport for all" (e.g., the extent to which women with lower sociodemographic status and lower physical activity levels were represented) as well as the characteristics of women participating in different races. A comparison with men might, however, reveal interesting aspects that have been missed in our analysis. Thus, it is recommended that future research attempts to make such comparisons.

Recommendations for Future Research

The topic of women's participation in MPSEs remains under-researched. Some academic studies exist, but large parts of the information are still provided by market surveys or reports produced by race organizers or other organizations (see, e.g., Running USA©). We recommend that future research seeks to enhance the quality of data collection, employing validated questionnaires (possibly informed by solid theoretical frameworks) and in-depth interviews. Studies including follow-up assessment of physical activity levels pre- and post-race are also needed, as well as studies investigating long-term engagement with MPSEs (i.e., regular participants). We also recommend that future research focuses on women's perceptions of barriers and factors that might negatively affect the race experience.

CONCLUSION

The results from this study shed light on women's participation in an iconic MPSE in Norway. Considering that in Norway levels of sport participation among women are relatively high, and that cross-country skiing is (still) embedded in the national identity of the population, this context offers interesting insight into the larger topic of women's participation in MPSEs. Specifically, our research offers insights into the role of event configuration in providing meaningful experiences to differing sub-groups of women. In general, the findings corroborate known patters in MPSEs, especially with respect to: (i) low involvement of women, as well as other disadvantaged sub-groups (e.g., women with lower socioeconomic status and low physical activity levels); (ii) indication of a progressively increasing prevalence of women in the main race; (iii) different sociodemographic and motivational profile of women engaged in different races (especially when comparing full-distance vs. women-only races). On the other hand, novel and encouraging findings have also been highlighted, such as a relatively large involvement of local communities, indicating some potential benefits in terms of exercise promotion in a region with higher prevalence of insufficiently active individuals (rather than, for example, to MPSEs taking places in major cities). Moreover, by focusing on women's participation across different races, our findings show that the specific race context plays an important role in broadening and supporting women's inclusion in sporting events. It is worthy of note, however, that the combination of main race and its variants seems to be a good strategy for locking people in to participation over time as they age and develop different interests. More research is needed in this field, which can help further enhance the understanding of how to best foster women's participation in MPSEs.

DATA AVAILABILITY STATEMENT

The datasets generated for this study will not be made publicly available. The datasets used and/or analyzed during this study are of property of Birken AS (Rena, Norway) and Differ Strategy Consulting (Oslo, Norway). The datasets used and/or analyzed during the current study may be available from Differ Strategy Consulting on reasonable request.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Norwegian Centre for Research Data (Project No. 58439). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

GC conceived and designed the study, led the team of authors, and drafted the overall manuscript. PJ retrieved the data, structured the datasets and, together with MT, performed the analysis on the qualitative data and drafted the presentation of methods and findings relative to this part. AR performed the analysis on the quantitative data and drafted the presentation of methods and findings relative to this part. All authors provided substantial contributions to the design of the study as well as the revision of the intellectual content and final development of the manuscript and approved its final version.

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Core Temperature Response During the Marathon Portion of the Ironman World Championship (Kona-Hawaii)

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The Ironman triathlon consists of a 3.8 km swim, 180 km bike, and 42.195 km run. Thermoregulation responses play an important role in performance optimization and injury prevention. Factors such as environmental conditions including heat and humidity, athlete training level, and race duration can affect thermoregulation. Hyperthermia occurs when the core temperature rises above 38.5°C. The present study aims to describe core temperature (Tcore) in top-level and well-trained age group triathletes during the marathon of Ironman World Championship 2014 in Kona-Hawaii under thermal stress conditions. Tcore of 15 triathletes (age: 36.11 ± 7.36 years, body mass: 71.14 ± 7.12 kg, height: 179 ± 0.04 cm, and fat %: 8.48 ± 0.85) who classified for the Ironman World Championship was measured by an ingestible pill telemetry system prior to competition, during the marathon and 60 min after finishing the race. Mean wet bulb globe temperature (WBGT) during the marathon was 24.66°C (range 22.44–28.50°C). Body mass index (BMI) and perceived exertion (Borg Scale and Visual Analog Scale-Pain) were collected before the race and 60 min after the event. Time variables were extracted from their official race time and split times. Finish time was 10: 06:56 ± 0:48:30. Tcore was initially 36.62 ± 0.17°C, increased at the end of the event (38.55 ± 0.64; $p < 0.01$) and remained elevated 60 min after the event (38.65 ± 0.41°C; $p < 0.002$). BMI significantly decreased after the event (22.85 ± 1.11 vs. 21.73 ± 1.36; $p < 0.05$), whereas both exercise perceived exertion [Borg Scale (10.2 ± 1.64 vs. 18.60 ± 1.67; $p < 0.003$)] and perceived muscle pain [VAS Pain (2.75 ± 1.59 vs. 9.08 ± 1.13; $p < 0.001$)] increased significantly after the event. Tcore during competition correlated negatively with position in age group (r – 0.949, $p = 0.051$), but not with race time ($r = -0.817$; $p = 0.183$). High-level age group triathletes competing under thermal stress conditions in the Kona Ironman reached a state of hyperthermia during the marathon. After 60 min of recovery the hyperthermia persisted. Strategies to aid post-event cooling and recovery should be considered to avoid the potentially dangerous adverse health effects of hyperthermia.

Keywords: endurance, performance, competition, hyperthermia, triathlon, marathon

INTRODUCTION

A triathlon race involves consecutive sequences of a 3.8 km swim, a 180 km cycle ride, and a 42.2 km run. The Ironman triathlon has gained significant popularity in recent years. During the Ironman triathlon, participants compete for best overall race time, including timed transitions between the swimming, biking, and running legs. The multiple, worldwide Ironman competitions (Lepers, 2008) have become popular as they are accessible to multitudes of amateur and recreational athletes. With the increasing popularity of these competitions, numerous studies have been published in recent years aiming to analyze the physiologic responses of endurance triathletes in competition.

Laursen and colleagues demonstrated that during an Ironman triathlon recreational triathletes' Tcore reached 38.1 ± 0.3°C (Laursen et al., 2006). Increases in Tcore above 38°C, induced by intense exercise, produce central fatigue (Nybo and Nielsen, 2001); moreover, time-to-exhaustion is reduced in the heat (Gonzalez-Alonso et al., 1999). Additionally, Nybo and colleagues demonstrated that elevated core temperature alters prefrontal cerebral activity (Nybo and Nielsen, 2001). Hyperthermia (H) is defined as an elevation of core body temperature (Tcore) greater than 38.5°C. Exertional heat illness is a spectrum of conditions involving elevated body temperature; the two most serious of these conditions are heat exhaustion and exertional heat stroke (EHS). Core temperature is a critical vital sign in the assessment of a collapsed marathon runner who may have EHS (Ronneberg et al., 2008).

During exercise, Tcore is proportional to the metabolic rate and is largely independent of a wide range of environmental conditions. Accelerated hyperthermia-mediated fatigue during maximal and prolonged exercise is preceded by functional alterations in central nervous and cardiovascular systems as well as in skeletal muscle. Parry and colleagues proposed that impaired marathon running performance in warm environments is associated with greater thermal, cardiovascular, and metabolic strain as well as greater perceived exertion; research demonstrated positive correlations between distance covered and rating of perceived exertion (Parry et al., 2011). These effects prevent marathon runners from competing at their personal record speed without inducing accelerated regulatory dysfunction in multiple bodily systems (González-Alonso, 2007).

A reliable core body temperature is important for differentiating between heat exhaustion and EHS, as well as monitoring the success of cooling therapies. An accurate measurement of Tcore is essential to protect individuals from heat injury during exposure to high levels of thermal stress (Bernard and Kenney, 1994). This stress is not necessarily commensurate with high ambient temperature and or relative humidity (Cheung et al., 2000). The measurement of Tcore is typically achieved using either ear, esophageal, gastro-intestinal, or rectal thermometry. However, at least for research purposes, using telemetric ingestible pills to measure gastro-intestinal temperature *in vivo* in the field is recommended given their accuracy and non-invasive nature (Bongers et al., 2015).

The original Ironman triathlon is now known as the Ironman World Championship and is held in Kailua-Kona, Hawaii, USA annually. Thousands of triathletes from across the globe compete to qualify in this coveted race. One of the main characteristics of this event is its high thermal stress conditions including heat, relative humidity, and solar radiation. Stearns et al., 2018 showed how age group triathletes finished the event with an average Tcore (gastro-intestinal) of 38.3°C. However, it remains unclear if well-trained triathletes experience hyperthermia under thermal stress conditions during the marathon portion of the ironman or only at the end of the event. Well-trained athletes are able to achieve higher velocities and therefore generate increased heat production relative to their competitors, but theoretically, these elite athletes possess efficient mechanisms to dissipate heat and maintain Tcore stability.

Regarding performance, a decrease in running speed following attainment of a critically high Tcore has been demonstrated during the marathon portion of the Ironman in recreational triathletes (Laursen et al., 2009). Despite prior investigations, the true relationship between thermal stress conditions, core hyperthermia, and running performance is unknown. The main purpose of the present study was to evaluate Tcore in top-level, well-trained triathletes before, during, and after the marathon portion of Kona Ironman World Championship (Hawaii) under thermal stress conditions and investigate correlations with running performance. The authors hypothesize that despite the rigorous training status and high performance level of participants, triathletes will obtain elevated core temperatures during the marathon and the temperature elevation will impair their running performance.

MATERIALS AND METHODS

Participants

Fifteen trained and experienced male triathletes were recruited by email to participate in this study (**Table 1**). Volunteers with a previous history of muscle disorder, cardiac, or kidney disease or those taking medications during the prior 2 week period were excluded from the study. Participants were informed

TABLE 1 | Physical characteristics of participants and ironman official data.

Variable (units)	
Age (year)	36.11 ± 7.36
Height (cm)	1.79 ± 0.04
Body mass (kg)	71.14 ± 7.12
∑ 6 skin folds (mm)	53.83 ± 8.59
Fat mass (%)	8.48 ± 0.85
Ironman experience (yr)	3.78 ± 1.99
Finish time (h:min:s)	10:06:56 ± 0:48:30
Swimming time (h:min:s)	1:05:23 ± 0:04:49
Transition 1 time (min:s)	3:15 ± 0:48
Cycling time (h:min:s)	5:19:26 ± 0:16:38
Transition 2 time (min:s)	4:29 ± 1:05
Marathon time (h:min:s)	3:34:21 ± 0:38:29
Overall rank (position)	471 ± 397
Age group rank (position)	62 ± 56
Time behind overall elite winner (%)	22.8 ± 9.7
Time behind overall age group winner (%)	10.4 ± 9.1

of any potential risks associated with the experiment before providing written consent to participate. The research was carried out during the Ironman World Championship 2014 in Kona, HI (USA). Our selection of highly trained and motivated triathletes for this study was based on our experience that competitive triathletes are generally willing and able to withstand considerable discomfort and to exercise until the development of physiological signs of exhaustion. We scored the number of years that the triathletes had participated in a high-volume training program (>750 h/year). Triathletes arrived on Kona Island 10 days before the race to train in race conditions for the purpose of heat acclimatization. Triathletes and their coaches were informed about the experimental procedure, the possible risks, and benefits of the study with the approval of the local committee of ethics and gave written consent to participate, in accordance with the latest rendering of the Declaration of Helsinki, 2008 (Fortaleza, 2013).

Experimental Protocol

The triathlon was held on October 11, 2014 in Kona which is situated 2.13 m above the sea level. Mean dry temperature during the event ranged from 24.4 to 30.0°C. Water temperature was approximately 26°C. Average ambient humidity was approximately 60.4%. Due to the segments of the course where triathletes were most exposed to sun radiation, such as the cycle and run portions, wet bulb globe temperature (WBGT) measurements were calculated (Liljegren et al., 2008; Lemke and Kjellstrom, 2012) according to meteorological data retrieved from the National Weather Service (National Oceanic and Atmospheric Administration, USA).

Mean WBGT during the entire Ironman competition was 24.1°C (range 18.6–30.2°C), while during the marathon portion mean WBGT was 24.7°C (range 22.4–28.5°C). Given these parameters, race officials advised participants to hydrate ad libitum and exercise at their own pace.

Before the Race

The race start time was 6:45 am. Three hours before the start of the race (3:45 am local time), participants arrived at a zone near the starting line (main lobby at the official race hotel, the King Kamehameha's Kona Beach Hotel). Investigators had not provided participants with prior instructions about pre-exercise hydration or nutrition. Nevertheless, all study participants indicated they had consumed breakfast at least 1 hour prior to arriving at the start line. Upon arrival, each participant received an ingestible telemetry pill for the measurement of intra-intestinal temperature (HT150002, HQ® Inc., US). Participants immediately swallowed the pill with 50 ml of water, then rested for 5 min, and completed a survey with two main scales: rating of perceived exertion scale and pain scale. Finally, anthropometric data were obtained. Triathletes were weighed in under garments and all anthropometric measurements were obtained by the same investigator. Investigators did not provide any specific instructions regarding pace, rehydration, or fuel ingestion in order to avoid any undue influence on their routine habits during the race.

During the Race

The race consisted of a 3.8 km of open water swim in Kailua-Kona Bay, a 180 km cycle ride across the Hawaiian lava desert (elevation: 1,090 m) and a 42.2 km run along the coast and roads close to the airport. During the race the telemetric sensor registered Tcore.

After the Race

Within 1 h of the end of the race, participants proceeded to a secure finish area. Participants were instructed to avoid ingesting fluids from the time they crossed the finish line until the post-race weigh-in where an investigator could assure compliance. Body mass was immediately measured using the same apparatus and methodology employed prior to the race. During this time, scales for ratings of perceived exertion and pain were also completed. The entire post-race process was completed in less than 3 min. Afterward, participants were provided with fluid (water and sports drink) *ad libitum*. At 1 h after finished the race, triathletes left the finish area and moved to corner lobby, official King Kamehameha's Kona Beach Hotel, where Tcore was registered.

Anthropometric Data

Height (cm) was measured by a stadiometer, model SECA® (Germany), with a 2 mm precision and 130–210 cm range. Body mass (kg) was recorded by a scale, model SECA® (Germany), with a precision of 0.2 kg and a range from 2 kg to 130 kg. Body fat percentage was estimated by measuring skinfold thickness (locations: subscapular, tricipital, suprailiac, abdominal, thigh and lower leg) using skinfold calipers (Harpenden, British Indicators, LTD), with an accuracy of 0.2 mm following "The International Society for the Advancement of Kinanthropometry" (ISAK) protocol (Stewart et al., 2011). Additionally, all anthropometric measurements were recorded by the same investigator, who was certified in anthropometric testing (ISAK level 2) (Stewart et al., 2011). Body mass index (BMI) was calculated, and the body mass change attained during the race was calculated as a percent reduction in BMI (pre-to post-race) given that height was constant.

Perception Scales

Borg rating of perceived exertion scale (RPE scale) was used to assess participants RPE, where six was equivalent to no exertion and 20 denoted the maximum (Borg, 1982). Visual Analog Scale (VAS pain) was employed to determine the muscular pain as perceived by the subjects in a 90° knee-bending position after trials. Zero on the scale represented no pain experienced, while 10 signified that the movement was extremely painful. This evaluation method has been used in other studies as a non-invasive means of measuring the degree of subjective agreement with certain attitudes or characteristics, such as pain or discomfort (Hicks et al., 2001).

Core Temperature

Core body temperature (Tcore) was measured by a telemetric temperature sensor (CorTempTM Ingestible Thermometer®, HQInc. USA) using an ingestible pill telemetry system (Byrne and Lim, 2007). Tcore signals were collected and recorded (CorTempTM 2000 Recorder®; HQInc. USA) 15 min before the start of the competition (PRE), during the marathon close to km 16 (PER), and 1 h after finishing the ironman (POST).

The manufacture's reported sensitivity ranges from 0 to 50°C with an accuracy of ±0.1°C. A low-frequency radio wave is transmitted to an external receiver/data logger from a crystal quartz oscillator contained within each pill. The ingestible pill was swallowed 3 h before the race to ensure passage past the stomach, rendering it insensitive to swallowed hot or cold liquids (sensor pills ingested immediately prior to physical activity cannot be used to measure core body temperature accurately in all individuals over the following 13 hours if cool fluids are regularly ingested) (Wilkinson et al., 2008). The calibration of the ingestible pills was verified at four different temperatures against a certified mercury thermometer in a water bath at temperatures ranging from 30 to 42°C. A linear regression of the relationship between the measured temperatures and those from the certified thermometer was used after the test to adjust pill measurements (Edwards and Clark, 2006).

Performance and Official Time

The official finish times and the partial times of each of the race components were obtained from the official page of the Kona Ironman World Championship (Hawaii)[1].

Statistical Analyses

Data are presented as the mean ± standard deviation (SD). Standard statistical methods were used for the calculation of the mean and SDs. Shapiro-Wilk test ($n < 50$) was conducted to show the distribution of the studied variables and Levene's test was used for homogeneity of variance. A *t*-test was used to analyze the paired data. A one-way ANOVA *post hoc* Bonferroni test was applied for Tcore analysis. A Pearson's correlation coefficient was used to test the statistical relationship between different variables. The Cohen's *d* was calculated to determine the effect size (ES) of the differences with thresholds considered as trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), large (1.2–2.0), or very large (>2.0) (Cohen, 1988). The differences were considered statistically significant when $p < 0.05$ [SPSS statistical package, version 25.0 was used (SPSS, Inc., Chicago, IL, USA)].

[1]www.eu.ironman.com/triathlon/event

RESULTS

Table 2 shows dependent variables used in the study in comparison PRE vs. POST. The BMI of participants decreased an average of 4.9% after the ironman reaching statistical significance and with a notable size effect. Perceptual variables, perceived exertion, and perceived muscle pain all increased after finishing the ironman, approaching the highest values of their respective scales. These changes were statistically significant with a moderate and large size effect, respectively.

Table 3 describes the results for Tcore of the triathletes. All participants had a normal Tcore before the start of the competition; however, they reached a hyperthermic state during the marathon which persisted at least 1 h after completion of the race. Both the degree of initial increase as well as the degree of persistently elevated temperature in Tcore were statistically significant.

Relationships Among Variables

Race Time and Age Group Rank

Positive correlations were observed between the final placement of age group and marathon time ($r = 0.913$; $p = 0.01$), final time ($r = 0.816$; $p = 0.007$), body mass ($r = 0.803$; $p = 0.009$,) and post-BMI ($r = 0.931$; $p = 0.007$). Similarly, positive correlations were observed between the final race time and body mass ($r = 0.742$; $p = 0.022$), post-BMI ($r = 0.911$; $p = 0.012$) and with time in marathon portion ($r = 0.892$; $p = 0.001$).

Core Temperature

Regarding Tcore during the race, the Pearson's correlation coefficient demonstrated a relationship between Tcore during marathon and Tcore post-competition ($r = 0.970$; $p = 0.003$). Likewise, Tcore during marathon correlated negatively with position in age group ($r - 0.949$, $p = 0.051$) but not with race time ($r = -0.817$;

TABLE 2 | BMI and perceptual variables changes pre/post competition.

Variable (units)	PRE	POST	Δ (%)	p	ES d Cohen
BMI (kg/m²)	22.85 ± 1.11	21.73 ± 1.36	−4.9	0.056	3.2 *Very Large*
RPE (units)	10.2 ± 1.64	18.60 ± 1.67	+82.4	0.003	1.1 *Moderate*
VAS pain 0–10 (units)	2.75 ± 1.59	9.08 ± 1.13	+230.2	0.001	2.9 *Very large*

TABLE 3 | Core temperature measurement during the ironman.

Variable (units)	PRE (1)	PER (2)	POST (3)	Δ (1–2) (%)	p	ES d Cohen	Δ (1–3) (%)	p	ES d Cohen	Δ (2–3) (%)	p	ES d Cohen
Core temperature (°C)	36.62 ± 0.17	38.55 ± 0.64	38.65 ± 0.41	+4.99	0.01	1.1 large	+5.54	0.002	1.7 *very large*	+0.52	0.182	0.19 *small*

p = 0.183). Additionally, an inverse low relationship was found with skin fold summation (r = −0.219; p = 0.025).

On the other hand, a negative relationship was seen between Tcore post-competition and position in age group (r = −0.936, p = 0.064) but not with race time (r = −0.809; p = 0.191). T core post competition showed no correlation with skin fold summation (r = −0.164, p = 0.806).

Perception Scales

A significant correlation was found between the average race time for the run portion and pre-race pain levels (r = 0.788; $p < 0.01$). Similarly, a significant association was described between body mass and pain pre-race (r = 0.707; $p < 0.01$).

DISCUSSION

This study was designed to measure Tcore in high-level and well-trained triathletes, under thermal stress conditions, during the marathon portion of one of the most difficult championships in the world, the Ironman World Championship (Hawaii, Kona 2014), (Laird and Johnson, 2012).

The combined 3.8-km swim, 180-km cycle, and 42.192-km run is often considered one of the world's most challenging endurance races (Lepers, 2008). Given the ACSM position stand about exertional heat illness during training and competition (Armstrong et al., 2007), the average WBGT during the event falls within a higher risk zone for all competitors, but especially for those who are incompletely acclimatized or possess inadequate fitness. Participants in this study demonstrated overall high levels of fitness, given their qualification for an elite Ironman competition, their low fat mass percentage (Kandel et al., 2014) and because their final race time was almost 1 h faster than other Kona participants in similar studies (Stearns et al., 2018).

Exercising in the heat can produce an excessive increase in body Tcore and the resultant hyperthermia can be detrimental to health and endurance performance (Tan and Lee, 2015). Several studies have previously examined Tcore during ironman events in hot conditions. Laursen et al. found that in the Western Australia Ironman in 2006, triathletes averaged a Tcore of 38.1 ± 0.3°C during the event in warm conditions (23.3°C and 60% relative humidity), averaging a lower Tcore during the marathon portion. During the Kona Ironman, recent studies (Stearns et al., 2018) measured Tcore in triathletes immediately after crossing the finish line. With hotter conditions than in Western Australia, the fastest triathletes achieved core temperatures of 38.3 ± 0.6°C while the slowest athletes remained in normothermia with a Tcore about 37.3°C. However, the investigators did not measure or report Tcore during any part of the actual competition.

Our study, performed in the same location but in a different year, demonstrated how 1 hour after finishing the event, triathletes were in an hyperthermic state with a Tcore of 38.65 ± 0.41°C. This means they likely achieved their highest Tcore just after finishing. The Tcore data in our investigation were higher than in other studies referenced, with the main differences being the hotter conditions (Laursen et al., 2006) and faster finish race time in our study (Stearns et al., 2018). The increased heat generated by elite, top-speed athletes as well as the hot, humid ambient conditions are two factors that like increase Tcore.

Regarding Tcore during the event, in the first part of the marathon, triathletes had reached hyperthermia (38.55 ± 0.64°C) in our study, data that explain the high Tcore reached 1 h after finished the event supported by a high and statistically significant correlation (r = 0.970; p = 0.003). To our knowledge this work represents the first actual reporting of Tcore measurements obtained during the race of the Ironman World Championships.

In our study, the persistent elevation of Tcore for at least 60 min after the event (38.65 ± 0.41°C, $p < 0.002$) represents a somewhat surprising and novel finding. After cessation of exercise, the rate at which body produces heat decreases while the mechanisms used to dissipate heat remain in operation until the T core returns to its normal level. The effectiveness of the thermoregulatory system in regulating body temperature is influenced by the acclimatization state of the individual (Wenger, 1988). In hot and humid race venues such as the Kona Ironman, many professional triathletes effectively utilize strategies to "beat the heat and humidity" such as training in the heat in the days leading up to the event (Lockett, 2012). For this reason, many triathletes arrive in Kona early and spend 7–10 days training in the heat with the goal of acclimatization leading to improved performance.

The assumption that high internal T core can cause fatigue has been accepted (González-Alonso, 2007) and is supported by a case report in an Ironman triathlon (Laursen et al., 2009). Correlation established in our study shows how a higher Tcore during the marathon is inversely related to age group rank (r = −0.949, p = 0.051).

During these long endurance events, body mass changes are substantial. Mueller showed that participation in an Ironman event can lead to important changes in body composition such as a substantial loss of fat mass, which can affect energy availability since fat provides up to 50% of whole energy expenditure (Mueller et al., 2013). Knechtle and colleagues showed that male triathletes in an Ironman lose an average of 1.8 kg of body mass and 1 kg of skeletal muscle mass, presumably due to a depletion of stored glycogen and lipids within myocytes (Knechtle et al., 2010). In our study the post-event BMI decreased 4.9% with a very large size effect. Considering that height is stable, the reduction implicates a decrease in body mass, which is similar to findings discovered during the Ironman of South Africa by Hew-Butler et al. (2007). This change in body mass is likely attributed primarily to a loss of fluid. Stearns et al., 2018 found in the Kona Ironman only a 2.4% decrease in body mass, but the participants' urine specific gravity was 1.021 after finishing the race, implying a significant ingestion of fluids. Unfortunately in our study, we were not able to asses biological markers related to hydration/dehydration status.

Body composition is also related to performance in endurance sports, including triathlons. An excess of body mass may be especially disadvantageous in the run segment (Sleivert and Rowlands, 1996). Some research claims that a loss in body mass during marathon and triathlon events contributes to an athlete's success, especially for those who lose substantially more than 3–4% body weight during competition.

In our study, positive correlations were found between the final age group rank and final BMI (r = 0.931; p = 0.007) what might indicate that triathletes who complete the race with a lower BMI, i.e., lower body mass, finish with a higher rank position. To get an optimal position in age group rank, ideally a competitor secures a favorable marathon split ($r = 0.913$; $p = 0.01$). Also to achieve a lower finish time, one must have a lower marathon split time ($r = 0.892$; $p = 0.001$) and a low pre-race body mass ($r = 0.742$; $p = 0.022$). Fast time in running, as well as other factors, has been previously reported as an important predictive variable for a fast race in long distance triathlons (Knechtle et al., 2015).

The results of our study reiterate the importance of a fast marathon pace for achieving a higher rank in one's age group, due to their positive and strong correlation. A loss of body mass up to 5% may allow an athlete to increase velocity but may not positively affect thermoregulation as a negative relationship was seen between Tcore during marathon and one's position in age group. Subsequently, cooling strategies during marathon or heat acclimation before the event may enhance performance in triathletes.

In regard to perceptual variables, in sports and particularly exercise testing, the rating of perceived exertion (RPE), as measured by the Borg rating of perceived exertion scale (RPE scale) (Borg, 1982) is frequently used to quantify measures of perceived exertion. An interesting study conducted in Ironman triathletes (Parry et al., 2011) concluded that RPE followed a linear progression during each triathlon discipline followed by a return of the perception of effort to baseline levels at the start of the next discipline. Our results revealed that RPE values increased significantly after the event, which is in concordance with Parry and colleagues, who previously demonstrated that the increase in RPE for the entire event followed a linear pattern. Confounding the results, anxiety and mood responses of participants seem to indicate that the emotional response of athletes before and after ultra-endurance events is closely aligned with their conscious thoughts (Parry et al., 2011). Furthermore, RPE values of triathletes after completing the Ironman World Championship in Kona from this study were very similar to those achieved years before in the same race by a different cohort (Stearns et al., 2018).

Visual Analog Scales (VAS) are psychometric tools. The VAS has been used in other studies as a non-invasive method of monitoring the changes in muscular pain perception after exercising, and the consequent muscle damage. In triathletes from this study, subjective levels of muscle pain increased significantly by 230% after the event with a score of 9.08 ± 1.13. Muscle pain may be severe and may interfere with gait, causing participants to seek assistance in the medical tent after the event. Such discomfort derives from muscle damage which may multifactorial in nature (Gleeson and Bishop, 2000).

Prior studies have assessed pain and plasma muscle enzyme levels as potential markers for muscle damage; however, general consensus indicates that these parameters do not accurately measure the degree of injury to skeletal muscle (Kim et al., 2007). Muscle damage associated with prolonged activities, such as the Ironman triathlon, is associated with increases in creatine kinase (CK) levels (Machado et al., 2010), release of interleukins, and consequently, modulation of the immune system. It has been suggested that immunological and hormone alterations occur due to high-volume and high-intensity training which, combined with the emotional and physiologic stress caused by the competition, may be perceived after the event (Walsh et al., 2011). This fact supports the need for a more detailed examination of athletes <35 years and to identify people who are at risk for muscle damage (Leischik and Spelsberg, 2014).

In summary, hyperthermia is reached during the marathon portion of Ironman World Championship in Kona under thermal stress conditions. Increased core temperature appears to make triathletes run more slowly while a fast marathon split is very important for a good rank in age groups. Also hyperthermia persists 1 h after the event. Cooling strategies during the race and heat acclimation must be utilized for preparing these types of competitions.

One limitation of this study was that Tcore was registered only in three separate moments. A full register of Tcore during the entire event may provide additional information about Tcore alterations and timing of reaching hyperthermia, whether during the marathon or before. Another limitation was the inability to perform blood/urine analysis to obtain biological markers for a more complete, multifactorial analysis of results obtained.

Future research regarding to this world championship should focus on continuous monitoring of Tcore in order to identify the degree of hyperthermia experienced by triathletes or the effects of different cooling strategies during the race.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Extremadura. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

GO conceptualized the study. GO, CC, JC-G, and RT assisted with the methodology. GO, CC, and JC-G acquired measurements and assisted with the data field acquisition. GO, RT, and JC-G contributed in formal analysis. GO, JM, and JC-G assisted with the writing and with the original draft preparation. GO, CC, RT, JM, and JC-G assisted with the writing, review, and editing.

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Multidisciplinary Analysis of Differences Between Finisher and Non-finisher Ultra-Endurance Mountain Athletes

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Ultra-endurance races are one of the most physically and psychologically demanding sports, depending performance on several elements. The aims of the present study were (i) to analyze differences in selected psychophysiological parameters between finisher and non-finisher ultra-endurance mountain athletes, and (ii) to analyze modifications in psychophysiological parameters before and after an ultra-endurance mountain event. Selected psychophysiological variables were assessed in 46 finishers and 24 non-finishers in two over 100 km ultra-endurance races were examined. We found how an ultra-endurance mountain race produced dehydration, a decrease in systolic blood pressure, weight and leg strength muscle values, as well as an increase in heart rate and rate of perceived exertion values. Finishers presented lower systolic blood pressure, weight, body mass index, half marathon time and fluid intake before competition day compared to non-finishers. In addition, body mass index, pre-race hydration, and performance in lower distance races were predictors of performance in these ultra-endurance mountain races.

Keywords: psychology, odontology, nutrition, training, stress, mountain running

INTRODUCTION

Ultra-endurance mountain events are increasing their popularity and the number of participants, showing an exponential increase in recent years (Knechtle et al., 2009b). Human performance under extreme conditions has been understudied mainly due to the sample-accessibility difficulties. Previous research has focused on the evaluation of anthropometric characteristics demonstrating that low body fat percentage is a key success factor in ultra-endurance events (Barandun et al., 2012), as well as describing acute physiological effects showing increased protein catabolism and muscle breakdown (Jamart et al., 2012), and autonomic sympathetic modulation (Valenzano et al., 2016).

These extreme events can also produce increased creatinine kinase and urea concentrations, due to muscle destruction and catabolic status of athletes (Marklund et al., 2013), blood lactate values related to the anaerobic threshold (Clemente-Suarez, 2015), sustained hemoglobin levels due to increased erythropoiesis in order to compensate for exercise-induced hemolysis (Schumacher et al., 2002). In addition, increased triglyceride metabolism (Volek et al., 2016), overexpression of the sympathetic nervous system (Belinchon-deMiguel and Clemente-Suárez, 2018) and cardiovascular effort which could reach up to 71% of the maximum heart rate (Valenzano et al., 2016) have also been reported. From a psychological perspective, athletes have a significant anxiogenic response, expressed by the levels of post-exercise cortisol values (Nicolas et al., 2011), fact also related with the metabolic response in these extreme events.

Other studies analyzed the role of the number of training sessions (Zaryski and Smith, 2005), the effect of chronological age (Clemente-Suarez and Nikolaidis, 2017), the contribution of different biomechanical and morphological factors (Hoffman and Fogard, 2011) as well as emotional and personality constructs (Lane and Wilson, 2011), as key performance parameters for ultra-endurance events. Latest studies observed greater performance in ultra-endurance sport events with an appropriated hydration and optimal nutritional status (Peters, 2003; Costa et al., 2014), oral health status and periodontal disease (Needleman et al., 2013, 2015; Ashley et al., 2015; Frese et al., 2015), higher training intensity and volume (Knechtle et al., 2012), higher pain tolerance (Schutz et al., 2012; Freund et al., 2013) and stress management (Baker et al., 2005; O'Neil and Steyn, 2007). Moreover, a previous study analyzed specific psychological parameters such as the vital commitment, coping with anxiety, self-perception, stress perception and psychological flexibility showing their relationship with athletic performance (Hughes et al., 2003).

Moreover, ultra-endurance athletes are accustomed to consuming non-steroidal anti-inflammatory drugs (NSAIDs) or central nervous system activators, as caffeine, which can lead to gastrointestinal discomfort, as well as potential side effects on the gastrointestinal tract and kidneys (Joslin et al., 2013); however most of the athletes are not aware of the side effects, while a widely use among ultra-endurance athletes has been reported despite the medical and professional advise (Wichardt et al., 2011). Furthermore, it has been postulated that most of the ultra-endurance athletes do not adjust their fluid and energy balance requirements during the race (Belinchon-deMiguel and Clemente-Suárez, 2018), mostly due to a lack of knowledge and supervision. Nevertheless, successful athletes have shown an appropriate liquid and fuel ingestion, prior and during the race, fulfilling their demands and keeping an appropriate water and energy balance (Clemente-Suarez, 2015).

Ultra-endurance races are a complex multifactorial phenomenon, affected by different physiological and psychological parameters. Then, to better understand the psychophysiological variables related to performance in this events, as well as, the effect of this extreme races in the organism we conducted the present research with the aims of (i) to analyze differences in selected psychophysiological parameters between finishers and non-finishers ultra-endurance mountain athletes, and, (ii) to analyze modifications in psychophysiological parameters before and after an ultra-endurance mountain event. The initial hypothesis were (i) finisher ultra-endurance mountain athletes would present a different psychophysiological profile than non-finishers, and (ii) ultra-endurance mountain race would decrease weight and strength of participants as well as increase cardiovascular response and deshydration status.

MATERIALS AND METHODS

Participants

Seventy volunteer (46 finishers and 24 non-finishers) male ultra-endurance mountain athletes were analyzed (chronological age 42.7 ± 7.8 years; height 173.2 ± 6.8 cm; body mass 69.2 ± 7.2 kg; and body mass index 23.1 ± 1.5 kg m^2) of a total of 146 races participants. Prior to the start of the study, the experimental procedures were explained to all the participants, who gave their voluntary written informed consent in accordance with the Declaration of Helsinki. The study was approved by the European University of Madrid Bioethics Committee (CIPI/002/17).

Ultraendurance Race

The Canfranc-Canfranc ultra-endurance mountain race edition 2016, composed of 100 km of distance and 8848 m of positive change of altitude and 17696 accumulated changes of altitude, as well as and the GTP (Gran Trail de Peñalara) ultra-endurance mountain race edition 2016 with 112 km and 5100 m of positive change of altitude and 10200 m of accumulated change of altitude were analyzed.

Materials and Method

The following parameters were analyzed in the ultra-endurance athletes following procedures of previous authors in ultraendurance events (Suarez et al., 2011; Belinchon-deMiguel and Clemente-Suárez, 2018; Belinchón-Demiguel and Clemente-Suárez, 2019).

Physiological Measurements

- Body mass was measured by using a SECA scale model 714 with a precision of 100 g (range: 0.1–130 kg), located on a flat and smooth surface and calibrated at zero. Participants were barefoot and with minimal clothes. Once located in the center of the platform, they remained without their body being in contact with surrounding objects, with the weight evenly distributed on both feet facing forward.
- Body height was measured with a height rod incorporated in the scale SECA model 714 with a precision of 0.1 mm (range: 60–200 cm). Participants stood up barefoot with the

head oriented in the Frankfort plane that joins the inner edge of the eye socket and the upper one of the external auditory meatus, arms on both sides of the trunk, extended and with palms touching external face of the thighs, heels together touching the lower end of the vertical surface with the inner edge of the feet in the 45 to 60°, occipital area, scapular, buttocks, posterior face of the knees and calves touching the vertical surface of the anthropometer.

- Body Mass Index (BMI = Weight in kg/Size^2 in meters) was calculated according to the World Health Organization.
- Heart Rate (HR) was recorded with a Polar V800 HR monitor (Kempele, Finland). HR was analyzed before and immediately after the race. In order to record baseline values, athletes remained in the waiting room without any disturb.
- The Omron M6 Confort (Osaka, Japan) was used for the blood pressure measurement (BP) with the participants seated with their arm flexed at the level of the heart in a waiting room without any disturb.
- Blood oxygen saturation (BOS) was calculated using an oximeter OXYM4000 (Quirumed, Madrid), placed in the index finger of the right arm.
- The isometric hand-grip strength was assessed using a TKK 5402 dynamometer (Takei Scientific Instruments, Co., Ltd.). Each athlete's hand grip strength was measured in the dominant hand. Athletes were placed sitting with 0 degrees of shoulder flexion, 90 degrees of elbow flexion and the forearm in neutral. The highest result of the two trials was recorded.
- Lower limbs strength was evaluated by a horizontal jump test. Athletes were standing behind a line marked on the ground with feet slightly apart. A two-feet take-off and landing was used, with swinging of the arms and bending of the knees to provide forward drive. Athletes had 3 attempts, analyzing the highest result; the measurement was taken from take-off line to the nearest point of contact on the landing, which is the back of the shoe heels.
- Hydration status was assessed by a urine measurement using the urine color chart methodology (Armstrong et al., 1994).
- Forced vital capacity (FVC) and forced expiratory volume (Fev1) were calculated using a QM-SP100 (Quirumed, Spain) spirometer in a maximum inhale-exhale cycle.
- Rate of perceived exertion (RPE) was measured using the 6–20 scale (Costa et al., 2014).

Moreover, training, nutritional, psychological and odontological differences between finisher and non-finisher ultra-endurance mountain runners were analyzed by a questionnaire filled out the week before the race reporting the following parameters.

Training Parameters

Total distance (km), positive or negative change of altitude accumulated race (m), training experience (years), mountain race experience (years), marathon best mark (min), half marathon time (min), expected race position, expected time (min), weeks injured, training per week (h), training per session (min), training sessions per week, mean speed training per week (min/km), positive change of altitude accumulated per week (m), change of altitude accumulated per week (m), resistance training sessions (per week), load percentage during resistance training (% of 1RM), stretching time per week (min) and stretching sessions per week.

Nutritional Parameters

Carbohydrates meals during the pre-competition week (n°) and fluid intake before competition day (Knechtle et al., 2009b).

Psychological Parameters

Perceived stress (as measured by the Perceived Stress Scale (PSS-14) (Remor, 2006), and general mental health status (as measured by the Acceptance and Action Questionnaire, AAQ-II (Bond et al., 2011).

Odontological Parameters

Grinding or clenching teeth while performing usual tasks, nibbles objects, bites his nails, wakes up with fatigue in mouth muscle, consumption of vitamin C pills, wet pillow upon awakening and repeated burps.

Statistical Analysis

To analyze the data, we used the SPSS statistical package (version 22.0; SPSS, Inc., Chicago, IL, United States). Normality of the sample was determined with the Shapiro–Wilk event. To analyze differences between pre and post samples, a dependent-*t*-test was performed for all the variables as they presented a parametric distribution. To analyze differences between finishers and non-finishers an independent-*t*-test was conducted. The effect size was evaluated by the Cohen d event. Finally a correlation analysis between study variables and finalization of the probe was calculated by the Pearson Test. For all comparisons, the significance index of $p < 0.05$ was accepted.

RESULTS

Results are reported as mean ± *SD* values. Regarding pre-race physiological differences between finishers and non-finishers, systolic blood pressure and body weight presented significant differences, being greater in non-finishers. Greater isometric hand grip strength and explosive strength of the lower limbs, measured through the horizontal jump length, were greater in non-finishers, as well as the FVC and RPE values (**Table 1**).

Significant differences were found between finishers and non-finishers, regarding the half marathon time, in where finishers had significant lower time. In addition, non-finishers presented a greater number of injured weeks, a greater number of training sessions, as well as a lower mean speed during training and a lower percentage of load during resistance training, compared with finishers (**Table 2**).

Regarding questionnaire analysis between finisher and non-finishers, significant differences were found in BMI and height,

TABLE 1 | Differences between mountain ultra-endurance finishers and non-finishers in pre-race body mass and psychophysiological parameters.

Variable	Finisher	Non-finisher	T	P	Effect size	% Change	95% Interval confidence	
							Lower	Higher
Body mass (kg)	69.2 ± 7.2	75.4 ± 7.1	−3.557	0.001	−0.86	−4.0	1.75	2.63
RPE	8.4 ± 1.7	9.2 ± 2.0	−1.707	0.092	5.54	113.5	−10.52	−8.81
Urine colorimetry	2.2 ± 1.4	2.5 ± 1.2	−0.808	0.422	1.39	91.2	−3.11	−1.51
IHS (N)	46.2 ± 6.5	50.5 ± 9.5	−1.794	0.080	0.22	3.1	−5.23	0.57
Temperature °C	36.6 ± 0.4	36.5 ± 0.5	0.632	0.529	−0.09	−0.1	−0.38	0.35
Horizontal jump length (cm)	125.7 ± 69.9	132.9 ± 73.8	−0.416	0.679	−0.53	−29.5	10.03	32.08
Systolic blood pressure (mmHg)	122.8 ± 13.2	129.0 ± 11.7	−2.053	0.044	−1.30	−14.0	11.97	21.9
Diastolic blood pressure (mmHg)	71.3 ± 9.3	74.2 ± 12.9	−1.097	0.276	−0.21	−2.7	−2.14	4.65
HR (bmp)	65.0 ± 11.1	67.2 ± 9.8	−0.854	0.396	2.10	36.0	−30.17	−21.87
BOS (%)	96.9 ± 1.2	96.6 ± 1.5	1.059	0.293	−0.27	−0.4	−0.13	1.16
FVC	2016.3 ± 2143.4	2428.9 ± 2576.7	−0.736	0.464	0.20	21.3	−233.79	266.32
FEV1	582.0 ± 71.8	589.7 ± 90.5	−0.321	0.750	−0.81	−87.7	−7.89	104.38

IHS, isometric hand strength; RPE, rating of perceived effort; HR, heart rate; BOS, blood oxygen saturation; FVC, forced vital capacity; Fev1, forced expiratory volume.

TABLE 2 | Differences between mountain ultra-endurance finishers and non-finishers in training and psychological parameters.

Variable	Finisher	Non-finisher	T	P	Effect size	95% Interval confidence	
						Lower	Higher
Training parameters							
Distance (km)	106.3 ± 4.8	106.4 ± 4.8	−0.106	0.916	0.02	−2.21	2.46
Positive change of altitude accumulated race (m)	6485.1 ± 1829.1	6438.5 ± 1828.8	0.106	0.916	−0.03	−920.49	827.38
Negative change of altitude accumulated race (m)	6485.1 ± 1829.1	6438.5 ± 1828.8	0.106	0.916	−0.03	−920.49	827.38
Years sport practice	24.0 ± 12.0	24.2 ± 12.7	−0.038	0.970	0.02	−6.25	6.50
Years of mountain race practice	6.3 ± 3.8	5.4 ± 3.7	−0.091	0.728	0.03	−1.86	2.05
Marathon best mark (min)	227.8 ± 67.2	230.4 ± 80.8	−0.128	0.898	0.04	−37.84	43.02
Half marathon time (min)	89.8 ± 8.2	101.0 ± 30.4	−2.171	0.034	1.37	0.877	21.52
Expected race position	67.8 ± 69.6	68.1 ± 72.4	−0.014	0.989	0.00	−40.85	41.43
Expected time (min)	1314.8 ± 229.6	1295.5 ± 273.0	0.314	0.754	−0.08	−142.43	103.67
Weeks injured	2.1 ± 3.4	3.1 ± 6.5	−0.872	0.386	0.29	−1.34	3.42
Training per week (h)	10.4 ± 5.0	11.2 ± 4.7	−0.707	0.482	0.16	−1.58	3.32
Training per session (min)	97.3 ± 35.6	99.0 ± 41.2	−0.181	0.857	0.05	−17.24	20.69
Training sessions per week	4.7 ± 1.1	5.1 ± 1.6	−1.203	0.233	0.36	−0.26	1.07
Medium speed training per week (min/km)	6.0 ± 1.8	5.5 ± 1.4	1.124	0.266	−0.28	−1.48	0.41
Positive change of altitude accumulated per week (m)	1792.1 ± 1083.8	1714.2 ± 1605.9	0.222	0.825	−0.07	−780.93	625.29
Change of altitude accumulated per week (m)	3700.0 ± 2066.2	3523.8 ± 3210.1	0.256	0.799	−0.09	−1552.25	1199.87
Resistance training (0 no. 1 yes)	0.5 ± 0.5	0.5 ± 0.5	−0.616	0.540	0.00	−0.17	0.33
% of load in resistance training (% of 1RM)	59.7 ± 21.8	44.2 ± 25.4	1.844	0.075	−0.71	−32.67	1.66
Stretch (0 no. 1 yes)	0.9 ± 0.1	1.0 ± 0.0	−0.775	0.441	1.00	−0.036	0.08
Stretching per week (min)	13.3 ± 5.7	12.2 ± 4.9	0.799	0.427	−0.19	−3.87	1.66
Stretching sessions per week	4.3 ± 1.4	4.2 ± 1.4	0.155	0.877	−0.07	−0.80	0.68
Physiological parameters							
Perceived stress (PPS)	28.4 ± 5.7	29.6 ± 4.3	−0.959	0.341	0.21	−1.35	3.86
General mental health (AAQII)	15.0 ± 6.6	14.1 ± 8.2	0.475	0.636	−0.14	−4.43	2.72

presenting finishers lower values. Non-finishers presented lower chronological age, lower fluid intake before competition day and lower grinding or clenching the teeth while performing usual tasks (**Table 3**).

During the post ultra-endurance race event, a significant increase was presented in the urine colorimetry, RPE and HR, while significant decreases were observed in the explosive strength of the lower limbs, systolic blood pressure and body weight (**Table 4**).

Finally, we found a negative significant correlation between systolic blood pressure (r: −0.237; p: 0.044), height (r: −0.262; p: 0.024), weight (r: −0.389; p: 0.001),

TABLE 3 | Differences between mountain ultra-endurance finishers and non-finishers in anthropometrical, nutritional and odontological parameters.

						95% Interval confidence	
Variable	**Finisher**	**Non-finisher**	***T***	***P***	**Effect size**	**Lower**	**Higher**
Anthropometrical parameters							
Age (years)	42.7 ± 7.8	40.8 ± 6.7	1.067	0.289	−0.24	−5.46	1.65
Body mass index (kg/m^2)	23.1 ± 1.5	24.1 ± 2.0	2.439	0.017	0.67	0.19	1.86
Height (cm)	173.2 ± 6.8	176.7 ± 5.7	−2.305	0.024	0.51	0.48	6.65
Nutritional parameters							
Carbohydrates meals the competition week (n°)	6.0 ± 2.7	6.0 ± 1.6	−0.128	0.899	0.00	−1.12	1.28
Fluid intake before competition day (l)	2.4 ± 1.0	3.3 ± 2.6	−2.105	0.039	0.90	0.05	1.87
Odontological parameters							
Grinding or clenching your teeth while performing your usual tasks (0 no. 1 yes)	0.1 ± 0.3	0.3 ± 0.4	−1.916	0.046	0.67	−0.01	0.40
Nibbles objects	0.2 ± 0.4	0.2 ± 0.4	0.145	0.885	0.00	−0.24	0.21
Bites his nails	0.3 ± 0.4	0.3 ± 0.4	−0.368	0.714	0.00	−0.20	0.30
He wakes up with fatigue muscle pain (0 no. 1 yes)	0.1 ± 0.3	0.0 ± 0.2	0.622	0.536	−0.14	−0.23	0.12
Vitamin C pills	0.0 ± 0.3	0.0 ± 0.2	0.721	0.474	−0.17	−0.19	0.09
Wet pillow upon awakening	0.1 ± 0.3	0.0 ± 0.2	0.978	0.332	−0.24	−0.23	0.08
Repeated burps	0.0 ± 0.2	0.0 ± 0.2	0.058	0.954	0.00	−0.11769	0.11104

TABLE 4 | Modification of study variables before and after the ultraendurance events.

Variables	**Pre**	**Post**	***T***	***P***	**Effect size**	**Higher**
Body mass (kg)	68.6 ± 7.0	66.5 ± 6.3	10.031	0.000	−0.31	2.63
RPE	8.2 ± 1.6	17.9 ± 1.7	−22.927	0.000	5.74	−8.81
Urine colorimetry	1.9 ± 1.1	4.2 ± 2.1	−5.893	0.000	1.95	−1.52
IHS (N)	45.4 ± 6.2	47.8 ± 7.7	−1.667	0.110	0.37	0.58
Horizontal jump length (cm)	112.1 ± 71.9	91.1 ± 59.5	3.890	0.000	−0.29	32.09
Systolic blood pressure (mmHg)	123.1 ± 12.9	106.1 ± 12.0	6.893	0.000	−1.31	21.93
Diastolic blood pressure (mmHg)	70.8 ± 8.8	69.5 ± 9.9	0.748	0.459	−0.14	4.66
Temperature (°C)	36.6 ± 0.4	36.6 ± 0.9	−0.058	0.954	0.02	0.36
Heart rate (bpm)	63.0 ± 10.5	89.0 ± 10.5	−12.697	0.000	2.47	−21.89
Blood oxygen saturation (%)	97.1 ± 1.1	96.6 ± 1.8	1.603	0.117	−0.44	1.16
FVC	2287.0 ± 2239.0	2270.7 ± 2199.1	0.132	0.896	−0.01	266.33
FEV1	572.0 ± 80.1	523.7 ± 85.8	1.799	0.088	−0.60	104.39

RPE, rating of perceived effort; IHS, isometric hand grip strength; HR, FVC, forced vital capacity; Fev1, forced expiratory volume.

half marathon time (*r*: −272; *p*: 0.034), fluid intake before competition day (*r*: −0.253; *p*: 0.039) and the finalization of the ultraendurance mountain probe.

DISCUSSION

The aims of the present research were (i) to analyze differences in selected psychophysiological parameters between finisher and non-finisher ultra-endurance mountain athletes, and (ii) to analyze modifications in psychophysiological parameters before and after an ultra-endurance mountain event. The data presented here showed that finishers and non-finishers showed differences in psychophysiological, training, anthropometrical, nutritional, and odontological variables. In addition, it was shown that finishing an ultramarathon mountain event produced dehydration, a significant increase in rating of perceived effort and heart rate, and a significant decrease in weight, horizontal jump length, and systolic blood pressure.

Regarding pre-race differences between finishers and non-finishers, half marathon time presented significant and large ES lower values in finisher than non-finishers, result consequent with other studies where lower marathon time was also correlated to greater performance in ultra-endurance race events above 100 km (Knechtle et al., 2010). This results emphasized the capacity to perform higher intensity as a parameter related with ultraendurance performance, high intensity allow ultraendurance athletes to improve their aerobic metabolic system in the same way or even higher than traditional low intensity and high volume training (Clemente-Suárez et al., 2014; Clemente-Suárez and Ramos-Campo, 2019). Furthermore, another performance predictor according to the literature is body composition, where lower BMI values have been linked with greater performance in long-distance ultra-endurance events (Knechtle, 2014), consequent with our data since finishers presented lower BMI values and weight and height presented a negative correlation with the finallization of the probe. In addition, traditionally, greater body height has been linked with greater performance in this type of events, especially in female ultra-endurance events (Whyte et al., 2000). However, considering body height as an isolated value may be inappropriate, since there are other anthropometric and biomechanical factors related to this parameter, such as the circumference of the calves or upper arm, that need to be taken into account (Knechtle et al., 2009a). This is in accordance with our data, since body height was greater in non-finishers.

Regarding the water intake the day before the race event, finishers presented a smaller consumption of liquid fluid compared with non-finishers. Interestingly, previous authors have highlighted the importance of appropriate fluid intake during the competition instead of greater fluid intake before the competition as it can lead to a deterioration of performance (Von Duvillard et al., 2004). Thus, incorrect hydration can lead to a hyper-hydration state that can conclude to hyponatremia as a consequence of electrolyte imbalance, producing alterations in the cardiovascular response and alterations in athlete performance, either to a dehydration process in where the health and performance of the athlete are also going to be compromised (Von Duvillard et al., 2004). In addition, previous authors have reported that experienced athletes have greater self-perception and self-knowledge according to their hydration needs; hence, they arrive at the race event with optimal hydration levels, avoiding dehydration or hyponatremia (Hoffman et al., 2019). This fact may partially explain hydration and dehydration results, since finishers presented greater experience in this type of race events compared to non-finishers, as finishers presented lower pre-race hydration levels, same colorimetry as non-finishers before competition, but significant lower colorimetry after the race event. Furthermore, previous authors have showed how values over 4 in the colorimetry chart, and acute weight loss over the 2% lead to not only a loss of performance, but to health-related risks (Tornero-Aguilera and Clemente-Suarez, 2019). Our data showed a weight loss of 3.2% in both groups, even though it seems inevitable to avoid dehydration in events as demanding as ultra-endurance mountain events, it can be established as a health and performance key factor.

Physiological values, such as systolic blood pressure, presented lower values in finishers compared to non-finishers. In this line, the correlational analysis showed how the systolic blood pressure presented a negative significant correlation with the finalization of the probe. Lower systolic blood pressure was previously reported as a physiological adaptation to aerobic training, highlighting these training adaptations due to endurance training in these extreme ultraendurance events (Portier et al., 2001). Yet, there was a significant decrease in the systolic blood pressure after the race event, as in previous researches concerning a 51.2 km ultra-sustainability race event (Belinchon-deMiguel and Clemente-Suárez, 2018). Regarding the cardiovascular response, it remained at the aerobic threshold level, with a mean HR increase of 41% from baseline values.

Another acute effect of this type of events is a decrease in muscle strength values, not generalized, since only the strength of the lower limbs was negatively affected, which is consequent with previous studies in similar ultra-endurance events (Belinchon-deMiguel et al., 2019), explained due to the higher implication of lower body muscles. However, significant increases were found in isometric hand grip strength, which leads us to think that the greater sympathetic activation which occurs in this type of events (Belinchon-deMiguel and Clemente-Suárez, 2018), can lead to increases in muscle strength, as it has been shown in other stressful and extreme conditions, such a military contexts (Tornero-Aguilera et al., 2017; Tornero-Aguilera and Clemente-Suarez, 2018). This tendency was not similar with an ultra-endurance Paralympic athlete, where hand strength values decreased after an ultra-endurance mountain event, probably due to the fact the upper body muscles were the principal implicated in this event (Belinchon-deMiguel et al., 2019).

The nutritional analysis did not present any differences according to the intake of carbohydrate meals during the race week between finishers and non-finishers; however, it is known that correct storage of energy is essential for adequate performance, since in ultra-endurance mountain events the energy balance is extremely negative (Clemente-Suarez, 2015). Nerveless, correct hydration (by urine colorimetry) showed a large ES between finisher and non-finisher, fact that reinforce previous author in the importance of hydration in ultraendurance events (Costa et al., 2014). Correct nutrition is a key factor in ultra-endurance events, but it should be analyzed in greater depth in order to determine its scope for the successful completion during mountain ultra-endurance events.

The psychological analysis revealed no differences between finisher and non-finisher athletes regarding perceived stress or mental health in general. One possible explanation is that participants in this ultraendurance events reported low levels of stress and good general mental health compared to the general population (Bond et al., 2011). In this line, the rated of perceived exertion increased significantly at the end of the ultra-endurance event, a fact that is in line with previous investigations that showed RPE values of 17.5 ± 2.1 with a distance greater than 90 km (Belinchón-Demiguel and Clemente-Suárez, 2019). Finally, in the odontological parameters analyzed we found no differences between finishers and non-finishers, result opposite to previous studies that found relationships between poor oral health and sport performance (Needleman et al., 2015). The participants of this study presented correct odontological health patterns, fact that would explain the lack of significant differences between the group studied. However, we must consider that the general odontological health presented by both athlete's groups were good, a fact that could explain the lack of differences between finishers and non-finishers.

Limitation of the Study

The principal limitations of the present study were the lack of biochemical control of muscle destruction (urea, ck), autonomic modulation, and stress hormones (cortisol, alpha amylase) for a better understanding of a multivariable phenomenon that is the ultra-endurance events. With a larger study sample, predictive models of performance in this type of extreme events could be designed.

CONCLUSION

An ultra-endurance mountain race produced dehydration, a decrease in systolic blood pressure, weight and leg strength muscle values, as well as an increase in heart rate and RPE values. Finishers presented lower systolic blood pressure, weight, body mass index, half marathon time and fluid intake before competition day compared to non-finishers. In addition, body mass index, pre-race hydration, and performance in lower distance races were predictors of performance in these ultra-endurance mountain races.

This information could help both, trainers and athletes, to improve training, nutritional and psychological interventions as well as, to make more safe the participation in this extreme events.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University Bioethics Committee (CIPI/002/17). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PB-D and VC-S collected the data. PB-D, JT-A, and VC-S analyzed the data. P-BD, JT-A, AD, PN, TR, BK, and VC-S wrote the manuscript.

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Do It, Don't Feel It, and Be Invincible: A Prolog of Exercise Addiction in Endurance Sports

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The social relevance of endurance sports has increased people's motivation to engage in these particular physical activities, associating their practice with a particular lifestyle (e.g., feeling victorious and a feeling of self-improvement). Therefore, the dark personality traits (not because they are negative but because they are more hidden), understood as a personal and adaptive response to the psychosocial relationships that athletes establish while practicing these sports. Following these arguments, Grit has been used to trace the response of athletes in their quest to improve performance and endurance in the face of common setbacks suffered as a result of long hours of training. Empirical studies should help to discover how these personality traits can pose real challenges to their adaptation, and what the impact of their psychological response may be in a functional or dysfunctional way [e.g., exercise addiction (EA)], in order to classify them as risk or protective factors. Through transversal design, the present study sought to explore the relationship between Grit and Dark Traits of Personality regarding the appearance of EA in a sample (N = 241) of amateur endurance sport athletes (M_{age} = 31.80; SD = 9.87). The results show that men not only score higher for addiction levels but also for narcissism (grandiosity feelings) and psychopathy (coldness) factors. If signs of narcissism and Machiavellianism increase, perseverance efforts grow too, and the likelihood of EA increases considerably. The conclusions drawn on the basis of the results allow us to place consistency of interest as a protective factor for the EA, whereas Dark Traits of personality – especially Machiavellianism – constitute a risk factor.

Keywords: narcissism, Machiavellianism, psychopathy, grit, exercise addiction

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INTRODUCTION

"The more the merrier" – it seems like a really common statement among amateur athletes, especially between those who practice endurance sports (e.g., 5 and 10-km runs, half-marathons, marathons, triathlons, ultra-endurance races, mountain trails, cycling, ironman races, etc.) and other recent sport modalities like CrossFit, which combines aerobic and anaerobic exercises with the ultimate goal of improving fitness and physical performance (Glassman, 2007; Belger, 2012; Lichtenstein and Jensen, 2016). The principal precursors for both modalities have been referenced by González-Hernández et al. (2019b), and are aligned with "trying to give the best of one-self combined with high intensity" (Simpson et al., 2017) and the achievement of new challenges in the search for unlimited improvement (Cruz, 2013).

In addition to these benefits, one of the greatest attractions of endurance sports is the speed with which these gains can be achieved (Lee et al., 2014) and the subjective perception of improvement that is entailed within. The practice of an endurance sport (e.g., running or cycling) implies a series of vigorous physical efforts, in which it is necessary to preserve resources and beliefs, maintained at high levels of energy and activation (Lukács et al., 2019). This is combined with the emergence of impulses and the consequent need to regulate them both, emotionally and behaviorally (González-Hernández et al., 2019a).

These sudden results ("*here and now*") are maybe one of the main reasons why these sports have received a boost in popularity during the last decade (Knechtle et al., 2014; Lara et al., 2014). We live in a system that hardly enables us enough time to meet our fitness goals, and we try to compensate by signing into shorter but more intense training programs with the rationale of achieving visible benefits in the short/mid-term. On this matter, endurance sports (especially running or CrossFit) fit perfectly within today's packed schedules because they provide high intensity training (Holt et al., 2014; Predel, 2014; Davies et al., 2016; Köteles et al., 2016; Lichtenstein and Jensen, 2016).

However, this can become a double-edged sword as the immediate benefits may lead toward creating unhealthy sports behaviors, such as "Exercise Addiction" (EA) (Nogueira et al., 2018). This concept is used to refer to any physical activity that is carried out excessively (an imbalance in the dose–response among exercise and health) without control and that has become the central axis in people's lives (Landolfi, 2013; Kovacsik et al., 2018). As with the rest of the addictions, EA can be identified by six components (or patterns): *salience*, *mood modification*, *tolerance*, *withdrawal symptoms*, *personal conflict*, and *relapse* – i.e., the tendency to return to excessive activity after periods of abstinence or control (Brown, 1993; Griffiths, 2005).

The prevalence values, according to previous research, can alter depending on the instrument or the sample used to register the data [e.g., Exercise Dependence Scale-Revised (EDS-R), Symons Downs et al., 2004; or Exercise Addiction Inventory (EAI), Terry et al., 2004; Exercise Addiction Inventory-Revised (EAI-R), Szabo et al., 2019]. For this reason, and considering the literature surrounding this topic, we decided to go by EAI; the most recent studies show how this instrument seems like a more appropriate tool to screen the risk for EA in specific populations of sportspeople due to its capacity to identify a higher proportion of people at risk of EA (Di Lodovico et al., 2019).

In the present study, based on the EAI cut-off score for individuals considered at risk of EA (Terry et al., 2004; Sicilia-Camacho et al., 2013), 9.5% of the amateur athletes were classified to be at risk of EA (total EAI score 24–30), while only 3.3% were considered asymptomatic (total EAI score 0–12). The major part of the participants of this study were considered as symptomatic (total EAI score 13–23), with a percentage of 87.2%.

Among all studies into EA, there is a line of research that is focused on the study of personality traits that increase the predisposition of addictive behaviors toward physical exercise linked with characteristics like big five general factors (Andreassen et al., 2013), perfectionism (Bircher et al., 2017), narcissism (Cook et al., 2018), or neuroticism (Lichtenstein et al., 2017). These studies confirmed the direct and combined role of the personality traits as predictive or mediator factors in the development of EA (Bruno et al., 2014). In this sense, high levels of narcissism, perfectionism, neuroticism, and low self-esteem are related to risk of EA (Lichtenstein et al., 2017). The correlations among neuroticism, extroversion and conscientiousness (positive), and agreeableness and openness to experience (negative), however, were identified as indicators of this type of dysfunctional behavior (Andreassen et al., 2013).

Grit (González-Hernández et al., 2019b) and Dark Triad of Personality (DTP; González et al., 2018) are two of the most recent personality traits that have been incorporated into the analysis of endurance training for these sport disciplines.

There are two concepts that create the basis for Grit: *Passion*, understood as the result of hours and hours of practice, and *Perseverance*, the ability to withstand and overcome a large number of obstacles (Mills, 2017; Dumas and Perry-Smith, 2018). These are the main factors that motivate individuals to achieve long-term goals beyond talent, which ultimately defines what makes great winners special (Duckworth, 2016, p. 8; Duckworth et al., 2007). Grit has been analyzed in detail in other areas such as educational contexts (Duckworth et al., 2011) and military contexts (USMA, West Point) (Duckworth et al., 2007; Maddi et al., 2012; Kelly et al., 2014) before even being studied in the domain of sports. In sports, the two factors presently under discussion – perseverance and passion – are usually the attributes required to obtain the best possible performance (Gilchrist et al., 2017).

The DTP (Paulhus and Williams, 2002) groups together *Narcissism* (defined by feelings of vanity, superiority, dominance, dependent needs, or prominence), *Machiavellianism* (defined by the use of charm, manipulation, strategy, or misrepresentation toward others), and *Psychopathy* (defined by impulsiveness, emotional coldness, aggressiveness, or empathic withdrawal). Initially described as process features with negative connotations, in the sporting context, these have been linked to the search for improvement, according to the kind of response (functionally–dysfunctionally), resulting from a competitive vision that the athlete puts into practice at any time and in any circumstance based on his sporting experiences (Luciano Soriano et al., 2002; Houston et al., 2015).

As Starcevic and Khazaal (2017) point out, everything related to behavioral addictions induces some controversy because this type of addiction falls somewhere that is halfway between impulse-control disorders and substance abuse disorders.

According to this, it is necessary to develop studies that provide new points of view about these addictions. Considering all of this, the present study seeks to understand in what way what it is that an initially desired activity (exercise) can become a risk factor (addiction) for those who practice it, and how the personality traits (Dark Traits and Grit) can modify and influence the athlete–sport relationship (particularly for CrossFit and endurance sports) to the point of functionally/dysfunctionally affecting the psychological response. An increase in the indicators of weekly training and high levels of Dark Personality traits are shown as risk factors, while high levels of consistency in interest are protective of EA.

METHODS

Procedure and Participants

Based on a cross-sectional, non-random, and descriptive design, it was requested through social networks that those who practice endurance sports (including recommending it to others) could respond to an *ad hoc* online survey through the website onlineencuestas.com. The structure of the questionnaires consists of two sections: the first section is used to collect socio-demographic information (e.g., gender, age, type of sport practiced, and amount of exercise per week), and the second section includes the three main scales of the study [the Short Grit Scale (Grit-S), the Short Dark Triad Scale (SD3), and the EAI] in their corresponding Spanish versions.

The study was conducted according to the ethical laws of the University of Granada and the World Medical Association and the Declaration of Helsinki (World Medical Association, 2013). Before the beginning of the participation process, people who agreed to take part in the research were informed of the confidentially and the anonymity of the process and the data collected (Lloret-Segura et al., 2014).

The final sample was composed of 241 endurance amateur athletes (38.60% women and 61.40% men), aged 17–61 (M = 31.80; SD = 9.87). Of these, 29.46% engaged in running and 70.54% engaged in other endurance modalities (e.g., BMX, triathlon, and CrossFit). Regardless of age, participants indicated that they spent 4.13 days per week on training (SD = 1.23), spending mainly 60–90 min per session. The participants claimed an experience in the range of 5–10 years in the practice of endurance sports (M = 4.86; SD = 7.23).

Measures

The Spanish version of the EAI was used (Terry et al., 2004; Sicilia-Camacho et al., 2013). This instrument was developed according to the "components" of the addiction model, creating one item (e.g., "*Exercise is the most important thing in my life*") for each one of them (*salience, mood modification, tolerance, withdrawal symptoms, personal conflict*, and *relapse*). The items use a Likert scale ranging from 1 (*Completely disagree*) to 5 (*Completely agree*), where the minimum score is 6 points (*no risk of EA*) and the maximum score is 30 points (*high risk of EA*). According to these scores, the scale allowed us to divide the sample in three categories: asymptomatic (i.e., scores between 0 and 12), symptomatic (i.e., scores between 13 and 23), and at risk of EA (i.e., scores of 24 or more). The internal reliability indicator showed an Alpha Cronbach of 0.90.

The Spanish version of Grit-S was also used (Duckworth and Quinn, 2009; Arco-Tirado et al., 2018). It is an instrument composed by eight items and two factors: Consistency of Interest (e.g., "*New ideas and projects sometimes distract me from previous ones*") and Perseverance in the Effort (e.g., "*Setbacks don't discourage me*"). Responses were collected on a 5-point Likert scale ranging from the defined values "*not like me at all*" (1) to "*very much like me*" (5). The final score was obtained by taking the average of the items, where higher scores corresponded with a higher level of grit. The Alpha Cronbach score showed a reliability of 0.84.

The Dark Triad personality traits were measured with the Spanish version of the SD3 (Jones and Paulhus, 2014), adapted for Pineda et al. (2018). This is an inventory composed of 27 items, divided into three first-order factors with the motivation of measuring individual levels of Narcissism (e.g., "*I know that I am special because everyone keeps telling me so*"), Machiavellianism (e.g., "*There are things you should hide from other people because they don't need to know*"), and Psychopathy (e.g., "*People who mess with me always regret it*"). Furthermore, the scale measure structure described a second-order factor (Dark Triad Personality). Responses were registered using a 5-point Likert scale from 1 (*Strongly disagree*) to 5 (*Strongly agree*). The internal reliability indicators showed an Alpha Cronbach of 0.87 for the second order factor and 0.76, 0.91, and 0.84 for the first order factors, respectively.

Data Analysis

The internal consistency of the instruments and sample normality and reliability tests were checked through use of the Cronbach alpha and Kolmogorov–Smirnov (K–S), respectively, assuming the suitability of the parametric tests. A descriptive analysis showed the frequencies and measures of central tendency (mean, standard deviation) of the sample distribution. Multivariant analyses (MANOVA over gender and addiction exercise levels) were used to create a differential analysis. A multiple linear and hierarchical regression analysis of EA (Vdependent) (controlled by gender) and a correlation analysis (Pearson) for establishing trends and the relationship between variables were carried out. The data analysis was conducted using the IBM SPSS statistical package version 23.0.

RESULTS

Table 1 shows the analysis of the variance with the objective of identifying the existence of statistically significant differences in Dark Personality Traits and Grit according to the addiction exercise levels of participants. The K–S test determined that variables were adjusted to the normality assumption. Significant differences were observed for the group of athletes with lower levels of EA (<0.05), specifically for those who showed lower scores with respect to the Grit variable.

Differences were also observed between men and women when addiction levels were low (<0.05) in both narcissism (in favor women) and psychopathy (in favor men). However, the comparison scores of the three groups of EA indicated significant differences in Machiavellianism, narcissism, and consistency of interest according to levels of addiction (in favor of the level of risk of addiction), while psychopathy and narcissism were shown to be significant according to gender (in favor of men). Furthermore, significant differences were found between the

TABLE 1 | Descriptive and differential scores, according gender, and addiction levels.

	K–S	Addiction levels								
		A (*n* = 40)		S (*n* = 162)		RA (*n* = 39)		Gender	Addiction level	Gender × addiction level
		Male (*n* = 22)	Female (*n* = 18)	Male (*n* = 121)	Female (*n* = 41)	Male (*n* = 22)	Female (*n* = 17)			
		M(SD)	*M(SD)*	*M(SD)*	*M(SD)*	*M(SD)*	*M(SD)*	*F(p)*	*F(p)*	*F(p)*
Perseverance in effort	0.22	3.13 (0.45)	3.04(0.50)	2.98(0.40)	2.93(0.40)	3.23(0.38)	3.25(0.39)	2.32	3.91	4.12*
Consistency in interest	0.23	2.91(0.48)	2.37(0.35)	2.84(0.64)	2.77(0.40)	3.41(0.36)	3.12(0.27)	3.72	4.01**	3.14
Narcissism	0.20	2.80(0.45)	3.22(0.95)	2.91(0.35)	2.93(0.38)	3.05(0.45)	2.87(0.35)	3.05*	3.48*	4.03**
Machiavellianism	0.20	2.95(0.75)	2.78(1.22)	2.97(0.52)	2.81(0.57)	3.26(0.72)	3.47(0.68)	2.07	2.46*	2.64
Psychopathy	0.18	2.55(0.79)	1.85(0.19)	2.72(0.42)	2.37(0.41)	2.63(0.68)	2.55(0.42)	3.04*	2.06	3.12*

**p* < 0.05. ***p* < 0.01. *A: asymptomatic; S: symptomatic; RA: risk addiction.*

levels of gender addiction interaction for perseverance in effort (<0.05), narcissism (<0.01), and psychopathy (<0.05).

Addiction levels ($F = 19.16$; $p < 0.01$, $\eta^2 = 0.03$) showed significance in the same way as Gender ($F = 23.04$; $p < 0.02$, $\eta^2 = 0.06$). In detail, the M of Box test was not significant ($F_{(235,5)} = 4.03$; $p > 0.24$). There was no multivariate heteroscedasticity, nor univariate, according to the Levene test [Grit: $F_{(235,5)} = 1.98$; $p > 0.27$; DTP: $F_{(235,5)} = 1.38$; $p > 0.63$; Narcissism: $F_{(235,5)} = 2.58$; $p > 0.35$; Machiavellianism: $F_{(235,5)} = 1.16$, $p > 0.72$; and Psychopathy: $F_{(235,5)} = 2.53$; $p > 0.35$], and this thus assumed compliance with the normal distribution for this type of analysis.

The correlation analyses (**Table 2**) showed, with low and moderate significance values, that, as age increased, perseverance in effort also increased, and consistency in interest, narcissism, and Machiavellianism in endurance athletes decreased. Perseverance in effort showed a significant inverse relationship to psychopathy, and a positive relationship with consistency in interest and EA. Both Machiavellianism and narcissism showed a direct, moderate, and significant relationship with respect to EA. The number of weekly training sessions showed significant and moderate correlations, both with Dark Features and with the dimensions of Grit and EA (**Figure 1**).

The results of the regression analysis procedure (successive steps forward and weighted by gender) (**Table 3**) indicated a Model 1 in which athletes showed higher levels of addiction as their weekly training time increased (explaining 33% of the total variance), a Model 2 that added greater indicators of Machiavellianism, thus explaining 28% of the total variance, and a Model 3 that also included an increase of Perseverance in effort scores (explaining 24% of variance).

DISCUSSION

Exercise addiction is one of the most representative and negative behavioral patterns that athletes of endurance sports are currently facing, with the highest prevalence rates of EA risk being 14.2% (Di Lodovico et al., 2019). Along with the scientific evidence, different research proposals have been contemplated in order to discover how they function and how EA might be described.

The increase in amateur athletes has, in turn, led to an increase in the likelihood of the appearance of cases of sportsmen and women under risk of EA. With the premise that sports practice is primarily oriented toward competition (including amateur sports), we can consider that a constant demand to improve performance can have an impact on the type of behavior patterns that could favor or protect the manifestation of this type of addictive behavior.

Thus, and through an approach based on the study of uncommon personality traits associated with these behaviors (Dark Traits), we have proposed the analysis of the relationship between Grit (perseverance and passion) and DTP (narcissism, Machiavellianism, and psychopathy) and these excessive behavior patterns in the context of sports (endurance sports) with an aim to explore new ways to explain the appearance and regulation of addiction behaviors by athletes.

TABLE 2 | Correlational analysis (Pearson) between variables.

	M (*SD*)	Range	1	2	3	4	5	6	7	8
Age	31.80 (9.8)	(17–65)	–	−0.04	0.20**	−0.31**	−0.29**	−0.27**	−0.12	−0.08
Training week (days)	4.13 (1.23)	(1–7)		–	0.51*	0.49**	0.46**	0.40*	0.47**	0.56**
Perseverance in effort	2.93 (0.43)	(1–5)			–	0.63**	0.56	0.32	−0.43**	0.38*
Consistency in interest	2.74 (0.36)	(1–5)				–	−0.45**	−0.34**	−0.55**	−0.47**
Narcissism	2.98 (0.38)	(1–5)					–	0.70**	0.84**	0.54**
Machiavellianism	3.17 (0.52)	(1–5)						–	0.70**	0.45*
Psychopathy	2.36 (0.45)	(1–5)							–	0.04
Exercise addiction	18.48 (3.56)	(8–30)								–

$^*p < 0.05$. $^{**}p < 0.01$.

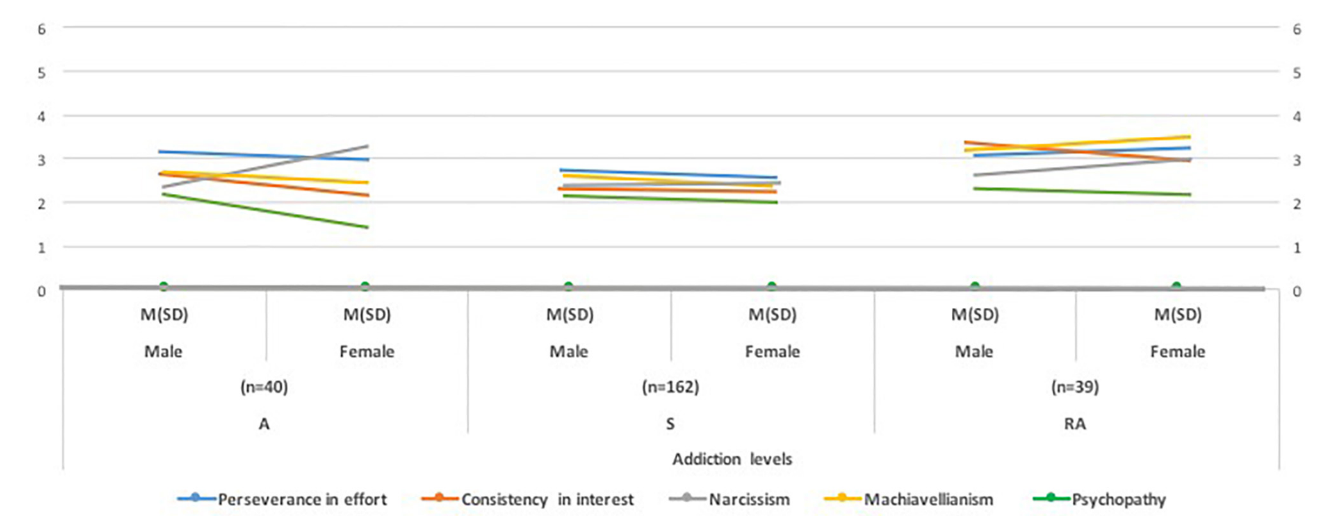

FIGURE 1 | Profiles according gender and addiction levels in endurance sports.

TABLE 3 | Regression analysis (stepwise) over addiction exercise.

Dependent variable: addiction exercise	**Step**	**Independent**	***B***	***t***	***p***
Model 1. $R = 0.61$; $R^2 = 0.33$; $F_{5,236} = 23.59$; $p < 0.00$	1	Training week	0.49	2.67	0.02*
		Constant		20.64	
Model 2. $R = 0.59$; $R^2 = 0.28$; $F_{5,236} = 26.79$; $p < 0.00$	2	Training week	0.29	2.67	0.02*
		Machiavellianism	0.31	3.46	0.00**
		Constant		18.74	
Model 3. $R = 0.49$; $R^2 = 0.24$; $F_{5,236} = 33.62$; $p < 0.00$	3	Training week	0.29	2.67	0.02*
		Machiavellianism	0.37	3.46	0.00**
		Narcissism	0.34	3.78	0.01*
		Perseverance in effort	0.31	3.06	0.03*
		Constant		26.37	

$^*p < 0.05$. $^{**}p < 0.01$. Independent variables Model 1 (first step): age; training week. Independent variables Model 2 (second step): age; training week, narcissism; Machiavellianism; psychopathy. Independent variables Model 3 (third step): age; training week, narcissism; Machiavellianism; psychopathy, perseverance in effort, consistency in interest. Weighted least squares regression: weighted by gender.

This evidence has shown how there exists a moderate risk of EA, and this does not differ much when compared with the most current results found by Szabo et al. (2019), whose study showed that 11.5% of the participants were classified to be at risk of EA based on the EAI-R – a similar percentage (9.0%) to when they use the EDS-R (Lindwall and Palmeira, 2011; Costa et al., 2012, 2013). Based on the results of our research, it appears that the prevalence of being at risk of addiction is ranged between 3 and 5% (Sussman et al., 2011; Berczik et al., 2012; Mónok et al., 2012; Szabo et al., 2013a; Griffiths et al., 2015; Grima et al., 2018; Lukács et al., 2019).

According scientific literature, in the addiction process there seems to be three socio-demographic variables that play an important role in defining the profile of the addicted athlete. These are the athlete's age, gender, and the number of hours spent training (Lichtenstein et al., 2017).

Regarding gender, the most common results have suggested that men show a higher risk of becoming addicted to exercise (Guszkowska and Rudnicki, 2012; Cook et al., 2013; Szabo et al., 2013b; Cunningham et al., 2016; González-Hernández et al., 2019b), similarly to what happened with the data of the present study. The vast majority of the research related this data to the changing trend in male body care. When this search for the "perfect physical condition," understood as a physical and mental self-perception (McNamara and McCabe, 2012), is taken to the extreme, exercise (specially in endurance sports) begins to favor the flourishing of addictive behaviors to fulfill the narcissistic desires of the sportsmen (mainly in males) (González et al., 2018). In the present study, men not only scored higher for addiction levels but also for narcissism (grandiosity feelings) and psychopathy (coldness) factors, as some of the studies carried out with high competition athletes have also shown (Ueno et al., 2017). Despite this, studies have recently been conducted on the structure of Dark Traits in athletes, where literature does not provide concrete evidence of invariability between men and women (Vaughan et al., 2019).

For the age variable, our results presented an inverse relationship to levels of addiction, as cited in previous studies (Bruno et al., 2014; Lichtenstein et al., 2014; Grima et al., 2018). At the same time, an inverse relationship between age and Grit and DTP scores (especially narcissism and Machiavellianism) was shown in endurance athletes, which could be explained through the nature of the maturation process of human beings. Over the years, sport and competitive learning experiences have offered athletes a greater ability to regulate their self-knowledge, to cope better with experiences under pressure with less of a need for notoriety or impulsivity, and a greater understanding of situations (Bruno et al., 2014), which helps reduce their compulsive nature and increases the way they control their psychological responses (González-Hernández et al., 2019b).

As with the last of the three indicators for EA – the number of hours spent training – the literature indicated that the athletes who trained more had higher EAI scores (Sicilia and González-Cutre, 2011; Szabo et al., 2013b; Latorre et al., 2016; Lukács et al., 2019; González-Hernández et al., 2019b). Besides this, if signs of narcissism and Machiavellianism increase, perseverance efforts grow too, and the likelihood of EA increases considerably, as similar studies have pointed out in the past (Spano, 2001; Lichtenstein et al., 2014; Miller and Mesagno, 2014; Bircher et al., 2017; Cook et al., 2018). Because of this, a narcissistic personality is often described as a pattern of characteristics present in neurotic and obsessive behavior according to the need to improve and excel when evaluated by others (Wallace and Baumeister, 2002) in the search for achieving any objective and performance. For this reason, in the study presented here, they appear together with narcissistic and Machiavellian features (for example, development of cynical or manipulative attitudes to achieve success or improvement, without valuing personal or social harm) (Miller and Mesagno, 2014).

Despite the few studies that have taken these personality concepts into account to understand the process of EA, González-Hernández et al. (2019b) found similar results on Grit (consistency in interest only) and its condition as a control mechanism. Meanwhile DTP, especially Machiavellianism and narcissism, seems to act as a risk factor. Studied in other contexts (Siah et al., 2010; Maddi et al., 2012; Borzikowsky and Bernhardt, 2018), Grit (general factor) has been shown to be a protection factor against addictive behaviors, such as internet and online game addiction, or in substance use disorders. Meanwhile, DTP studies (González et al., 2018) have linked narcissism indicators with EA (Basson and Myers, 2001; Bruno et al., 2014; Lichtenstein et al., 2014). Nevertheless, Machiavellianism has been associated with athletes with greater abilities of persuasion, both toward other people (including manipulation) and toward themselves (Deak et al., 2017; Tomankova, 2017).

LIMITATIONS

It is important to recognize the limitations of this research and to consider future research directions. First, in spite of the number of participants being acceptable, we acknowledge that we could have found stronger results with a larger number of athletes. In line with this limitation, the sample distribution regarding the addiction levels was not balanced, although the tendency shown in our data is very similar to other studies conducted on EA; we think it would be of significant interest to try to achieve a similar number of cases for each level. Secondly, since this study only had one sport that was analyzed, it would be interesting to examine if EA symptoms differ by sport modality. And thirdly, even with attention to detail in the data collection procedure, a possible bias regarding the desirability of pleasing responses associated with DTP could result in a limitation in the interpretation of the data. Although the scale offered statistics for this and for most of the studies in which it had been used, for this particular case we only checked the relationship between EA and Grit. It could be interesting to include other explanatory variables or personality traits such as perfectionism or impulsivity.

CONCLUSION

This research aimed to analyze and identify the role of two concepts related to personality – the Dark Triad (narcissism, Machiavellianism, and psychopathy) and Grit (perseverance and passion) – and their relationship with EA in endurance sports. These sport modalities demand not only a great physical dedication (hours of training) but also significant psychological efforts. It is important to know about the beliefs and personality traits of these sportsmen and women and know if they can act as a protector or facilitator of exercise addictive behaviors.

We can effectively see what seems to be a degree of accordance in regards to the way personality plays an important role in the manifestation of addictive exercise behaviors due to the significant differences that were found in Dark Personality Traits and Grit according to the levels of EA in participants. In this sense, higher levels of Grit could be associated with lower levels of addiction. Meanwhile, the opposite relationship occurs when the likelihood to suffer a "risk of addiction" increases with the presence of the Dark Triad, especially with the manifestation of the Machiavellianism trait.

Considering the role of the age, it seems that as runners get older they have higher levels of grit, although the manifestation of Dark Traits and EA is reduced. That fact confirms that when an athlete can manage the direction of their thoughts and guides them toward a conscious practice according to their reality. Grit could act as a factor of balance in self-regulation.

The significant differences found among both sexes, showed higher addiction levels in favor of sportsmen and higher indicators of grit, narcissism, and psychopathy. This proves that sportsmen were more impulsive and thrill-seeking at the same time they display lower levels empathy. Besides this, they showed a more competitive behavior and further dominance and superiority when they practice sports.

Finally, the predictive models confirmed the importance of the time spent training (number of training sessions per week) and the Machiavellianism, regarding the modulation of the manifestation of EA. As we have already indicated, the cognitions and their manipulative character play an important role in the relationship with the levels of EA, up to the point that the athletes feel the imperative need to train more (compulsion) to reduce their anxiety, which, at the same time, acts as a control mechanism (obsession).

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the University of Granada. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

AN: planning, development, data collection, and document writing. JG-H: planning, development, data collection, statistical analysis, and document writing. MT-G: final writing review and conclusions and theoretical frame review.

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Effects of Different Training Intensity Distribution in Recreational Runners

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Purpose: To compare the impact of two different training intensity distributions in terms of conditional and performance parameters and spent time to training in recreational athletes.

Methods: Two different training intensity distribution model were performed for 8 weeks by 38 recreational runners. Runners recruited were randomly assigned to 2 different training models based on HR intensity detected with maximal test. The percentage distribution splitted in zone 1, 2, and 3 were by 77/3/20 and 40/50/10 in polarized endurance training group (PET) and focused endurance training (FOC) group, respectively. Programs were balanced for total training impulse (TRIMP). To evaluate effects of training, before and after treatment were performed a maximal exercise test to determine Maximal Oxygen Uptake ($V'O_{2max}$), Ventilatory Threshold (VT), respiratory-compensation point (RCT) Running Economy (RE), and 2 Km performance. To investigate the effects of training on muscular performance were performed one repetition maximum (1 RM), squat jump (SJ), and counter movement jump (CMJ).

Results: Both groups significantly improved their velocity at $V'O_{2max}$ (3.2 and 4.0%), at VT (4.0 and 3.2%), RCT (5.7 and 3.4%), the average velocity in 2 Km performance (3.5 and 3.0%) and RE (−5.3 and −8.7%) for PET and FOC, respectively for each variable. No differences were found between the groups on any parameter investigated except about the total training time (PET = 29.9 ± 3.1 h and FOC = 24.8 ± 2.0 h).

Conclusion: Focused Endurance Training obtains similar improvements than Polarized Endurance Training saving 17% of training time in recreational runners.

Keywords: intensity distribution, focused training, polarized training, running economy, recreational runners

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INTRODUCTION

To maximize endurance performance, coaches, and scientists can manipulate the characteristics of training: intensity, duration, and frequency of training session during the entire training process (Seiler, 2010). There is general agreement on the physiological factors limiting performance (di Prampero, 2003; Coyle, 2007), however there is still no agreement on how the daily training process must be organize to improve physiological factors and performance.

In recent years many studies have suggested that training intensity distribution plays a key role on endurance training adaptation not only in elite (Seiler and Kjerland, 2006; Seiler et al., 2007; Laursen, 2010; Seiler, 2010; Ingham et al., 2012), but also in well-trained recreational athlete (Esteve-Lanao et al., 2005, 2007; Neal et al., 2013; Muñoz et al., 2014; Stöggl and Sperlich, 2014).

Training intensity distribution (TID) in endurance training programs is determined from the percentage of time spent exercising at low (zone 1, typically identified below the lactate threshold (LT), or ventilatory threshold (VT); moderate (zone 2, typically located between LT and maximal lactate steady state (MLSS) or respiratory-compensation threshold (RCT); and high (zone 3, typically above MLSS or RCT) intensities (Seiler and Kjerland, 2006; Faude et al., 2009). Although the topic is widely debated, just few studies at the moment are referred to running, while the reference studies for TID refer to other endurance sports such as cross country ski and cycling. Scientific literature has identified two well-differenced training models based on intensity distribution (Esteve-Lanao et al., 2007; Neal et al., 2013). First, a polarized training model (PET) that consist of a high percentage of exercise time at low exercise intensity (75–80%) and the remainder spent at high intensity (20–25%). In contrast, the second model is a traditional threshold training distribution (THR), in which the time distribution is: 45% at low, 35% moderate, and 20% high intensity, respectively. Several studies have observed the TID of well-trained and highly trained endurance athlete in different disciplines (Seiler and Kjerland, 2006; Esteve-Lanao et al., 2007; Plews and Laursen, 2017; Kenneally et al., 2018) and there are substantial evidences that PET may optimize adaptation to exercise while providing an acceptable level of training stress. Different studies have investigated the relation between adaptations and intensity of training and they affirm that LT is positive affected when a high proportion of training is conducted at low intensity (Esteve-Lanao et al., 2005, 2007; Ingham et al., 2008), they are suggesting that the proportion of time in zone 1 is a key aspect that drives endurance adaptations and performance outcomes. However, several other studies have observed improvements on 40 km time trial when high intensity training (zone 3) is added into the schedule of well-trained cyclist (Lindsay et al., 1996; Westgarth-Taylor et al., 1997; Weston et al., 1997). As Seiler states for highly trained athletes training 10–25 h/week, polarized intensity distribution may allow maximal adaptive signaling while minimizing autonomic and hormonal stress responses and reducing the risk of overtraining (Foster, 1998; Esteve-Lanao et al., 2007).

For recreational athletes is still unknown what intensity distribution is optimal or if the intensity distribution is or is not critical. In the study of Muñoz et al. (2014), polarized training model shown a better impact on 10 km performance in recreational runners compared with the threshold training model after 10 weeks of practice (−3.5% for THR and −5% for PET), but they conclude that there is not enough evidence in the overall findings to support one approach over the other.

To try to bring evidence in favor of the correct approach, the goal of the present study was to compare the conditional and performance effects of PET training model with a focused (FOC) training model on changes in limiting factors.

MATERIALS AND METHODS

Experimental Approach to the Problem

A two groups pretest-posttest design was used. The effects of different training were verified on the performance in 2 km and through the analysis of changing in the value of limiting factors measured during the test in laboratory pre and after intervention. The main difference between training models is the time spent in zone 2. One group of athletes performed a relatively higher percentage of their total training volume in zone 1, below their VT. The second group trained 50% of total training volume in zone 2, between VT and RCT, while training less in zone 1 and zone 3. To compare training the total training load (intensity × volume) was balanced using a modified version of the training-impulse approach (TRIMP) (Foster et al., 2001).

Subjects

Forty-three recreational runners were recruited to participate in this study. All subjects had been training consistently for >4 years (average experience 6.4 ± 1.6 years) and mean training volume in terms of duration before the study was 3.2 ± 0.5 h per week. Furthermore, they raced a half marathon a week before the beginning of the study. The University Ethical Committee approved the protocol (Prot. N. 165038, 28/06/2016) and the participants gave their written consent before taking part.

Runners recruited and randomly assigned to 2 different training groups (each $n = 19$), see **Table 1**, for an 8-week period. Dropout rate for the FOC group was 21% (two subjects was excluded from the analysis due to training program adherence <96%; two abandoned the experiment for personal reasons). Dropout rate for the PET group was 5% (one subject abandoned the study personal reason). Groups' characteristics are displayed in **Table 1**. Groups were similar regarding age, body mass, height, and $V'O_{2max}$ (see **Table 1**).

Training Plan and Prescription

The training plans were designed to reach a similar score for both total TRIMP accumulated over 8 weeks (2,492 ± 72 TRIMPs) and mean TRIMP accumulated each week (311 ± 9) (**Table 2**). We prescribed the training in terms of time goal rather than distance to track the relative time in each zone for each athlete and to control training load. The polarized endurance training (PET) was designed to achieve a total percentage distribution in zone 1, 2, and 3 corresponding to 77/3/20 based on HR at RCP. The second plan, focused endurance training (FOC), has a percentage distribution of 40/50/10 in zone 1, 2, and 3, respectively (**Figure 1**).

The program was divided into 2 weeks of introductory period same for all and two 3 weeks microcycles following a 2:1

TABLE 1 | Physical characteristics of runners included in the analysis.

Variables	Polarized endurance training (PET)	Focused endurance training (FOC)
N. (m / f)	15/4	16/3
Age (yr)	43.2 ± 8.4	39.4 ± 8.5
Weight (kg)	72.0 ± 7.7	70.9 ± 10.1
Height (cm)	175.2 ± 5.9	172.5 ± 4.3
$V'O_{2max}$ (ml min^{-1} kg^{-1})	52.9 ± 8.1	53.4 ± 8.3

load structure. The relative intensity distribution of groups was maintained both in loading and unloading weeks.

The weekly schedule for PET group included four sessions, two of which hard with interval or repetition workout at high intensities, one at moderate average intensity and one easy run. For FOC group the training session was three and all the session have medium and long repetition at moderate intensity.

Moderate and high intensity is essential in a program since involve large muscle mass and could lead at a better resistance at fatigue during running performance (Boccia et al., 2017).

No strength training sessions were performed during the training period.

Laboratory Testing

Laboratory, field running test and muscle function tests were performed during week 0 and week 9. The tests were separated by a 24-h resting period. All the tests were performed at the same time of the day ± 2 h in a climate-controlled laboratory (20–22°C, 55% humidity). The participants did not perform any physical activity in the 24-h resting periods and were requested to refrain from using caffeine containing food or beverages. All the subjects performed familiarization trials. The entire tests were randomized; however, the same order was respected in the pretest and posttest for everyone.

TABLE 2 | Results of training load over the 8 week total training time (TTT).

	Group	
	PET	FOC
	(*n* = 19)	(*n* = 19)
Total running time	29.9 ± 3.1	24.8 ± 2.0
TTT in zone 1 (h)	23.3 ± 2.7	9.6 ± 1.2
TTT in zone 2 (h)	0.9 ± 0.4	12.1 ± 2.1
TTT in zone 3 (h)	5.7 ± 1.4	3.1 ± 1.4
TTT % in zone 1 (%)	78 ± 9.2	38.7 ± 9.6
TTT % in zone 2 (%)	3.1 ± 1.3	48.8 ± 12.8
TTT % in zone 3 (%)	18.9 ± 4.6	12.5 ± 5.7
Mean RPE session	60.9 ± 15.5	65.4 ± 14.6
Total TRIMPs (au)	2464.0 ± 124.0	2558.2 ± 10.9
Mean TRIMPs/wk (au)	308.0 ± 47.46	319.8 ± 28.1

Incremental Test to Exhaustion

The three intensity zones were establish based on the results of treadmill testing performed in laboratory at week 0. Maximal oxygen uptake ($V'O_{2max}$) and heart rate (HR) was measured and recorded during a treadmill incremental maximal running test by breath by breath analysis of oxygen consumption and carbon dioxide production (Quark PFT; Cosmed, Rome, Italy). Before each test, flow meter was calibrated with a 3-L syringe, and the analyser was calibrated with known gas mixtures (16% O_2 and 5% CO_2) and environmental air (20.9% O_2 and 0.03% CO_2).

The protocol test was individualized for each subject to control the duration of each test. Therefore, the initial speed was determined by the subject capacity, and it was increased by 0.5 km h^{-1} every minute until exhaustion. The duration of the test was expected to be between 10 and 15 min. The treadmill (Run Race 800; Technogym, Gambettola, Italy) was maintained at 1% grade throughout the test, a standard method to simulate level running on treadmill. All subjects were familiarized to run on treadmill (Galbraith et al., 2014).

$V'O_{2max}$ was defined as the highest 30 s average achieved during the test. The first ventilatory threshold (VT) was defined as an increase in $V_E \cdot V'O_2^{-1}$ corresponding with a break in linearity in VE, but without increase in $V_E \cdot V'CO_2^{-1}$. The respiratory-compensation threshold (RCT) was defined as the intensity where $V_E \cdot V'CO_2^{-1}$ also began to rise. Two independent evaluators made the threshold determination. If the difference in VO_2 values at VT_1 and VT_2 was higher than 200 ml min^{-1}

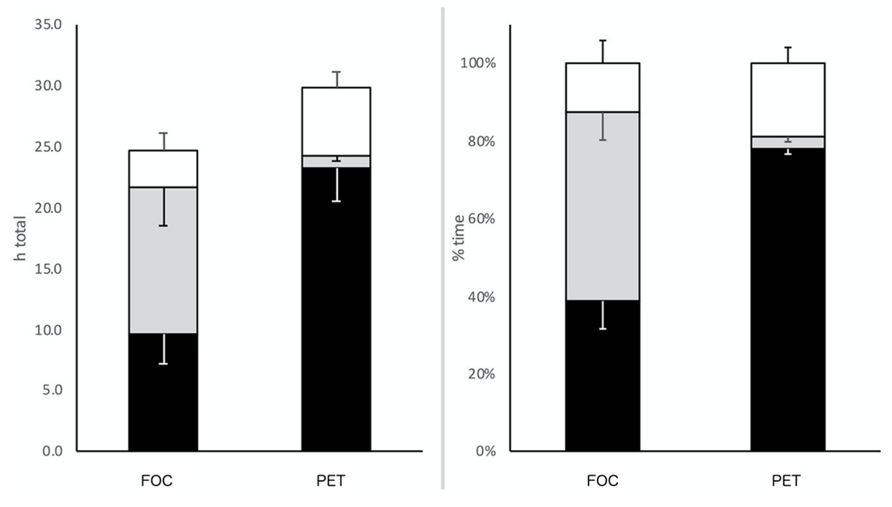

FIGURE 1 | Total running time (h) on the left and percentage of TTT in each zone (%) on the right of different training groups.

between the 2 observers (% of agreement = 88%), a third was brought in Beaver et al. (1986).

Running Economy

Running Economy (RE) was determined by measuring submaximal $V'O_2$ during running on treadmill (Barnes and Kilding, 2015): 4 min at 1 km h^{-1} slower than the last individual marathon pace (8.9 ± 0.2 km h^{-1}) after a standardized warm up (4′ at 90% of marathon pace). Before each test, flow meter was calibrated with a 3-L syringe, and the analyser was calibrated with known gas mixtures (16% O_2 and 5% CO_2) and environmental air (20.9% O_2 and 0.03% CO_2). During each test heart rate was monitored and recorded with Cosmed flow meter (Quark PFT, Cosmed, Rome, Italy). The RE was defined as the mean $V'O_2$ collected at last 1 min of each running speed. The RE was measured at week 0 and after completing the training program at week 9. All tests were performed at the same time of the day for everyone.

2 km Performance

Before and after training after a standardized warm-up session the subjects participated in a 2 Km simulated race on 400 m running track. Performance time was the mean value between the time recorded by two people manually. The average difference time between the two evaluators was <0.3± 0.14 s. The race-test was conducted at the same day and hour of week.

Estimation of One-Repetition Maximum

Maximal strength was estimated with a 6RM test on leg press machine. All subjects were positioned on a horizontal leg press (Technogym, Gambettola, Italy) and the knee angle (90°) was fixed to maintain the same position in all test occasions. After a 5-min warm-up (4 min moderate cycling + 1 min of free weight exercise) with and a correct rest period, the subject performed the first session with a preliminary load of 15 repetitions. Thereafter, the load was increased every step by 30% until the athlete could not successively complete a 6 RM repetition (American College of Sports Medicine, 2018). The 1 RM was estimated through a conversion table.

Jumping Performance

All subjects performed a squat jump (SJ) and counter movement jump (CMJ) test. Vertical jump performance was assessed using the SJ and the CMJ test according to the procedures suggested by Bosco et al. (1983). Jumping height was calculated from flight time using kinematics equation (Lehance et al., 2005). Flight time was recorded using an infrared photocell connected to a digital computer (Optojump System, Microgate SARL, Bolzano, Italy). All tests were performed in a randomized order; however, the same order was respected during test after training period.

Exercise Training Load

All subject recorded HR continuously during each training session over the training period. To assess the training load (intensity × training duration) for both, PET and FOC groups the TRIMP proposed by Foster et al. (2001) was used. This method was used by Muñoz et al. (2014) to estimate exercise load of 10 weeks of training in recreational runners (Muñoz et al., 2014) and also to monitor the exercise load of 3 weeks professional cycling race (Santalla et al., 2012). This method integrates heart rate data with volume and relative intensity to the three zones detected by the heart rate at VT and RCT. From the incremental test results, heart rate values for VT and RCT are determined and then quantified the time spent in each intensity zone: zone 1, HR below the VT; zone 2, HR between VT and RCT and zone 3, HR above RCT. TRIMP is computed by multiplying the accumulated time in each zone by an intensity weighted coefficient (1 for zone 1, 2 for zone 2 and 3 for zone 3) to obtain a score. Total TRIMP load is then obtained by summing the 3 zone scores.

Internal Training Load Monitoring

During the training period, each session was recorded and uploaded on a network platform that allowed the recording of the time spent in each intensity zone during each session. A 100 point rating perceived exertion (RPE) (Borg and Kaijser, 2006) was obtained at the end of each session.

Statistical Analyses

Data was presented as M ± SD. Assumptions verification were performed before each test. Normality distribution for each dependent variable were checked with Shapiro–Wilks tests. In the case of any normality violation, the non-parametric test version was applied. Independent samples *t*-tests were used to determine the significance of differences in the measured variables indicative of anthropometric and fitness levels before training between independent groups. To ensure that total training load and distribution in intensity zones were different were also compared total TRIMP and total time spent in zone 1, 2, and 3. A 2 × 2 mixed measure ANOVA was performed after training for all variable using Bonferroni's correction method. Differences between PRE vs. POST were reported in absolute values, the precision of estimates for absolute values was indicated with 90% confidence limits (CL), effect size (d), and benchmark for significance was set at $p \leq 0.05$.

RESULTS

Normality was respected for each dependent variable (all $p > 0.05$).

Total training time over 8-weeks was significantly different and was 29.9 ± 3.1 h and 24.8 ± 2.00 for PET and FOC group, respectively. Weekly 308.0 ± 47.5 and 319.8 ± 28.1 and total 2464 ± 124.0 and 2558.2 ± 10.9 TRIMP scores were not different between the two groups (Effect size −0.65 $P > 0.05$). Total time spent in training zone 1 (PET = 23.3 ± 2.7 h vs. FOC = 9.1 ± 2.4 h, $P < 0.0001$), zone 2 (PET = 0.9 ± 0.4 h vs. FOC = 11.5 ± 3.2 h, $P < 0.0001$), and zone 3 (PET = 5.7 ± 1.4 h vs. FOC = 3.1 ± 1.4 h, $P = 0.0001$).

No significant difference was found in the comparison between the groups in any investigated variable before and after training. However, significant improvements from the pre-training to the post-training were observed in both PET and FOC in physiological parameters. For PET, there are significant improvements in speed at $V'O_{2max}$ ($vV'O_{2max}$) of 3.2% (12.9 ± 1.7 km h^{-1} vs. 14.3 ± 1.5 km h^{-1}, $P < 0.01$), speed at VT of 4.0% (10.5 ± 1.2 km h^{-1} vs. 10.9 ± 1.2 km h^{-1}, $P < 0.001$), speed at RCT of 5.7% (12.1 ± 1.5 km h^{-1} vs. 12.8 ± 1.4 km h^{-1},

$P < 0.01$) RE of 5.3% (226.3 ± 35.2 vs. 214.3 ± 33.0 ml min^{-1} km^{-1}, $P = 0.04$) and average velocity on 2 km performance 3.5% (13.8 ± 2.0 vs. 14.3 ± 1.7 km h^{-1}). Also for FOC group were recorded significant improvements in the same variable at speed at vV'O_{2max} of 4.0% (13.8 ± 1.9 km h^{-1} vs. 14.3 ± 1.8 km h^{-1}, $P = 0.03$), speed at VT_1 of 3.2% (10.8 ± 1.4 km h^{-1} vs. 11.1 ± 1.5 km h^{-1}, $P = 0.04$), speed at RCT of 3.4% (12.4 ± 1.7 km h^{-1} vs. 12.8 ± 1.7 km h^{-1}) average velocity on 2 km performance 3.0% (13.9 ± 1.9 km h^{-1} vs. 14.3 ± 1.9 km h^{-1}) (**Tables 3**, **4**).

DISCUSSION

The first purpose of this study was to evaluate the effects of a different intensity distribution on laboratory tests and performance. Both groups, polarized and focused (intensity distribution 77/3/20 and 40/50/10, respectively) showed a significant improvement in velocity at V'O_{2max}, VT, RCT, running economy and in performance on 2 km without a variation of value of V'O_{2max}. There are no significant differences between groups that support one approach over another with recreational athletes. In the study of Muñoz et al. (2014) on recreational runners, they found improvement on 10 km performance between pre-post training, but no differences between groups that followed training program with emphasis on a polarized intensity distribution and threshold emphasis distribution. The changes recorded in our study are in agree with the results of several training studies reported using different training modalities for 8 weeks in recreational runners. In the recent study of Pugliese et al. (2018) there was an improvement

TABLE 3 | Structural, functional, and performance results in the PET group.

	Pretraining	Posttraining	Difference	Lower bound	Upper bound	Effect size (d)
STRUCTURAL						
Weight (kg)	72.0 ± 7.7	71.8 ± 7.3	−0.22	−0.56	1.00	0.0
Fat mass (%)	19.9 ± 5.9	17.4 ± 4.9	−2.52	0.69	4.34	0.4*
FUNCTIONAL						
V'O_{2max} (ml min^{-1} kg^{-1})	53.0 ± 5.9	53.6 ± 4.8	0.63	−2.01	0.75	0.1
vV'O_{2max} (km h^{-1})	13.9 ± 1.7	14.3 ± 1.5	0.45	−0.67	−0.22	0.3*
vVT (km h^{-1})	10.5 ± 1.2	10.9 ± 1.2	0.42	−0.62	−0.22	0.3*
vRCT (km h^{-1})	12.1 ± 1.5	12.8 ± 1.4	0.68	−0.94	−0.43	0.4*
RE (ml kg^{-1} km^{-1})	226.3 ± 35.2	214.3 ± 33.0	−12.02	1.39	22.64	0.4*
1 RM leg press (kg)	223.7 ± 64.6	223.9 ± 61.1	0.23	−31.39	30.92	0.0
SJ (cm)	22.7 ± 4.6	23.3 ± 4.4	0.64	−2.03	0.75	0.1
CMJ (cm)	24.9 ± 5.3	24.9 ± 4.9	0.07	−1.41	1.26	0.0
PERFORMANCE						
Avg velocity 2 Km (km h^{-1})	13.8 ± 2.0	14.3 ± 1.7	0.48	−0.86	−0.11	0.1*

*Results are presented as mean ± SD. *p value PRE vs. POST < 0.05.*

TABLE 4 | Structural, functional, and performance results in the FOC group.

	Pretraining	Posttraining	Difference	lower bound	Upper bound	Effect size (d)
STRUCTURAL						
Weight (kg)	70.9 ± 2.5	69.9 ± 2.5	−1.0	0.08	1.87	0.1
Fat mass (%)	18.5 ± 1.8	16.9 ± 1.7	−1.6	−0.15	3.41	0.3*
FUNCTIONAL						
V'$O2_{max}$ (ml min^{-1} kg^{-1})	53.7 ± 1.9	53.2 ± 1.9	−0.5	−1.00	2.00	0.1
vV'$O2_{max}$ (km h^{-1})	13.8 ± 0.5	14.3 ± 0.4	0.5	−0.85	−0.15	0.3*
vVT (km h^{-1})	10.8 ± 0.3	11.1 ± 0.4	0.3	−0.65	−0.04	0.3*
vRCT (km h^{-1})	12.4 ± 0.4	12.8 ± 0.4	0.4	−0.67	−0.14	0.3*
RE (ml kg^{-1} km^{-1})	231.8 ± 9.1	211.6 ± 6.3	−20.2	8.88	31.54	0.6*
1 RM leg press (kg)	210.5 ± 18.8	193.8 ± 15.5	−16.8	−11.92	45.47	0.3
SJ (cm)	24.1 ± 1.7	25.3 ± 1.7	1.2	−3.02	0.62	0.2
CMJ (cm)	27.1 ± 1.9	27.1 ± 2.0	0.1	−1.49	1.35	0.0
PERFORMANCE						
Avg velocity 2 Km (km h^{-1})	13.9 ± 0.5	14.3 ± 0.5	0.4	−0.62	−0.18	0.1*

*Results are presented as mean ± SD. *p value PRE vs. POST < 0.05.*

in the speed at $V'O_{2max}$ about +6% and speed at VT about +5% with any increment in $V'O_{2max}$, while the improvement in performance on 5 km was about 3%. Similar results were observed also in master runners following concurrent strength and endurance training (Piacentini et al., 2013). Also the changes recorded for RE are aligned with changes reported in several study (Spurrs et al., 2003; Piacentini et al., 2013; Festa et al., 2019).

To date these are the only studies that have analyzed the effect of different intensity distribution on recreational runners. A study of Neal et al. (2013) observed superior performance effects of polarized training in a group of cyclist with a better fitness level to the current study runners. The study was well-controlled and the difference between the group was emphasized because they have eliminated all training above the RCT (zone 3) in their threshold group.

While there is strong agreement that polarized training model it is widely used among elite coaches and athletes, and several studies have shown that it allows them to achieve greater improvements in performance, on recreational athletes no evidence has yet emerged among the compared models.

This distribution is necessary for athletes who perform a large volume of training, to prevent overtraining or steady state of performance (Tarperi et al., 2017). Moreover, by accumulating less effort, the quality of high-intensity sessions is better and this could lead to a greater improvement compared to thresholds or focused model (Muñoz et al., 2014). Average volume for recreational runners is 3–5 h per week, and the possibility of overtraining occurring is very low, and they seem to show that they have a good tolerance to accumulate time at such intensity.

The limited volume of training hours for recreational athletes is determined primarily by the availability of time to train. The focused model seems to better meet the needs of recreational athletes to maximize the improvement from training.

The current study has some potential limitations regarding the lack of observed results on the effects of training on half marathon and marathon performances. However, in order to quantify any likely training effect, we performed a 2 km time-trials before and after the training intervention in both groups. Such shorter testing distance, even though not directly representative of a longer distance performance (e.g., half marathon), represents a more practical and time-effective way to quantify training effect. In future studies, it would be important to include some longer testing sessions to directly verify any training effect over performances more related to half and full marathon distance.

The results of this study seem to confirm the ability of recreational subjects to be equally sensitive to the different modes of intensity distribution over a limited period of time. Further studies regarding the long-term sustainability of this distribution method are required.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary material.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethical Committee for Experimentation of Department of Neuroscience, Biomedicine and Movement Science, University of Verona (Italy). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CT and LF: conceptualization and formal analysis. CT, AL, and FS: methodology, supervision, and writing–review and editing. LF, CT, and KS: investigation. LF: data curation and writing–original draft preparation. FS: project administration.

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frontiers in Physiology

SYSTEMATIC REVIEW
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Effect of Acute and Chronic Aerobic Exercise on Immunological Markers: A Systematic Review

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Introduction: The effects of aerobic exercise on the immune system are not yet fully defined in the scientific literature. This fact demonstrates the need to investigate its influence on existing immunological markers by classifying and quantifying their acute and chronic effects.

Objective: To investigate the effects of acute and chronic aerobic exercise on inflammatory markers of healthy adults.

Methods: This study is a systematic review according to PRISMA recommendations. The following databases were searched: MEDLINE (via PubMed), Science Direct, Scopus, Web of Science, SciELO, Bireme and Cochrane Library, and article references. The last search was performed in March 2019. We included randomized controlled trials (RCTs) and non-randomized controlled trials (NRCTs) investigating the acute and chronic effects of aerobic exercise on immune markers in healthy male and female adults aged 20 to 45 years, without restrictions in language or year of publication. Two authors independently analyzed the studies by reading the titles, abstracts, and full texts. Risk of Study bias was analyzed using Cochrane's Risk of Bias Tool.

Outcomes: We included 15 studies in this systematic review, 13 of which were acute intervention and 2 were chronic, with 296 participants, 196 men and 100 women all being healthy individuals. It was observed that the acute intervention promotes changes in most immunological markers, while the chronic intervention interferes with a smaller proportion, this being in lymphocyte subpopulations. In the evaluation of quality, it was found that most studies did not present a high risk of bias in the evaluated aspects, but an unclear related risk of bias was observed, requiring a more careful analysis.

Conclusion: Thus, it can be concluded that the evidence indicates that acute and chronic interventions may modify most immune markers, but aspects such as gender, contraceptive pill use in women, physical capacity of the investigated individuals, environment, and type and intensity of the exercises may interfere with these markers as well as the data analysis. Therefore, this review suggests that further research is needed to contribute to the confirmation and estimation of results.

Keywords: immune markers, immune system, physical activity, leukocytes, lymphocytes

INTRODUCTION

The immune system (IS) is a complex interaction between cells and molecules that acts to protect the host against possible microorganism invasions, prevent disease and enable wound healing (Simpson et al., 2015). The system itself is divided into 2 major groups that act synergistically on the overall immune response: The innate system (phagocytes and natural killer cells) and the adaptive system (B and T cells). Communication between defense systems is performed through cytokines and other messengers (Berger, 2000; Raphael et al., 2015), which interact to produce defense responses.

Interestingly, physical exercise has been shown to be a stressor capable of promoting an acute breakdown of the IS stable state and promoting chronic adaptations (Córdova et al., 2010). Aerobic exercise itself is a potential disruptor of the cells of healthy athletes (Nieman et al., 1995), as it can be structured into different volumes and intensities (Hofmann and Tschakert, 2017). Continuous aerobic exercise practice is likely to induce an increase in leukocytes, cytokines, interleukins, and tumor necrosis factor alpha in blood serum (Andersson et al., 2010). Adaptive immunity is not significantly altered by athletic exertion, but the innate system responds differently to chronic stress by increasing natural killer cell activity and decreasing neutrophil action (Nieman and Pedersen, 1999).

Several immunological markers change after long periods of physical exertion allowing the "open window" phenomenon to occur for 3 to 72 h which decreases immunity and provides a greater onset of airway infections (Pedersen and Ullum, 1994; Nieman and Pedersen, 1999; Gleeson, 2007). This impact of exercise is well-characterized when it is analyzed in conjunction with the occurrence of upper airway infections. Exercising at different intensities and the subject's level of physical fitness directly interfere with the immune system response, as shown in the explanatory model of the "J" shaped curve (Nieman, 1994). Exercise can induce hormonal changes, such as increased cortisol levels (Wang et al., 2019). These changes are described as mediating immunosuppression after the training session (Smith, 2004).

Despite the existence of evidence on the effects of physical exercise on the immune system of trained individuals, cyclists, triathletes and marathon runners, the acute and chronic responses brought on by aerobic exercise need to be investigated due to the existence of omissions related to the recommendations that stimulate changes in the immunological markers (Nieman et al., 2001; Brown et al., 2015; Barros et al., 2017; Koh and Park, 2018). This information is important to clarify the role of aerobic exercise in immune markers and to suggest new evidence that will contribute to the prescription of aerobic training in inducing different immune responses. This systematic review aims to investigate the effects of acute and chronic aerobic exercise on immune markers in healthy individuals.

METHODS

Search Strategy

This systematic review was performed following the guidelines and recommendations of the PRISMA Systematic Review and Meta-Analysis Preferred Report items (Moher et al., 2009). The protocol of the review has been registered in the Prospective Registry (PROSPERO) data file under the registration number: CRD42017058899.

The studies were searched for in the following databases: MEDLINE (via PubMed), Science Direct, Scopus, Web of Science, SciELO, Bireme and Cochrane Library. The following search strategies, terms (MESH), and Boolean operators were considered: "physical activity" OR exercise OR training AND "Immune System" OR "immune function" OR "immune cell" AND "killer cell" OR "t cell" OR "cytokine*" OR "interleukin*" OR "leukocyte*" OR "lymphocyte*" OR "adhesion molecule" AND "adult*" OR "human*". The last search was performed in March 2019. Two authors (CAMG, IKS) independently reviewed the titles and abstracts (Level 1). Subsequently, full versions of the articles that met the inclusion criteria were obtained (Level 2). After the analyzes, the reference list of the articles that met the criteria was analyzed to identify additional studies. The study analyzes were resolved with the help of a third author (MPD), duplicate studies with lack of content and access (after sending an email to the authors requesting more information) were excluded.

Inclusion and Exclusion Criteria

Inclusion criteria were as follows: randomized controlled trials (RCTs) and non-randomized controlled trials (NRCTs), interventions that use acute or chronic aerobic exercise, which analyze certain markers of the immune system, and healthy adults of both sexes aged between 20 and 45 years. This age group excluded adolescent individuals and menopausal women due to immunological interference (Giefing-Kröll et al., 2015; Chen et al., 2016; Brazil Ministry of Health, 2018). There were no restrictions for language or year of publication in the inclusion of the articles. Studies with adult smokers, pregnant women, patients undergoing any type of cardiac treatment, and patients with any type of immune system disorder (e.g., immunodeficiencies, inflammatory and autoimmune diseases) were excluded. Other studies that were excluded were: unpublished data, observational studies, review articles, studies using other types of neuromuscular training (strength, endurance), with diet and drug restriction, and comparisons between running and the effects of environmental conditions (e.g., cold and hot).

Outcome Measurements

Outcome measurements assessed to understand the involvement of cells, immune cells and binding molecules in short and long term exercise were: Leukocytes, neutrophils and granulocytes; NK and NKT Lymphocytes and Cells: CD3+, CD4+, CD8+, CD16+, CD18+, CD19+, CD20+, CD22+, CD44+, CD45+, CD56+, CD95+, and their proportions; Cytokines and interleukins (IL): IL-1, IL-2, IL-6, IL-8, IL-10, and IL12; Tumor Necrosis Factor (TNF-α); Interferon-Gamma (IFN-γ); Immunoglobulin (Ig): IgG, IgA, and IgM; Adhesion Molecules: ICAM-1, ICAM-2, ICAM-3 (Pedersen and Hoffman-Goetz, 2000; Nieman et al., 2001; Mooren et al., 2002; Barron et al., 2015; Brown et al., 2015; Barros et al., 2017; Koh and Park, 2018).

Quality Assessment

The quality and risk of bias assessment of each included study was independently assessed by three authors (CAMG, MPD, IKS) using the Cochrane Risk of Bias Tool (Higgins and Green, 2011; Higgins et al., 2011; De Carvalho et al., 2013). The tool contains six domains in which each domain was classified as low, unclear or high risk of bias. Disagreements about the risk of bias assessments were resolved by consensus or by consulting the fourth author (GBCJ).

RESULTS

Search Strategy

Initially, 8,633 articles were selected from the databases. After analysis, 2,708 articles were excluded because they were duplicated. 5,707 studies were then excluded by the analysis of titles and abstracts. Of the total, 218 studies had their full texts analyzed, and 203 were excluded because they were not eligible according to the inclusion criteria (**Data Sheet 1_v1**). After this step, 15 articles were included in this systematic review, in which 13 are related to the effect of acute exercise on immunological markers and 2 to chronic markers. The findings of the search strategy are shown in **Figure 1**.

Study Features

The characteristics of the selected studies are shown in **Table 1**. All studies evaluated the effect of endurance exercise on the immune profile of healthy humans. Of the 15 included studies, 8 were RCTs and 7 non-RCTs, 13 were acute studies, and in two studies participants in the control and experimental groups were not the same (Nehlsen-Cannarella et al., 1991; Moyna et al., 1996a). The two studies that evaluated the chronic effect were also constituted of different individuals in the control and experimental groups (LaPerriere et al., 1994; Mitchell et al., 1996), being that 11 studies were cross-over, and 4 parallel. Cycling was performed only in 2 studies (Akerstrom et al., 2005; Scharhag et al., 2005). It was found that the practice of cycling on cycle ergometers was used as an intervention in 10 studies. While walking or running training was developed in 3 studies (Nehlsen-Cannarella et al., 1991; Green et al., 2002).

Participants

The total of participants in the studies were 296 healthy individuals, 196 men and 100 women. Ten studies only included men (including studies with chronic effects), 3 studies investigated men and women and just 2 studies in the included sample were women only. In the studies selected in this review, the samples were composed of triathletes and runners (Gabriel and Kindermann, 1998; Green et al., 2002; Ronsen et al., 2002; Scharhag et al., 2005), active and sedentary participants (Moyna et al., 1996b), recreational sport practitioners (Edwards et al., 2006), and sedentary individuals (LaPerriere et al., 1994; Mitchell et al., 1996). In the 5 studies that had women as participants only by Nehlsen-Cannarella et al. (1991), there was an observation about the use of oral contraceptives by women, as can be seen in **Table 1**.

Intervention

Acute intervention was used in most studies included in this systematic review. The interventions performed in these observations were: cycling (Akerstrom et al., 2005; Scharhag et al., 2005), cycle ergometer (Nehlsen-Cannarella et al., 1991; Kurokawa et al., 1995; Moyna et al., 1996a; Gabriel and Kindermann, 1998; Gannon et al., 2001; Ronsen et al., 2002; Edwards et al., 2006; Li and Cheng, 2007), racing (Green et al., 2002), and walking (Nehlsen-Cannarella et al., 1991). For chronic studies (LaPerriere et al., 1994; Mitchell et al., 1996), the cycle ergometer was also used.

Prescription intensity was presented as heterogeneous, using as a parameter the percentage of VO_2max, which ranged between 60, 65, and 75% (Nehlsen-Cannarella et al., 1991; Kurokawa et al., 1995; Gannon et al., 2001; Ronsen et al., 2002; Akerstrom et al., 2005), three studies used the VO_2 Pico percentage (Nehlsen-Cannarella et al., 1991; Moyna et al., 1996a; Li and Cheng, 2007), two used the anaerobic threshold (Gabriel and Kindermann, 1998; Scharhag et al., 2005), one study used the ventilatory threshold (Green et al., 2002) and one used Wmax/WPeak (Edwards et al., 2006). In both studies with chronic intervention, the maximum effort used was the percentage of HRMax (LaPerriere et al., 1994) and VO_2Peak (Mitchell et al., 1996).

To estimate workload, the intensity percentage was multiplied by the time in minutes of the intervention. Among the studies that used VO_2max, Gannon et al. (2001) applied the highest workload (u = 7,800), followed by Akerstrom et al. (2005; u = 7,200). The lowest workloads were applied with an intensity similar to the other studies (60% VO_2max), but with a shorter duration of 45 min (ua = 2,700; Nehlsen-Cannarella et al., 1991). With the use of VO_2peak, 2 studies presented an incremental intensity model (55, 70, and 85%), fulfilling 6 min at each stage (ua = 1,260; Nehlsen-Cannarella et al., 1991; Moyna et al., 1996a), while one presented a continuous model with 55% for 120 min (water = 6,600; Li and Cheng, 2007).

In the 13 acute studies, 12 had the duration in their interventions range from 18 to 240 min and 1 study went to exhaustion. In chronic studies, however, different prescription parameters were set, but these can be considered moderate intensities. Regarding the duration of interventions, the data were heterogeneous, since one study lasted 10 weeks with 45-min sessions (1,350 min of exercise; LaPerriere et al., 1994), while another lasted 12 weeks with 30-min sessions (1,080 min total exercise; Mitchell et al., 1996), both studies had a training frequency of 3 times per week.

Immunological Markers

The effect of post-aerobic regulation on the immunological markers that were evaluated in the studies are shown in **Table 2**. Endurance activity increased leukocytes, lymphocytes, granulocytes, neutrophils, eosinophils, and monocytes (Nehlsen-Cannarella et al., 1991; Kurokawa et al., 1995; Moyna et al., 1996a; Green et al., 2002; Scharhag et al., 2005; Li and Cheng, 2007). In the acute intervention, only one study identified no change in the amount of granulocytes and monocytes, although the leukocyte, lymphocyte, and neutrophil count was similar to other studies (Nehlsen-Cannarella et al., 1991). Other studies

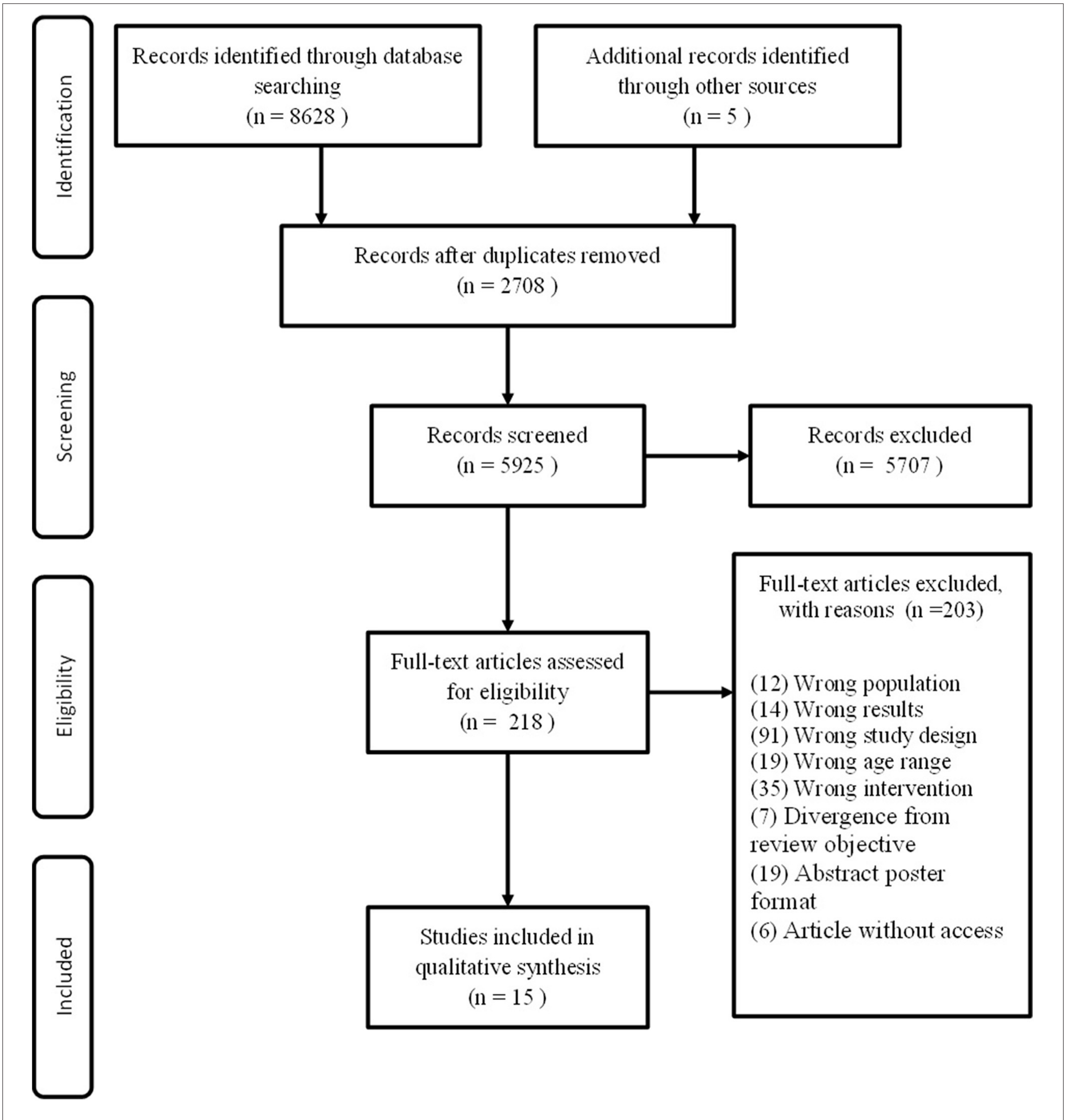

FIGURE 1 | Summary of search result.

have shown increased CD16-56 NK cells (Nehlsen-Cannarella et al., 1991; Moyna et al., 1996a,b; Gannon et al., 2001). In regard to chronic effects, only two studies were considered valid to be included in this review. In one study it was observed that there were no changes in the amount of leukocytes, lymphocytes and monocytes, but there was an increase in CD4+, CD8+, and CD20 lymphocyte subpopulations, although no change in CD56 cells (LaPerriere et al., 1994). Similarly, Mitchell et al. (1996), found no change in the amount of lymphocytes, and neither in the amount of IgG, IgA, and IgM.

In the lymphocyte subpopulations of the immune system there are contradictory results. Two studies investigated the effect of acute exercise on CD3+ T cells, showing an increase in the count of these cells (Moyna et al., 1996b) and a reduction in the

TABLE 1 | Characteristics of the studies.

References	Study design	*N*	Participants		Type of intervention	Duration (weeks)	Duration (min.)	Sessions (x/week)	Intensity
			Experimental	Control					
Akerstrom et al. (2005)	Non-RCTs Cross-over	11	Men Health Age: 21–28	Same as experimental	Cycling	–	120	–	60% VO_2máx
Edwards et al. (2006)	Non-RCTs Cross-over	24	12 Men 12 Women Health Recreational Age: 24.2 ± 3.2	Same as experimental	Cycle ergometer	–	45	–	Exercise 1: (M) 130 W (W) 95 W ↑ 35 W–3' (exhaustion) (M) 4' = 130 W (W) 4' = 95 W 45' = 55% W máx Exercise 2: (M) 16' = 84 a 231 W (W) 16' = 70 a 154 W (M) 4' =130 W (W) 4' = 95 W 25' = 55% W peak
Gabriel and Kindermann (1998)	Non-RCTs Cross-over	13	Men Health Triathletes Age: 27.5 ± 6.4	Same as experimental	Cycle ergometer	–	To exhaustion	–	110% Anaerobic Threshold
Gannon et al. (2001)	Non-RCTs Cross-over	10	Men Health Age: 26 ± 5.0	Same as experimental	Cycle ergometer	–	120	–	65% VO_2 máx
Green et al. (2002)	RCT Cross-over	12	Men Runners Age: 30.0 ± 7.0	Same as experimental	Treadmill racing	–	60	–	95% Ventilatory Threshold
Kurokawa et al. (1995)	Non-RCTs Cross-over	8	Men Health Age: 28.5 ± 5.1	Same as experimental	Cycle ergometer	–	60	–	60% VO_2 máx
LaPerriere et al. (1994)	RCT Parallel	14	7 Men Health Sedentary Age: 30.0 ± 6.4	7 Men Health Sedentary Age: 31.1 ± 3.1	Cycle ergometer	10	45	3	70–80% FC máx
Li and Cheng (2007)	Non-RCTs Cross-over	10	Men Health Age: 21.6 ± 0.9	Same as experimental	Cycle ergometer	–	120	–	55% VO_2 peak
Mitchell et al. (1996)	RCT Parallel	21	11 Men Health Sedentary Age: 23.4 ± 7.0	10 Men Health Sedentary Age: 20.1 ± 1.9	Cycle ergometer	12	30	3	75% VO_2 peak
Moyna et al. (1996a)	RCT Parallel	64	32 Adults Health 16 Men Age: 24.3 ± 0.5 16 Women Age: 23.6 ± 0.5	32 Adults Health 16 Men Age: 24.3 ± 0.5 16 Women Age: 23.6 ± 0.5	Cycle ergometer	–	18	–	55/70/85% VO_2 peak
Moyna et al. (1996b)	RCT Parallel	64	32 Adults Health 8 Men Active Age: 24.9 ± 0.8 8 Women Active Age: 23.3 ± 0.7 8 Men Sedentary Age: 25.0 ± 0.8 8 Women Sedentary Age: 23.8 ± 0.8	32 Adults Health 8 Men Active Age: 24.9 ± 0.8 8 Women Active Age: 23.3 ± 0.7 8 Men Sedentary Age: 25.0 ± 0.8 8 Women Sedentary Age: 23.8 ± 0.8	Cycle ergometer	–	18	–	55/70/85% VO_2 peak
Nehlsen-Cannarella et al. (1991)	RCT Cross-over	12	Women Health Age: 36.9 ± 2.2	Same as experimental	Treadmill walking	–	45	–	60% VO_2 max
Nehlsen-Cannarella et al. (1991)	RCT Cross-over	12	Women Health Age: 36.9 ± 2.2	Same as experimental	Track walking	–	45	–	60% VO_2 max
Ronsen et al. (2002)	RCT Cross-over	9	Men Athletes Triathletes— Skaters Age: 21–27	Same as experimental	Cycle ergometer	–	75	–	75% VO_2 max
Scharhag et al. (2005)	Non-RCTs Cross-over	12	Men Athletes Triathletes— Cyclists Age: 26.9 ± 7.0	Same as experimental	Cycling on the running track	–	240	–	70% Anaerobic Threshold

TABLE 2 | Post-aerobic exercise regulation and immunological markers.

References	Immune markers end regulation after exercise																					
	Leuc	Linf	Gran	Neut	Mon	Eosin	IL-1	IL-2	IL-6	IL-8	CD3	CD4	CD8	CD4 /CD8	CD16-56	CD16	CD56	CD18	CD19	CD20	IgG	IgA	IgM
Akerstrom et al. (2005)										↔													
Edwards et al. (2006)									↑														
Gabriel and Kindermann (1998)																		↑					
Gannon et al. (2001)												↑	↑	↓	↑				↔				
Green et al. (2002)	↑	↑		↑	↑																		
Kurokawa et al. (1995)	↑	↑	↑									↔	↔			↑							
LaPerriere et al. (1994)	↔	↔			↔							↑	↑	↔			↔			↑			
Li and Cheng (2007)	↑	↑		↑	↑																		
Mitchell et al. (1996)		↔																			↔	↔	↔
Moyna et al. (1996a)		↑			↑						↓				↑				↓				
Moyna et al. (1996b)		↑	↑	↑	↑	↑					↑	↑	↑	↓	↑				↑				
Nehlsen-Cannarella et al. (1991)	↑	↑						↔													↑	↔	↔
Nehlsen-Cannarella et al. (1991)	↑	↑	↔	↑	↔							↔	↑		↑					↔			
Ronsen et al. (2002)							↔		↑														
Scharhag et al. (2005)	↑	↑		↑	↔			↔	↑							↑							

Leuc, Leukocytes; Lymph, Lymphocytes; Gran, Granulocytes; Neut, Neutrophils; Mon, Monocytes; Eosn, Eosinophils (↑ increased, ↓ decreased, ↔ no change).

percentage of CD3+ among lymphocytes (Moyna et al., 1996a). The data on the effect on the interventions of CD4+ T helper and CD8+ cytotoxic T cells are similar. Three studies showed an increase in CD4 and CD8+ (LaPerriere et al., 1994; Moyna et al., 1996b; Gannon et al., 2001), while two showed an increase in CD8+ and unchanged CD4+ values (Nehlsen-Cannarella et al., 1991; Kurokawa et al., 1995). There is a lack of studies with the characteristics determined in the inclusion criteria of the present review that have verified the effect of exercise on CD18 cells, with only one study showing an increase in these cells (Gabriel and Kindermann, 1998). Similarly, only one study verified the effect on CD20, showing no change (Nehlsen-Cannarella et al., 1991). Data for CD19 are contradictory, with only one study presenting information on its increase (Moyna et al., 1996b), while other studies showed a reduction or lack of change in this marker (Moyna et al., 1996a; Gannon et al., 2001). Concomitantly, one study demonstrated increased IgG but no change in IgA and IgM (Nehlsen-Cannarella et al., 1991). These observations are presented in **Table 2**.

Few studies from those included in this review addressed the effect of aerobic exercise on interleukins. Exercise has not been found to promote IL-1 alteration (Ronsen et al., 2002), two studies have indicated that exercise does not alter IL-2 levels (Nehlsen-Cannarella et al., 1991; Scharhag et al., 2005) and just one demonstrated that IL-8 values did not change (Akerstrom et al., 2005). Three studies found increased IL-6 after an aerobic exercise session (Ronsen et al., 2002; Scharhag et al., 2005; Edwards et al., 2006). These results are expressed in **Table 2**.

Quality Assessment

After using the Cochrane risk of bias tool, the results are shown in **Figures 2A,B**.

Random sequence generation: In 11 studies no process methods were described for the generation of their random sequences, characterized as risk of unknown bias. These methods could be by generating random computer numbers, throwing coins, shuffling cards or envelopes, throwing dice or by lottery.

Allocation concealment: 12 articles in their entirety did not provide sufficient information, so, in this way, it was not possible to detect how the sequence and allocation of participants occurred.

Blindness of practitioners, participants, outcome assessors: In randomized controlled trials using exercise intervention, everyone involved cannot be blinded to treatment allocation. In the studies where supervised physical exercise was administered, the professionals who performed the intervention could not be blinded. Regarding the blindness of the outcome evaluators, this information did not exist in the evaluated studies. These facts meant that the classification of all the studies had an "unclear" risk of bias, i.e., unknown because of their lack of information.

Incomplete outcomes: In 13 studies, it was impossible to verify risk bias for losses and for the sampling stages due to the lack of described information related to randomized numbers and the reasons for losses.

Selective outcome: It can be observed that in all the studies the risk of bias for reporting a selective outcome was classified as

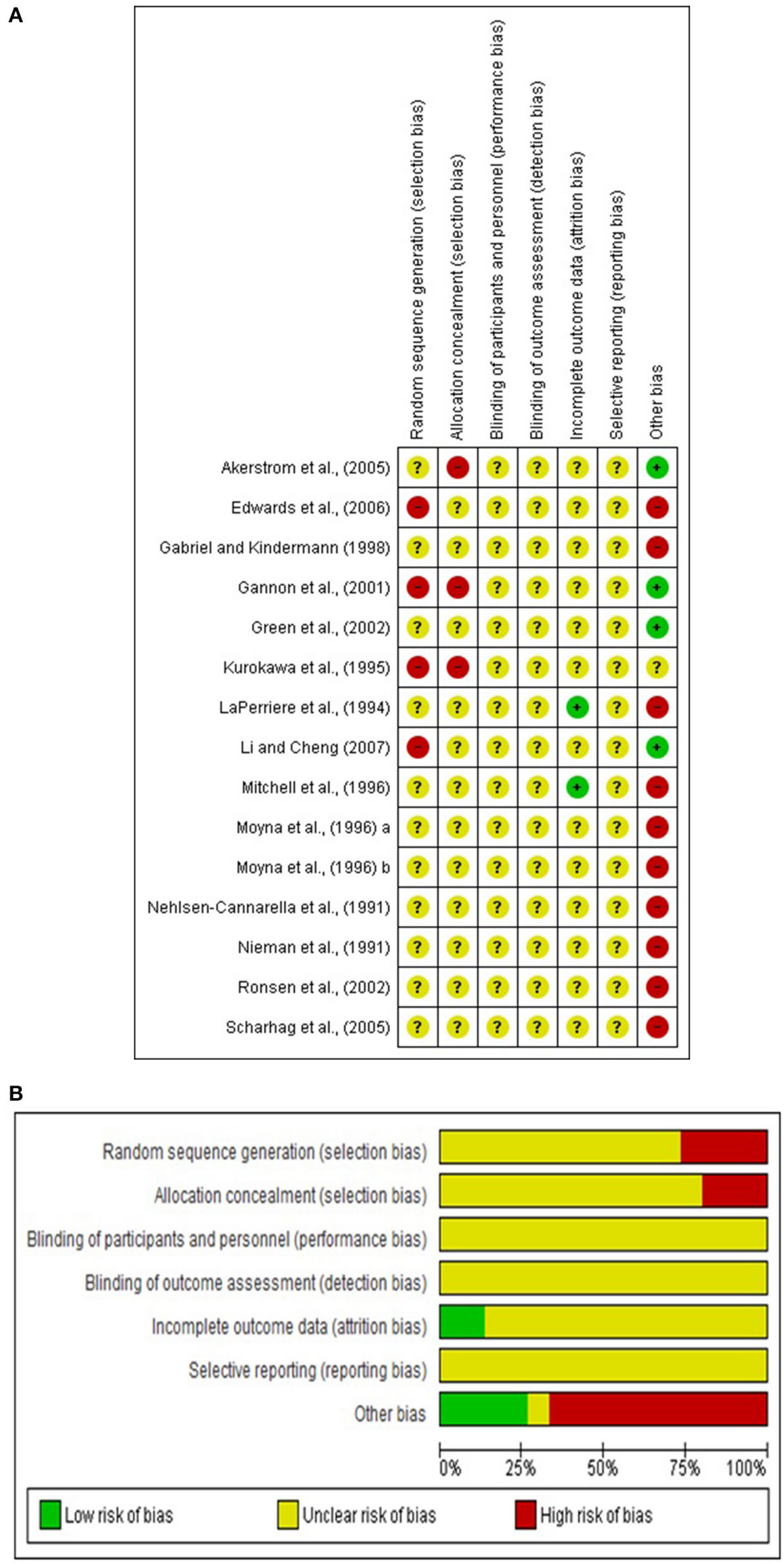

FIGURE 2 | (A,B) Risk of bias tool.

unknown due to insufficient information in the studies. They did not have their protocols or did not allow access to them.

Other sources of bias: These sources were easily detected in 10 studies. In these there was no information relating to the nutritional status of the participants during data collection or any daily dietary report in the weeks prior to these same study evaluations.

DISCUSSION

The present systematic review aimed to analyze the scientific evidence on the acute and chronic effects of aerobic exercise on immune markers in healthy individuals. It was found in our study that aerobic exercise promotes changes in the immune response of leukocytes, lymphocytes, lymphocyte subpopulations, interleukins, NK cells and immunoglobulins. Several authors confirm the occurrence of these modifications in the same immunological markers due to the performance of cardiorespiratory physical training (Barron et al., 2015; Brown et al., 2015; Barros et al., 2017; Koh and Park, 2018). Therefore, the characteristics of the sample collected, such as: gender, level of fitness, sport practiced and intensity of intervention, may interfere in the values, becoming a limitation in our analysis despite the adequate comparison and generalization of the results found.

A large number of studies analyze the likely effects of aerobic exercise on immune cells by bringing together individuals of both genders in their samples (Morgado et al., 2012, 2014; Rowlands et al., 2012; Li et al., 2017). This fact limits the results found due to the existence of different sex-related immune responses in healthy individuals (Klein and Flanagan, 2016). Some female centered studies have been conducted considering the use of contraception in women (Nehlsen-Cannarella et al., 1991). There are limitations in the results found due to the use of this pharmacological therapy. These drugs directly influence leukocyte and other immune system concentrations by altering their absolute and relative numbers and may even raise them above normal values for healthy individuals (Timmons et al., 2005; Medeiros et al., 2007; Gough et al., 2015). The chronic studies used only healthy but sedentary men. This fact allows a comparative analysis of immune function with adaptation to prolonged physical training that provides an improvement in physical fitness and immune response (Sato et al., 1998; Farhangimaleki et al., 2009; Patlar, 2010; Su et al., 2011; Morgado et al., 2012).

Several authors report acute and chronic changes in immune system cells in practitioners of aerobic sports such as running, cycling, triathlon, and skating (Díaz et al., 2011; LaVoy et al., 2011; Brown et al., 2015; Santos et al., 2016; Barros et al., 2017; Koh and Park, 2018). The heterogeneity of the ways of estimating the intensity of interventions does not allow us to stipulate a better homogeneous pattern to be used. Studies show that moderate to severe aerobic exercise, whether short or long term, promotes acute and chronic changes in immune function (Pedersen, 1991; Nieman and Nehlsen-Cannarella, 1994; Pedersen and Ullum, 1994; Pedersen et al., 1998; Nieman and Pedersen, 1999; Pedersen and Hoffman-Goetz, 2000; Maltseva et al., 2011; Walsh et al., 2011; Suzuki, 2018). Acute studies with an intensity of 60% of VO_2max during 45 and 60 min on an ergometer cycle did not cause changes in the CD4+ lymphocyte (Nehlsen-Cannarella et al., 1991; Kurokawa et al., 1995). The same intervention at 65% VO_2max and 55/70/85% VO_2peak increased the concentrations (Moyna et al., 1996b; Gannon et al., 2001). Therefore, changes in CD4+ are likely to be more sensitive to exercise intensity. Immunological markers such as leukocytes, lymphocytes (CD3+, CD4+, CD8+), neutrophils, monocytes, and T cells have their concentrations increased above normal values through adventure running, depending on the intensity of execution (Tossige-Gomes et al., 2014). Catecholamines and cortisol have been shown to act directly on leukocytosis during and after exercise (Mccarthy and Dale, 1998), but the intensity and volume of this activity modulate its response in the immune system. Several studies that analyze and compare the duration and intensity of interventions on the same population point to significant differences between pre and post-intervention in most of the immunological markers analyzed (Auersperger et al., 2012; Ibis et al., 2012; Witard et al., 2012; Lira et al., 2017).

Aspects related to the studies analyzed, such as the participants' level of physical fitness, type of intervention, in regard to its time and intensity, and the use of contraceptives by women may interfere with the analyzed immune cell concentrations. These possible changes in immune function bring up an important question to be answered through further investigation in future studies.

Acute aerobic exercise has been shown to be a potential influencer of immune cell concentrations, while data from chronic studies are still contradictory (Mitchell et al., 1996; Barros et al., 2017). Acute intervention influences the regulation of the immune system (Pedersen, 1991; Nieman and Nehlsen-Cannarella, 1994; Pedersen and Ullum, 1994; Pedersen et al., 1998; Nieman and Pedersen, 1999; Pedersen and Hoffman-Goetz, 2000; Maltseva et al., 2011; Walsh et al., 2011; Suzuki, 2018).

In many studies, authors report that acute aerobic exercise promotes changes in most immune markers like leukocytes, lymphocytes, and natural killer cells, among others (Scharhag et al., 2005; Patlar, 2010; Su et al., 2011; Santos et al., 2013). Long-term acute aerobic exercise with cycling, marathons, and triathlons lasting longer than multiple hours promotes elevations in plasma concentrations of IL-1ra, IL-6, IL-8, and IL-10 cytokines after exercise (Nieman et al., 2001; Ronsen et al., 2002; Suzuki, 2018). Leukocytes, neutrophils, interleukins 6, 10, 8, 12, tumor necrosis factor (TNF-α) and adhesion molecule (ICAM-1) have their plasma concentrations increased immediately after a 42.2 km marathon, enabling a post-exercise state of infection (Suzuki et al., 2003; Santos et al., 2016).

Mid-distance running (21.1 km) stimulates growth in leukocyte, neutrophil and monocyte numbers in amateur runners (Lippi et al., 2010, 2014). During a moderate 4-hour session of cycling, the absolute number of circulating NK cells, monocytes and neutrophils in the bloodstream increases, but after the exercise is finished only IL-6 concentrations remain high (Scharhag et al., 2005). Performing moderate walking for 45 min does not change T-cell (CD5 and CD25) and interleukin-2 concentrations, however, immunoglobulins have their plasma concentrations increased immediately after this walk (Nehlsen-Cannarella et al., 1991).

Lymphocyte subpopulations also increase with 10-week aerobic training, with three sessions of 45 min per week on the cycle ergometer at 70–80% intensity of the predicted maximum heart rate per age (LaPerriere et al., 1994). Corroborating with the findings of LaPerriere et al. (1994), a training session performed 3 times per week for 12 weeks, 30 min/session at 75% of VO_2peak, also did not verify changes in total lymphocyte count (Mitchell et al., 1996). In addition, the authors also did not identify changes in IgG, IgA, and IgM immunoglobulins. The chronic effects of aerobic exercise on immunological markers are still controversial and need further investigation in further studies.

As a limitation of this study, we can highlight the difficulty of finding studies with experimental and controlled conditions. Regarding the physical fitness of the chosen study participants, which can vary from sedentary to athlete, the results cannot be generalized. In regard to gender, which is a factor of great influence on the immune system, only five articles were found from all the articles selected that investigated the female sex and in three of these both of the sexes were mixed in the sample. In regard to the intensity of physical effort used in the interventions, there is the limitation of stipulating a zone of training when considering the heterogeneity found, and that each one has an acute or chronic effect on a certain immunological marker. Another limitation of our study was the difficulty of finding studies that report on the chronic effect of exercise with only two studies being chosen for this review, thus not allowing a thorough analysis of this aspect.

In addition, the use of birth control pills in studies with women limits our ability to reach conclusions. Thus, there is a considerable need for further studies in order to identify the factors that really influence these discrepancies and also further research is needed in chronic intervention to verify its actual interference with immunological markers.

We therefore highlight the exclusivity of this review because it is the first to widely cover this subject analyzing the effects of acute and chronic aerobic exercises on all existing immunological markers. The inclusion of randomized studies, the methodological precautions adopted to reduce the risk of bias, the predefinitions of a protocol to be registered on a specific web platform, and the inclusion of experimental studies with control and experimental groups of similar characteristics helped in the observation of the true interference of aerobic exercise on immune cells. These facts show that this study has made an important contribution with great research potential within the existing scientific literature.

According to the results found in this research it was possible to understand which immune markers are affected by aerobic exercise from acute and chronic perspectives. Aspects such as the intensity of each intervention performed, its type, the place where it was developed and the characteristics of the individuals undergoing it make up important knowledge that allows for a better understanding of these immunological changes caused by aerobic exercises. This review provides an up-to-date insight into the content investigated herein, improving the safety in the work of health professionals when prescribing these aerobic exercises for healthy adults in the promotion of health.

Therefore, it is concluded from the results found in this study that acute intervention promotes changes in most immunological markers while chronic interventions influence a smaller part of them. There were differences between the results of studies with acute intervention with certain immunological markers. These may be related to the level of physical fitness of the subjects, and type and intensity of intervention.

External factors such as characteristics of the environment where the intervention was performed and its intensity and also the internal aspects related to the training time and oral contraceptive use of the participants should be taken into consideration in new studies for a better understanding of the relationship between aerobic exercise, acute and chronic interventions and their real influence on immunological markers.

AUTHOR CONTRIBUTIONS

CG, MD, and IS contributed to the conception and design, search, and eligibility and outcome measures. CG, MD, and GJ contributed to the quality assessment. CG, MD, IS, PD, DS, and GJ contributed to the writing of the manuscript. CG, MD, IS, PD, DS, BC, RG, and GJ contributed to the revision and approval of the final manuscript version and interpretation of the results.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fphys.2019.01602/full#supplementary-material

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Pacing Strategy Affects the Sub-Elite Marathoner's Cardiac Drift and Performance

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The question of cardiac strain arises when considering the emerging class of recreational runners whose running strategy could be a non-optimal running pace. Heart rate (HR) monitoring, which reflects exercise intensity and environmental factors, is often used for running strategies in marathons. However, it is difficult to obtain appropriate feedback for only the HR value since the cardiovascular drift (CV drift) occurs during prolonged exercise. The cardiac cost (CC: HR divided by running velocity) has been shown to be a potential index for evaluation of CV drift during the marathon race. We sought to establish the relationship between recreational marathoners' racing strategy, cardiac drift, and performance. We started with looking for a trend in the speed time series (by Kendall's non-parametric rank correlation coefficient) in 280 (2 h30–3 h40) marathoners. We distinguished two groups, with the one gathering the large majority of runners (n = 215, 77%), who had a significant decrease in their speed during the race that appeared at the 26th km. We therefore named this group of runners the "fallers." Furthermore, the fallers had significantly lower performance (p = 0.006) and higher cardiac drift (p < 0.0001) than the non-fallers. The asymmetry indicator of the faller group runners' speed is negative, meaning that the average speed of this category of riders is below the median, indicating that they ran more than the half marathon distance (56%) above their average speed before they "hit the wall" at the 26th km. Furthermore, we showed that marathon performance was correlated with the amplitude of the cardiac drift (r = 0.18, p = 0.0018) but not with those of the increase in HR (r = 0.01, p = 0.80). In conclusion, for addressing the question of the cardiac drift in marathon, which is very sensitive to the running strategy, we recommend to utilize the cardiac cost, which takes into account the running speed and that could be implemented in the future, on mobile phone applications.

Keywords: running, endurance, Kendall, Strava, big data

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INTRODUCTION

Every year, the New York, London, Berlin, and Paris marathons each attract around 30,000–50,000 adult runners of all levels. Most of these runners are recreational athletes. Many train alone and hope to progress by monitoring their heart rate and/or running speed. However, more and more studies showed that the self-pace exercise allows one to get the best performance. Indeed, it has been suggested that runners tend to adopt the same overall pacing strategy, even though several different strategies are available for events of different distances and durations. Hence, the most important factor in choosing a pacing strategy is knowledge of the endpoint of a particular event (St Clair Gibson et al., 2006). In line with this teleoanticipation hypothesis, the estimation of time limit corresponds to the perception of time when exercise at a constant power and a constant speed is performed until exhaustion (Coquart et al., 2012). However, the human self-paces his/her effort in real life, and notably in races from the 1,500-m middle-distance event upwards; we have used differential modeling of anaerobic and aerobic metabolism to show that runners continuously adjust their speed as a function of the remaining anaerobic capacity reserve (Billat V. et al., 2009). The latter finding demonstrated that runners are able to adjust their effort by varying their running speed according to perceived effort (Giovanelli et al., 2019; Molinari et al., 2019).

Every intensity zone of pacing corresponds to a specific effort perceived by the athlete (Kraemer et al., 2012). Indeed, the rate of perceived exertion (RPE) is closely related to the concept of exercise intensity, and more precisely, it is "the feeling of how heavy and strenuous a physical task is" (Borg, 1998). It does not take into account exclusively the workload but included many other factors that affect the performance (temperature, humidity, energy supply). Moreover, RPE is a key mediator in the regulation of the work rate (Tucker and Noakes, 2009). The importance of RPE in determining the self-selected exercise intensity (i.e., pacing) is underlined by authors (for details, see Abbiss and Laursen, 2008) who suggested that the brain processes a complex algorithm including peripheral feedback, previous experiences, and the remaining workload (Abbiss and Laursen, 2005; St Clair Gibson et al., 2006; Faulkner et al., 2008). Ceci and Hassmen (1991) showed that runners were able to self-adjust the running intensity at three different RPE values. These subjects adapted the speed in order to obtain an RPE of 11 ("light" on a 6–20 Borg scale) for 3 min, 13 ("somewhat hard") for 11 min, and 15 ("hard") for 5 min (17).

We recently found that recreational runners were able to adjust their acceleration every 4 s by asking them to do "soft," "medium," or "hard" accelerations (Billat et al., 2018). Molinari et al. (2019) showed that the runners maintained their speed in a steady-state manner during the submaximal stages (RPE 11 and 14) while increasing the intensity of their cardiorespiratory responses as the run continues. In contrast, our recreational runners maintained their $\dot{V}$O2max during the maximal stage (RPE 17) by dropping their running speed. Thus, one can hypothesize that a runner uses the variation in speed (i.e., acceleration) as a marker to preserve the power of running-specific muscles – even when the cardiorespiratory variables are rising (Billat et al., 2018).

However, we still do not know how the runner associates a given RPE with speed vs. time. In perspective of the practical applications, we know that most runners train by monitoring their heart rate and running speed, rather than the perceived effort. To better understand the mechanisms of self-paced control in an ecological setting (such as track tests and trail races), there is a need to examine the speed variation and the pacing strategy of the recreational runners for being able to analyze their performance not only with the average pace but also with the pacing at each kilometer of the race.

Indeed, we hypothesize that this emerging class of recreational runners, whose running pace would be non-optimal, could have a higher cardiac cost increase during the race, especially after the half marathon. A prior study of our working group registered the cardiac output (CO) during a marathon in 14 recreational runners (3 h30 ± 45 min) and demonstrated that marathon performance was inversely correlated with an upward drift in the CO/speed ratio (mL of CO m^{-1}) named the cardiac cost (Billat et al., 2012; Shimazu et al., 2013). This cardiac cost drift was due to the decrease in speed mainly after the half marathon while heart rate, stroke volume, and the CO were not significantly different between the first and the last 4 km (Billat et al., 2012). Furthermore, a recent study performed on big data available on Strava®, a social fitness network, has shown that 80% of recreational (2 h30–3 h40 min) marathoners had a negative distribution of their speed since it drops after the half race. In probability theory and statistics, skewness is a measure of the asymmetry of the probability distribution of a real-valued random variable about its mean. The skewness value can be positive or negative, or undefined. For a unimodal distribution, negative skew commonly indicates that the tail is on the left side of the distribution, and positive skew indicates that the tail is on the right side. In cases where one tail is long but the other tail is fat, skewness does not obey a simple rule. For example, a zero value means that the tails on both sides of the mean balance out overall; this is the case for a symmetric distribution, but can also be true for an asymmetric distribution where one tail is long and thin, and the other is short but fat. Hence, from a practical point of view, it means that they ran more distance (median speed) above their average speed (Billat et al., 2018). This was in opposition with best world performance marathons (Gebreselassie and Kipchoge races) (Billat et al., 2018).

When the runners wear a cardio frequency meter in addition to a GPS, the heart rate is also indicated in the runners' Strava® file. Therefore, it gives the possibility to highlight the relationship between speed strategy, heart dynamics, and performance in real racing conditions. Indeed, the marathon race is considered to demand extreme physical endurance and has provided a unique opportunity to study the limits of human thermoregulation for more than a century (Cheuvront and Haymes, 2001). Voluntary reduction in exercise intensity and/or duration is one of the most obvious behavioral thermoregulatory responses to hot environments and is done (at least partially consciously) in order to reduce heat production and the rate at which core body temperature rises (Tyler, 2019).

Therefore, in the present study, we sought to establish whether their racing strategy affects the sub-elite marathoner's cardiac drift and performance. The aim of this study was then to check the hypothesis that, in recreational but already good marathoners (2 h30–3 h40), their racing strategy impacted their performance in relation to a possible cardiac drift.

MATERIALS AND METHODS

Population

The 280 analyzed runs came from marathon runners who took part in the "Marathon de Paris" in 2018 (n = 140) or in the "Marathon de Berlin" in 2017 (n = 140). The chronometric performances were between 2 h30 and 3 h40 for each race. Every subject publicly shared his or her race data using the website Strava®, on which we proceeded to the gathering of the data. Therefore, given that the study used the Strava public data, we got neither the gender nor the age of the subjects.

Experiment Protocol

Data Sampling

In order to have a constant performance sample, we gathered them from the fastest run (2 h30) to the slowest (3 h40), with an interval of 30 s between each runner.

Observed Variables

We had access to the running pace (time passed for each kilometer ran) and to the mean of the heart rate (HR) by kilometer. In our study, we did not consider the last 195 m of the run.

Computed Variables

The cardiac cost (CC) (which has a unit corresponding to the amount of heartbeat by meter ran) was computed with the mean of the heart rate (in b min^{-1}) and the speed (in km min^{-1}) by kilometer using the following formula:

$$\text{Mean cardiac cost} = \frac{\text{HR (b min}^{-1})}{\text{speed (m min}^{-1})} \;/\; 6000$$

Statistical Study

Defining the Running Strategy by the Skewness of the Pace Distribution During the Race

In this study, we have characterized the running strategy by the skewness of the speed distribution during the race. The skewness was calculated from the number of kilometers ran above of the mean speed expressed in percentage of the 42 km of the marathon. In this study, we defined the running strategy as the skewness of the speed data by kilometer.

Modeling the Time Series Tendencies

We used Mann Kendall's non-parametric test of trend on the speed, HR, and CC series. The result of this test, Kendall's τ, between -1 and 1, gives us the statistical trend of the studied series. The statistic of Kendall's τ is defined by the following formula:

$$\tau = \frac{2}{n(n-1)} \sum_{i<j} K(v_i, v_j)$$

Like all the statistical tests, Mann Kendall's trend test is read with a p-value. The closer to 0 this one is, the stronger the significance of the trend is. On the other hand, the closer to 1 this p-value is, the weaker the significance of the trend is.

In order to get the range Δ of this trend, we used the evolution coefficient below, where μ_0 is the mean of the first 4 km and μ_1 is the mean of the last 4 km.

$$\Delta = \frac{(\mu_1 - \mu_0)}{\mu_0} \times 100$$

We chose to use the distance of 4 km because it represented nearly 10% of the marathon's distance.

Determining a Heterogeneity Among Time Series

We used Pettitt's non-parametric test, which is an adaptation of Mann–Whitney's rank-based test, allowing to identify the time where a shift occurs. This statistical test is read with a p-value.

Pettitt's statistic test is computed like the following:

We set:

$$D_{ij} = -1 \text{ if } (x_i - x_j) < 0,\; D_{ij} = 0 \text{ if } (x_i - x_j) = 0,$$

$$D_{ij} = 1 \text{ if } (x_i - x_j) > 0$$

We then define:

$$U_{t,T} = \sum_{i=1}^{t} \sum_{J=i+1}^{T} D_{ij}$$

The alternative bilateral assumption of Pettitt's test is defined by:

$$K_T = \max_{1 \le t < T} \left| U_{t,T} \right|$$

Applied to the time series of speed by kilometer, Pettitt's test allowed us to classify the runners in two categories: the "fallers" who have a slightly statistically heterogeneous speed, and the "non-fallers" who have a homogeneous speed during the whole run.

We used the Pearson's correlation coefficient to correlate the performance with the racing strategy (asymmetry of speed), the speed decrease (%), and the cardiac drift (cardiac cost increase). We then determined the significance level α = 0.05 for the interpretation of the statistical tests used. The entirety of the study has been conducted with the software XLSTAT® version 2019, developed by the Adinsoft society. All the results are presented with mean ± standard deviation. At the end, we can also use the coefficient of variation, another speed race characteristic of speed time series (CV, i.e., standard deviation/mean%) that appears to be an easy and high marker of the difference of running strategy between the two groups.

RESULTS

We started with looking for a trend in the speed time series (by Kendall's non-parametric rank correlation coefficient) and confirmed that almost 80% of the 280 marathoners (77%) had a decreasing trend in speed data. Then, we compared this group (n = 215) that we named the "fallers" with the group of the "non-faller" runners (n = 65) who did not have a significant speed decrease.

The Difference of Performance Between the Fallers and Non-fallers' Group

The ANOVA test showed that the fallers' group had a significantly lower performance (3 h01:42 s ± 18:10 s min vs. 2 h54 min09 s ± 17 min 13 s, $F = 15$, $p = 0.006$) than the non-fallers.

The Difference of Speed Strategy Between the Two Groups

All the marathoners ran in "positive split," that is to say, with a speed decrease trend. However, the fallers' group had a significantly higher speed decrease than those of the non-fallers' group (-0.49 vs. -0.25 for the Kendall's tau in the fallers' vs. non-fallers' group, $F = 15$, $p = 0.0001$).

In addition to this difference of the speed time course, the two groups had different speed race distribution. Indeed, the asymmetry indicator of the faller group runners' speed was negative (**Figure 1**) in contrast with the non-faller's group whose speed distribution was normal (**Figure 2**) ($F = 28$, $p < 0.0001$ and $F = 11$, $p = 0.001$, for speed and HR, respectively). Hence, the fallers' group average speed was below their median speed, running 56% of the 42,195 km above their average speed. Then, they hit "the wall" as their speed falls sharply at the 26th km (**Figure 3**). However, interestingly, we can underline the normality of the cardiac cost distribution in both groups ($F = 2.6$, $p = 0.1$). It means that, whichever their speed profile, all the marathoners ran 50% of the time above and below their average cardiac cost.

The Correlation Between Speed Strategy and Marathon Performance

The running asymmetry was significantly correlated with the performance ($r = -0.15$, $p = 0.018$) (**Figure 4**).

The Difference of Heart Rate and Cardiac Cost Time Courses Between the Fallers' and Non-fallers' Group

The heart rate increase between the first and last 4 km of the marathon was not significantly different between the two groups ($F = 2.0$, $p = 0.15$) and was not correlated with the performance ($r = 0.01$, $p = 0.80$). Given that the non-fallers did not decrease their speed, their heart rate increased significantly more than in the fallers' group (0.56 vs. 0.29, respectively, $F = 14$, $p = 0.002$). When we indexed the heart rate by the speed, we saw that in the fallers' group, the cardiac cost increased significantly at the 26th km, as the speed did (**Figure 3**), and hence, the cardiac drift was then mainly associated with the speed decrease. Indeed, the cardiac cost increase between these first and last 4-km sections was highly correlated with marathon performance ($r = 0.18$, $p = 0.002$). Furthermore, we showed that marathon performance was correlated with the amplitude of the cardiac drift but not with that of the increase in the heart rate ($r = 0.01$, $p = 0.80$).

The Relationship Between Heart Rate and Cardiac Cost Time Course and the Marathon Performance

The increase in cardiac cost (cardiac drift) between the first and last 4-km parts of the marathon was highly correlated with performance ($r = 0.28$, $p = 0.0018$) (**Figure 5**). Indeed, this higher speed decrease (10% vs. 2%, $F = 54$, $p < 0.0001$) in the fallers' group between the first and last 4-km parts of the marathon was highly inversely correlated with performance ($r = -0.19$, $p = 0.001$) (**Figure 6**).

The Coefficients of Variation of Speed, Heart Rate, and Cardiac Cost Are High Markers of Difference of Running Strategy and Performance

The coefficient of speed variation (CV) was highly different between the two groups (5.0 vs. 2.9%, $F = 36$, $p < 0.0001$) and was highly correlated with performance ($r = 0.30$, $p < 0.0001$) (**Figure 7**). The coefficient of heart rate variation was also significantly higher in fallers (CV and $F = p$) than non-fallers but was not correlated with performance ($r = 0.03$, $p = 0.63$). However, the cardiac cost's CV was significantly higher in the fallers' than in the non-fallers' group ($F = 36$, $p < 0.0001$) and correlated with performance ($r = 0.25$, $p < 0.0001$) (**Figure 8**).

DISCUSSION

We also remarked that, in the fallers' group, the heart rate started to increase already at the half marathon, before the high-speed drop, which only appeared at the 26th km (**Figure 3**). This means that this significant sensitive HR drift was probably one cause of the exercise intensity speed downregulation. The heart rate started to increase already at the half marathon, but the cardiac drift, i.e., the cardiac cost increase, significantly appeared at the 26th km following the speed dynamics (**Figure 3**). This means that the heart rate increases before the speed decrease, which could be a signal of cardiac strain for pacing (Tyler, 2019, p. 20).

The main finding of the present study was that the racing strategy affects the sub-elite marathoner's cardiac drift and performance.

Other important results have been achieved: (i) two groups of marathon runners can be distinguished according to their speed distribution and time series: the group of runners who have a drop in speed (77%) (called "speed fallers") and those (group 2) who maintained their speed at the finish; (ii) speed fallers had a significantly higher cardiac drift and lower performance than non-fallers; (iii) cardiac drift was correlated with performance. Therefore, this study showed that the running strategy influences both performance and cardiac drift that covaries.

Most of the marathoners hit the marathon wall.

While the minority of these recreational (around 3 h) runners were able to sustain a constant speed with a low coefficient of variation until arrival, the great majority of them (3/4) "hit the marathon wall" at the 26th km. Indeed, in accordance with prior studies (Alvarez-Ramirez and Rodriguez, 2006;

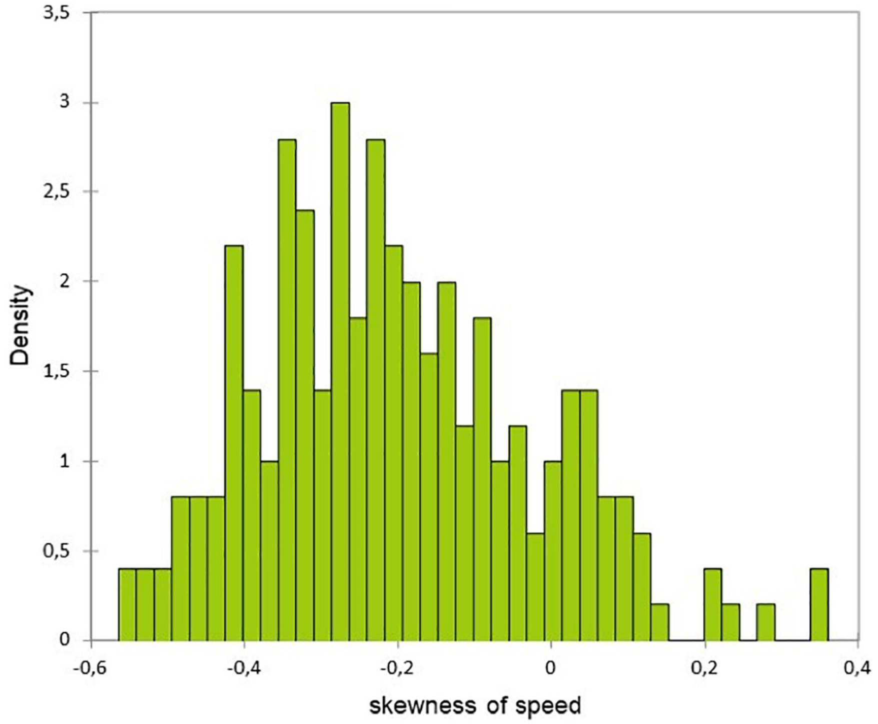

FIGURE 1 | Distribution of Pearson's asymmetry of speed for the faller group.

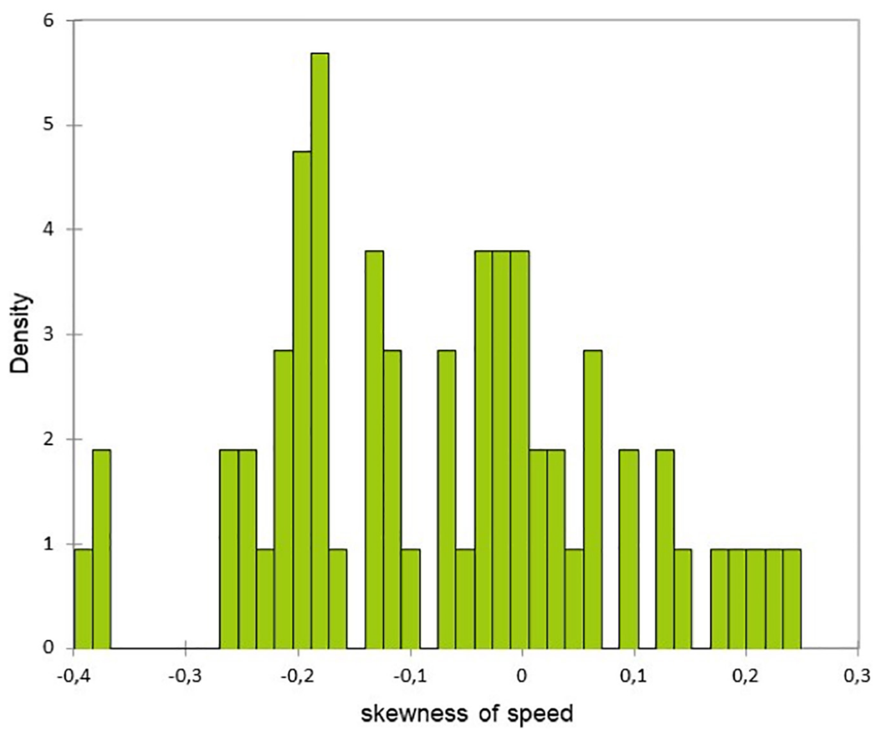

FIGURE 2 | Distribution of Pearson's asymmetry of speed for the non-faller group.

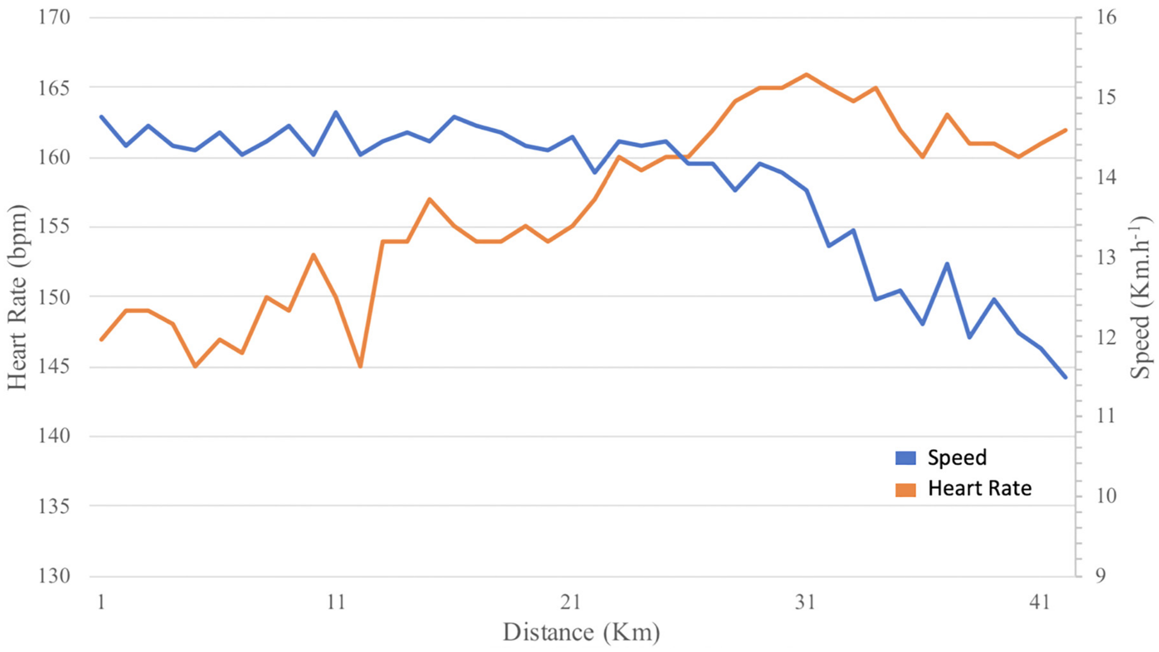

FIGURE 3 | Plot of average change of state speed (blue) (km h^{-1}) and heart rate (orange) (bpm) on the marathon.

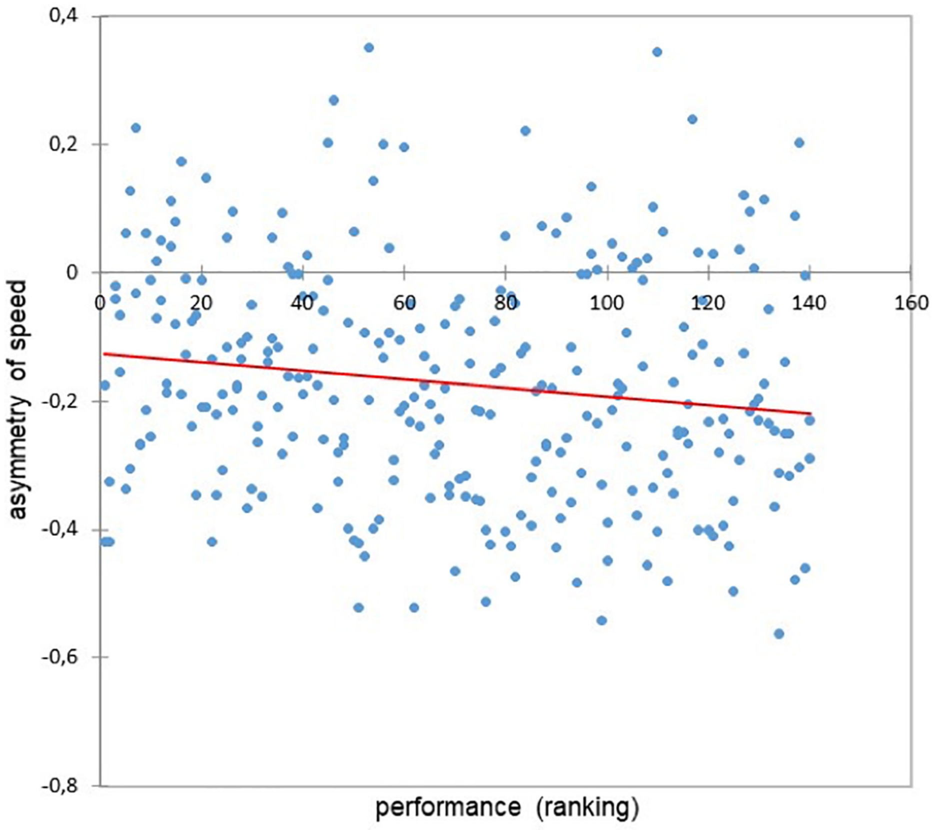

FIGURE 4 | Relationship between performance and the asymmetry of speed ($r = -0.15$, $p = 0.018$).

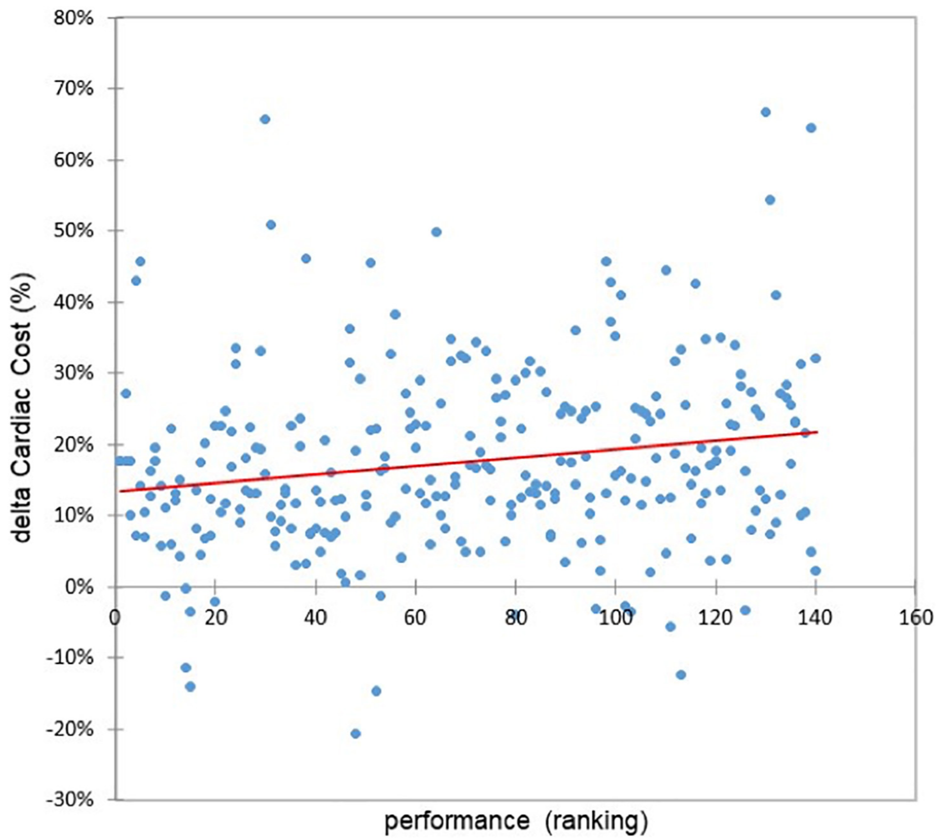

FIGURE 5 | Relationship between delta cardiac cost (%) and the performance ($r = 0.28$, $p = 0.0018$).

Billat V.L. et al., 2009; Wesfreid and Billat, 2009; Haney and Mercer, 2011; Renfree and St Clair Gibson, 2013), a change of the fractal scaling of the heart rate and speed in a marathon race has been detected, showing evidence of the significant effect of fatigue induced by such long and intensive exercise on the heart rate and speed variability (Wesfreid and Billat, 2009; Billat et al., 2012). Indeed, marathon elicits a high fraction of VO2max (70–90%), which has been estimated to be between 70 and 90% of VO2max according to the running economy at the marathon average speed (Costill, 1972; Sjödin and Svedenhag, 1985; Billat et al., 2001). This zone corresponds to subcritical speed, the one at which VO2 is not any more at a steady state and shows a drift until VO2max. Critical speed has been shown to be better correlated with marathon performance than VO2max or the ventilatory threshold (Billat et al., 1995; Florence and Weir, 1997). However, when real measures are performed during the real marathon race as did the excellent experiment of Maron et al. (1976), we can see that 100% of VO2max was elicited at the 26th km in one of the two good level marathoners (2 h30 min). Indeed, the speed is not constant and even more the oxygen cost of running per kilometer. This is due to the recruitment of supplementary fiber type II for compensating the muscular fatigue and strength responsible for losing elastic energy recoiling during the race (Gazeau et al., 1997; Slawinski and Billat, 2004; Rapoport, 2010). One has, indeed, considered that the ultimate limit to marathon performance might be dictated by the limits of running economy and a recruitment of the running musculature with a pattern that minimizes fatigue, possibly by spreading the work over many neurons (Coyle, 2007).

Running strategy must be integrated as a factor of marathon performance.

Indeed, marathon performance is explained not only by energetic factors but also by the running strategy that deserves more and more attention (Erdmann and Lipinska, 2013; Santos-Lozano et al., 2014; Renfree and Casado, 2018). The majority of marathoners, who were already experimented on, considered their performance given that our population average speed was around 3 h00 min, which was considered to be the Grail by marathon runners who wish to qualify for the historic Boston Marathon. We can also notice that this lack of stability of the running speed makes it more difficult to estimate the final time when speed beyond the half marathon is not available. However, the Massachusetts Institute of Technology mathematicians proposed a model to estimate the final time after the 2013 attack that prevented 6,000 marathon runners from reaching the finish line (Hammerling et al., 2014). A computational study has demonstrated that it was possible to predict the distance at which runners will exhaust their glycogen stores as a function of running intensity (Rapoport, 2010). They integrated several physiological variables including the muscle mass distribution, liver and muscle

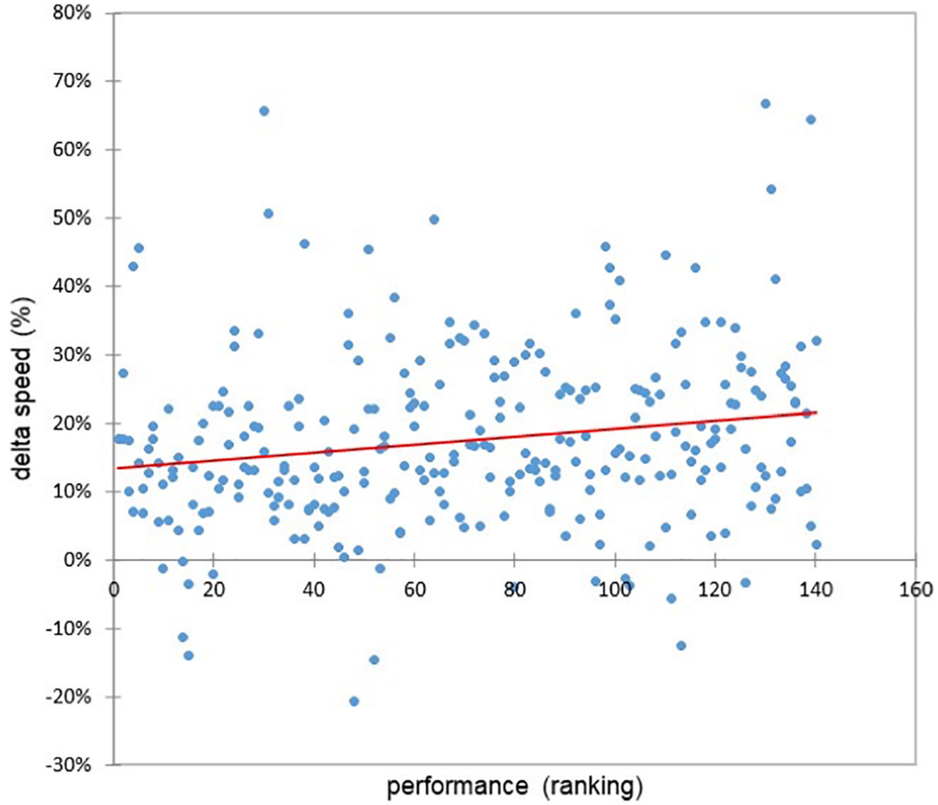

FIGURE 6 | Relationship between delta speed (%) and the performance ($r = -0.19$, $p = 0.001$).

glycogen densities, and running speed as a fraction of aerobic capacity, i.e., the velocity at VO2max (Rapoport, 2010). They already have (2010) in mind shedding the physiological principle light on important standards in marathon that until now have remained empirically defined the qualifying times for Boston Marathon (Rapoport, 2010).

However, beyond performance prediction based on such anaerobic threshold (Rhodes and McKenzie, 1984; Loftin et al., 2007), critical speed (Florence and Weir, 1997), and VO2max (Billat et al., 2001) measurements, the fundamental question to solve now is how to give a better understanding of the rationale of speed control during the race (Coyle, 2007).

The necessity to have an interdisciplinary approach of the complexity of marathon pacing strategy.

This can be achieved thanks to an interdisciplinary approach crossing disciplining as psychology, neuroscience, physiology, physics, and mathematics allowing one to think the speed, heart rate, and other signals registered during the marathon in an entropy model control as a measure for non-stationary signals (Bollt et al., 2009).

Mathematics and statistics already allowed us to better describe the kinematics of running tactics (Erdmann and Lipinska, 2013). Erdmann and Lipińska (2006) investigated marathon running at the highest competitive level by examining the velocity distribution during marathon running. To illustrate the difficulty of targeting an appropriate speed on the first 5 km, they gave us an example: a female runner (in Berlin Marathon 2002) who attempted to break the world record running the first 5 km at a mean velocity higher than 5.00 m/s. This was too fast since it gradually decreased in the course of the race, resulting in a lower velocity during the second part of the run than during the first, as observed in 77% of our 280 recreational marathon runners.

This shows that the choice of the right speed on the first kilometer is not reserved to recreational runners, but is also a problematic and probably the major limiting factor now for sub-2 h marathon record. Even if, in terms of mechanical and steering approaches' point of view, a long-distance run should be performed at a steady velocity (Foster et al., 1994; Maroński, 1996; Rapoport, 2010), stated that all deviations from the steady velocity should be within ± 2%, which was not the case even for the best performance. We can underline that it was the case for our 65 runners in the non-faller group who had a speed coefficient of variation of 2.9%, which was much lower than the coefficient of speed variation than the fallers (5%) and much lower than other less performer recreational runners (4 h).

It may also be possible to use the Talk Test (Foster et al., 2009) for calibrating the marathon speed at the condition to use the first stage before the one at which the runner cannot anymore declare to be able to "speak comfortably" during a Balke (incremental test). However, the Talk Test must be applied on real long event given that the heart rate response

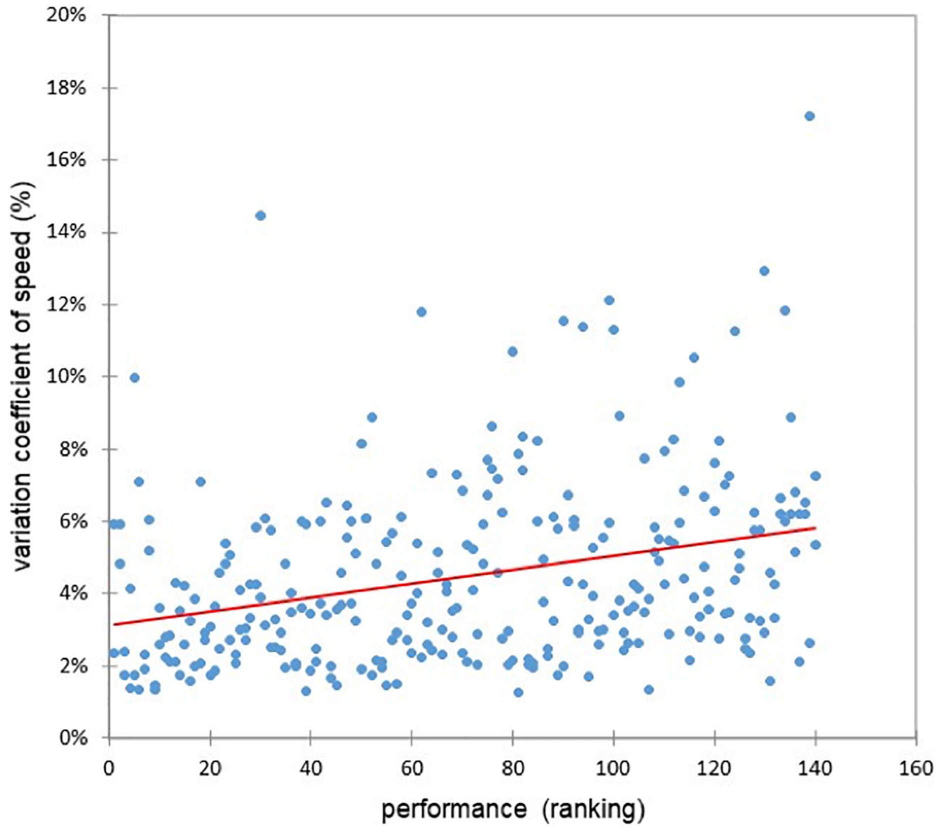

FIGURE 7 | Relationship between the coefficient of variation of speed and the performance ($r = 0.30$, $p < 0.0001$).

during long endurance event may be systematically higher (e.g., cardiovascular drift) than predicted from the Talk Test incremental exercise (Foster et al., 2008). That is why, by precaution, the speed at the last comfortable speaking one is recommended if the runner wants to use an incremental test such as the University Montréal Track Test (UMTT) currently used by marathoners for estimating their VO2max and then their marathon pace (Léger and Boucher, 1980).

We proposed, and another research group validated, a new field test based on a self-pace approach for estimating the ventilatory and VO2max speed. Indeed, if we want to reconnect the runner with himself, the goal of training would now be to self-pace-train and then run the race only with the rate of perception of exhaustion, calibrated prior by a self-pace test as the Rabit test recently validated, giving a biofeedback of the fractional utilization of VO2max for a given RPE value. This feeling of integrated approach of pacing allows avoiding the question of the cardiac drift for a given speed. Before reaching this faculty, we can suggest to use card cost, which has been reported to be maintained during the marathon in both groups. Indeed, such biofeedback could be recommended by mobile phone application and could be implemented in the already sophisticated cardio-frequency meter of GPS watches widely adopted by runners who use it only for controlling their schedule running times during the marathon.

Indeed, the increase in the heart rate, which appears in both groups at half marathon (5 km before the sharp speed drop in the fallers' group), probably induces a higher cardiovascular strain resulting in a higher rating of perceived exertion. Therefore, downregulation in speed occurs as a result of increased perceived exertion, which, in turn, is a product of thermal comfort/discomfort and cardiovascular strain due to the link between ratings of perceived exertion and cardiovascular strain (Tyler, 2019) as in marathon (Cheuvront and Haymes, 2001; Billat et al., 2012; Faude and Donath, 2016). This downregulation allowing heart rate increase while the speed is maintained could be a factor of marathon performance, and the knowledge of its threshold increase tolerance for one runner could be a major indicator of the "sensory tolerance" limit proposed as a hypothetical construct determining exercise performance by Hureau et al. (2016) whichever the cause (Thompson, 2006).

Thus, to address the question of cardiac drift in marathon, which is very sensitive to running strategy, we recommend to utilize the cardiac cost, which takes into account the running speed. In conclusion, this study suggests that the amatory runners should not control their speed but rather choose a self-pace strategy keeping the GPS for biofeedback after the race. For instance, small speed variation in a range defined for each runner according to his energetics profile as the speed reserve between the maximal speed and the critical speed

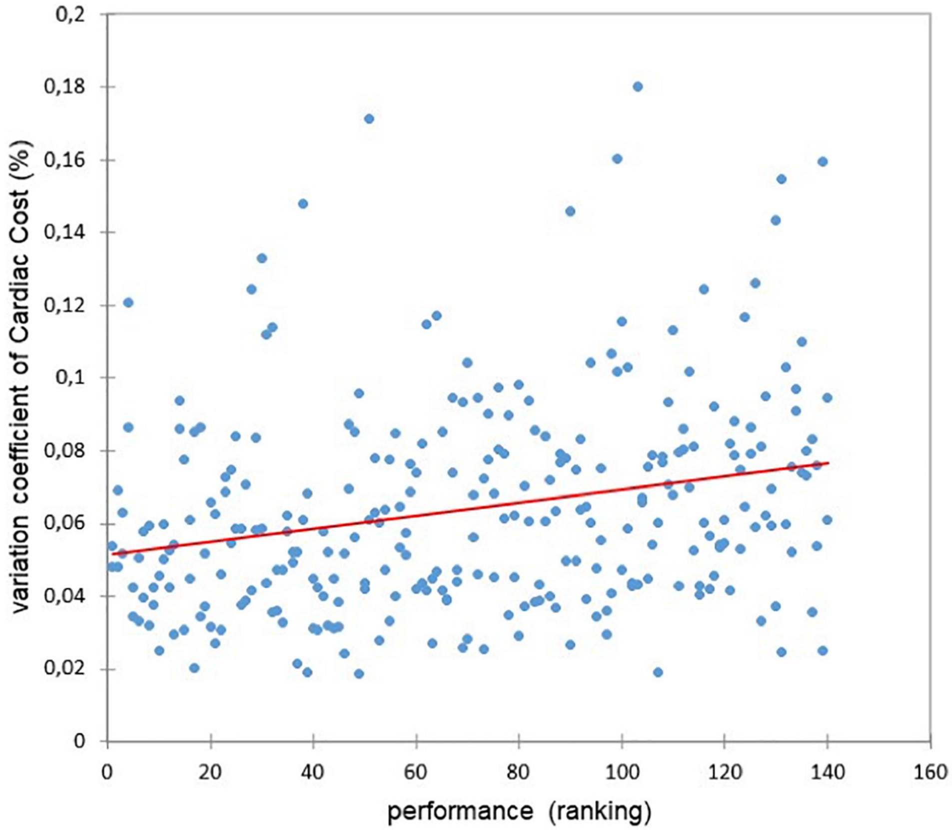

FIGURE 8 | Relationship between the coefficient of variation of cardiac cost and the performance ($r = 0.25$, $p < 0.0001$).

(Fukuba and Whipp, 1999; Renoux et al., 1999) could be used to allow a kind of intermittent exercise modality, which has been reported to prevent cardiovascular drift (Colakoglu et al., 2018). The cardiovascular drift has been reported to be highly correlated with the reduced maximal oxygen (Wingo et al., 2005). Therefore, and it may be then possible, that, as during the Mont-Blanc ascent where the alpinists decreased their accessional speed in such a way that they maintained their fractional use of VO2max equal to 75% (Billat et al., 2010), the marathoners adjust their pace for staying at the same fractional utilization of VO2max even after the increase in the cardiac drift. Indeed, the heart rate increase for a given speed represents an increase in the double product, which is an index of the myocardial VO2 (MVO2) increase (Mudge et al., 1979). This means that the respective skeletal and cardiac muscle VO2 could be changed and given that, in addition, the global VO2max during the race has been shown to be limited by the loss of power (Billat et al., 2013), this could force the runner to highly decrease his or her speed during the marathon (Billat et al., 2012).

Limitation of This Study

However, a covariance between marathon performance and cardiac drift is not a causality since this was a cross-sectional and not a longitudinal study. Further analysis using data from the same runner to compare a successful marathon with an unsuccessful one will allow further knowledge of the prescription on the optimal running strategy based on the runner's cardiac drift. The main limitations of this study concern the inability to control the physical conditions of the race (slope of the land, wind speed, etc.) and of the subjects (integration, supplementation, hydration, caffeine, cardiotonic substances, etc.).

CONCLUSION

The increasing volume of data split available on running community websites allowed a recent study to investigate a marathon running pacing strategy for various levels of performance. It is our scientific responsibility to use this database in addition to continuing to apply experimental protocols to better understand personal runners' optimal way, especially on such popular and intensive exercises such as marathon. Here we show that the use of cardiac cost as an objective tool for targeting marathon pace avoiding or at least minimizing hitting the wall could be the first step for learning how to self-pace long-distance run, which gathers almost all the metabolic and psychical limiting factors defining a sensory tolerance limit.

The perspective scope of future studies would be to include the cardiac cost in the analysis of the ability of runners to accurately maintain their pre-race target time and compare pacing and perceived exertion (RPE) of different groups of athletes according to how close they were to their predicted time as recently proposed by Piacentini et al. (2019).

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

The study was performed in accordance with the Polish law and was evaluated by the Bioethical Committee at the Jerzy Kukuczka Academy of Physical Education in Katowice, which granted official approval for the research (KB/47/17). The study was conducted in conformity with the Declaration of Helsinki. As online surveys or questionnaires do not require the completion of a separate participant information sheet or consent form, completion of the survey was deemed to constitute informed consent.

AUTHOR CONTRIBUTIONS

VB and MC contributed and conceived the study. VB, MC, and J-RP designed the study and drafted the manuscript. MC collected, analyzed, and interpreted the data. All authors revised the manuscript and approved the final version.

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Longitudinal Analysis of Marathon Runners' Psychological State and Its Relationship With Running Speed at Ventilatory Thresholds

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Psychological variables such as motivation, self-efficacy, and anxiety have been widely studied in marathon runners, usually within the framework of Bandura's theory of self-efficacy. It is also assumed a link between self-perceived fitness and physiological performance parameters such as speed at ventilatory thresholds and running economy. The purpose of this paper is to describe longitudinal trends of self-perceptions and examine their link to physiological performance parameters over time. Sixteen healthy recreational marathoners (8 males and 8 females), aged $M = 37.6$ ($SD = 3.9$) who were about to participate in a major marathon agreed to participate. After 3 months of regular training and competition in shorter distances, all participants trained during a 16-week macrocycle under the supervision of the same coaching staff. At 4-week intervals, the participants responded five times the Podium questionnaire, measuring self-perceived psychological state relative to the upcoming race, and performed five exercise performance parameters tests. Linear mixed-effects models were used to analyze the trends and associations. In general, Podium questionnaire scores were within the standard range, with the lowest values at the beginning and the highest values closer to race day. Although only perceived fitness ($p < 0.001$, Cohen's $f^2 = 1.19$) and somatic anxiety ($p < 0.001$, $f^2 = 0.32$) showed large effect sizes for the whole longitudinal period, other partial increases were found between time points. All physiological performance parameters presented significant improvements over time (Aerobic Threshold speed, $p < 0.001$, $f^2 = 1.04$; Anaerobic Threshold speed, $p < 0.001$, $f^2 = 0.498$; Running Economy in VO_2, $p < 0.001$, $f^2 = 0.349$; Running Economy in energy, $p = 0.024$, $f^2 = 0.197$). The analysis of changes between consecutive time points revealed that improving perceived physical condition predicted improving self-efficacy ($p < 0.001$, $f^2 = 1.33$), and improvements in motivation were predicted by improvements in either self-efficacy ($p < 0.001$, $f^2 = 0.36$) or perceived physical condition ($p = 0.003$, $f^2 = 0.17$). Improvements in perceived fitness, self-efficacy and motivation were associated with small effect-size improvements (decreases) in anxiety. None of the physiological performance parameters was shown to predict changes in psychological variables, although their general trends over time correlated. The results have practical implications for sport psychologists and running coaches, supporting the need for integrated working.

Keywords: marathon, running, self-efficacy, motivation, anxiety, fitness, ventilatory thresholds, running economy

INTRODUCTION

The worldwide participation rate in recreational running peaked in 2016 and slightly declined since then (Andersen, 2019). Nevertheless, the number of worldwide marathon finishers was estimated to be 1,298,725 in 2018 (Andersen and Nikolova, 2019). Consequently, there has also been a growing interest in running events from the applied field of sport psychology (e.g., Meijen et al., 2017; Larumbe-Zabala et al., 2019).

Much of the sport physiology literature extensively descried the physiological variables related to marathon performance (Joyner, 1991, 2017). Among other factors, finishing time is particularly associated to Aerobic Threshold (AeT) and Anaerobic Threshold (AnT) speeds. Running Economy (RE) has also been identified as a determinant of better performance in long distance running. Consequently, it is expected from a marathon-specific training program to pursue the athlete's optimal AeT and AnT speeds, and RE.

Performing well in shorter distances is also a strong predictor of physical condition and finishing times in longer distances (i.e., marathon). However, typically all training programs for the marathon distance limit the number of competitions the runners are advised to run during the season (Cardona et al., 2019). The reasons include controlling the effects of fatigue from the competition, and the need of concentrating the training program specifically on the marathon distance. The competition-induced fatigue can produce damaging effects, which explains why marathon runners do not cover the full distance during the preparation. Even though the aforementioned physiological variables interplay to determine running performance (finishing time), only tracking physiological variables over time would really reflect the fitness of a runner during the preparation (Jones, 2006).

From a psychological perspective, Bandura's (1977) theory of self-efficacy has been very extensively used for investigating the influence of psychological constructs on sport and motor performance. This author defined self-efficacy as people's beliefs about their capabilities to produce effects. It is assumed that high physical self-efficacy, together with other physical performance indicators, is a good predictor of finishing time and race performance of runners (e.g., Okwumabua, 1985; Gayton et al., 1986; LaGuardia and Labbé, 1993).

According to Bandura's theory, expectations of personal efficacy are based on four sources of information: performance accomplishments, vicarious experience, verbal persuasion, and emotional arousal (Bandura, 1977, p. 195). As a consequence, athletes' perceived improvement in physiological performance and running technique, as well as other factors such as experience, tactical skills, and self-regulation ability should be linked to higher perception of self-efficacy. Bandura (1997) made a clear distinction between self-efficacy and confidence. The former refers to the belief in one's agentive capabilities that one can produce given levels of attainment, while confidence is a colloquial term.

Beliefs of self-efficacy also play a key role in the self-regulation of motivation (Bandura, 1994). Anxiety has been shown to be inversely correlated with self-efficacy (e.g., LaGuardia and Labbé, 1993), while positive correlations have been found between motivation and self-efficacy (e.g., Martin and Gill, 1995). In agreement with Bandura's (1977) self-efficacy theory, qualitative studies have shown that high self-efficacy and motivation, and low anxiety characterize an optimal psychological state in marathon runners (Larumbe Zabala et al., 2009). However, both the normal and the optimal quantitative levels in the above-mentioned psychological variables to compete in a marathon still remain unexplored.

The majority of the studies measuring psychological variables are assessed cross-sectionally, as close as possible to the competition day. However, the theory often includes cause-effect relationships that are developed in the long-term. Despite psychological practice also demonstrates that psychological processes develop over time, and involve an intricate system of constructs, there is still lack of studies using longitudinal designs. As an example, a quick search on PsycInfo database between June 2009 and July 2019 for the term "sport psychology" yielded 5,621 academic publications. Among these items, only 245 contained the word "longitudinal" in any search field. Despite this information does not properly constitute a systematic review on the topic, one can assume that among a good number of the recent sport psychology-related studies only approximately 4.5% potentially involved longitudinal designs.

Consequently, the first aim of this study is to examine the longitudinal patterns of the psychological state of a group of standard recreational marathon runners, over the last 16-week macrocycle prior to competing in a race. If changes in motivation, self-efficacy, perception of physical fitness, or anxiety are detected, we hypothesize that anxiety will correlate negatively with the other psychological variables, based on inverse correlations shown in previous studies (Larumbe et al., 2015). Additionally, we also expect a high and positive correlation among motivation, self-efficacy, and perception of physical fitness according to Bandura's theory of self-efficacy.

The second aim is to investigate to what extent changes in physiological measurements are positively correlated with changes in perceived physical fitness. More specifically, we will use indicators of physiological performance in marathon such as RE tests, and AeT and AnT speed tests as predictors of self-perceived physical condition. Our hypothesis is that increases in perceived physical fitness will positively correlate with improvements in the physiological tests. Since self-efficacy is expected to improve in part due to improving physical fitness, we also expect to find a high correlation between self-efficacy and perceived physical fitness, and implicitly also with the physiological variables.

MATERIALS AND METHODS

Participants

Sixteen recreational runners, 8 males and 8 females, according to the current gender distribution of marathon runners described by Andersen (2019), aged $M = 37.6$ ($SD = 3.9$) who were to compete in a marathon and shared the same training group (location, program, and coaches) voluntarily consented to participate in this study. In order to ensure a homogenous sample of healthy recreational runners, inclusion criteria were: (a) to have been training for endurance running events at least during 1.5 years; (b) to show average physiological performance levels compared to recreational marathon runners; and (c) to show an average relative performance compared to marathon race winners. Exclusion criteria were: (a) to reveal any kind of coronary disorder via a stress test; (b) to miss more than three consecutive sessions by cause of an injury or disease; (c) to accomplish less than 90% of the training sessions specified in the program.

Sample Size, Power, and Precision

Using G-Power software, a minimum sample size of 13 runners was calculated assuming a 0.05 significance level, a 0.80 power, and a correlation $\geq$0.70 among five repeated measures in a one-way ANOVA model, in order to detect moderate effect sizes (Cohen's $f \geq 0.25$). In order to prevent possible attrition, we increased the required sample size by 23% to 16 participants, and all of them eventually completed the entire study.

Measures

Psychological Variables

The participants were asked to answer the Podium questionnaire (Larumbe et al., 2015). This questionnaire is composed of 20 items that measure the following scales of self-perceived psychological state relative to the upcoming race: motivation, self-efficacy, perceived fitness, perceived social support, somatic anxiety, and cognitive anxiety. The items are answered in visual analog scale (VAS) format of response, composed of two opposite words at the ends of a 100 mm line. The response is interpreted measuring the distance of the mark on each line with a ruler, and taking it as the score of each particular item (cf. Aitken, 1969). The reversed items were measured starting from the opposite end. The items were averaged within each of the six scales, to obtain final scores in a 0–100 range. Although the authors of Podium questionnaire used the term self-confidence to word the construct self-efficacy, the latter will be used in order to avoid confusion, as it better reflects the content of the factor.

Physiological Performance Assessments

A running performance graded test until voluntary exhaustion was conducted in order to identify Aerobic (AeT speed) and Anaerobic Threshold Speeds (AnT speed) and other descriptive variables such as VO_{2max} and Maximal Aerobic Speed (MAS). These procedures were applied under lab conditions and have been extensively described elsewhere (Muñoz et al., 2014). A breath-by-breath system was used for gas exchange data collection (Med Graphics PFX Ultima, Medical Graphics Corporation, St Paul, MN, United States). Heart activity was continuously monitored by the integrated ECG system (CardioPerfect PRO, Welch Allyn Cardio Control BV, Delft, Netherlands) and a Heart Rate (HR) monitor (Polar RC3 GPS, Polar Electro Oy, Kempele, Finland). This graded test was conducted only during the first visit to the lab. As it has been previously reported, thresholds-associated HR determined during laboratory testing remains stable over the season despite significant improvements in the workload eliciting both thresholds (Lucía et al., 2000).

At first visit, a RE assessment was conducted through constant load treadmill bout of 15 min duration at a 1% grade and a selected speed according to the individual's expected marathon pace (Jones and Doust, 1996). Once this speed was identified and used for the first assessment, it was kept constant through the remaining visits to the lab. Since it has been shown that RE calculations might be different in case of including Respiratory Quotient or considering O_2 only (Fletcher et al., 2009), RE was calculated both as oxygen cost in mL/kg/km (REmL) and as energy cost in kcal/kg/km (REkcal) as described elsewhere (Fletcher et al., 2009). All these tests were conducted under the supervision of a sports medicine physician and the coaches.

A field test was regularly conducted on a 400 m synthetic track. Two 20 min bouts, interspersed by a 5 min passive rest, were conducted keeping the HR zones associated AeT and AnT speeds, respectively. Considering the HR kinetics and the potential HR drift, runners were instructed to reach the target HR not before the 3rd minute. Lap by lap (400 m), self-recordings were averaged to estimate updated field AeT and AnT speeds.

Training Program

All sixteen participants were trained systematically, following a very similar training program with minor individual adaptations, in the same city, directly supervised by the same coaches, in order to compete in a major marathon on the same date. Before the specific marathon preparation, these runners followed 3–6 months of regular training focused on 10k and 21k competition distances.

A 16-weeks, specific marathon training macrocycle was conducted before the race. This program was divided in four mesocycles with 4 weeks each. The mesocycles had a 3:1 structure, so that the higher training load was promoted during the initial

3 weeks, followed by a 1-week reduced training load in order to facilitate recovery and supercompensation. Peak running training volume was set at week 11 while the longest distance run was conducted at the end of week 13 (21 days before the marathon race). This program structure was the same for all runners, except for minor adaptations of the total training volume performed on three separate subgroups (n = 5, 6, and 5) of runners according to their performance level (i.e., peak weekly training volume was between 80 and 100 km).

Research Design and Procedures

The study followed a single-group longitudinal design, with five repeated measures along a 16-week macrocycle. Ethical approval was sought and granted by the European University of Madrid, Spain (CIPI/035/15). Participants were asked to sign an informed consent form for their enrollment in the study, and had to perform the study assessments (Podium questionnaire, lab RE and field AeT/AnT speeds assessments) on five occasions: at 116, 80, 60, 32, and 11 days prior to competing in the marathon. Each visit included a psychological test, field-test measurements, RE lab assessments and physiological tests as described above. All tests were conducted during the same approximate day time (field tests between 5:00 and 6:30 am; lab tests at the same time for each athlete) and under similar weather conditions (field tests under no rain, no wind, temperature 23–25°C, humidity 70–75%; lab tests under 21°C and 70% humidity), preceded by a 15 min easy jog 1–15 bpm below the ventilatory threshold, followed by a dynamic stretching workout.

Statistical Analysis

Relative performance was calculated to compare men and women among the sample of marathon runners. For this purpose, each runner's personal best time was divided by the average of the best times of the 10 fastest performers in the world, including only one performance per individual (cf. Deaner et al., 2011), which was 2:03:03 for males and 2:17:44 for females as of July 18, 2019 (International Association of Athletics Federations, 2019). Then these ratios were converted into percentages. Sample characteristics were summarized using mean (standard deviation) or median (interquartile range, IQR) for continuous variables and frequency (percentage) for categorical variables. Shapiro-Wilk test and histograms were used to assess normality of the distributions. To check differences between sexes, two-tailed Student's t-test or Wilcoxon's rank sum test were used as appropriate.

Podium questionnaire variables (motivation, self-efficacy, perceived fitness, social support, somatic anxiety, and cognitive anxiety) and running physiology variables (AeT speed, AnT speed, REmL, and REkcal) were summarized, plotted and overlaid using adjusted means and 95% confidence intervals (CI) after running linear mixed effects models, where time and participants were set as the fixed and random effects of the models respectively. Statistical significance of changes over time for all the dependent variables was assessed using (a) contrasts between baseline and subsequent time points, and (b) linear mixed effects models on the relative change from any given time point to the next, adjusted for participant random effects. Percent change for all above-mentioned variables was calculated as: $(\text{Measure}_n - \text{Measure}_{n-1})/\text{Measure}_{n-1} \times 100$. Sidak correction was used to prevent multiple comparison error when necessary.

The association of physiological (AeT speed, AnT speed, REmL, and REkcal) with psychological variables (perceived physical fitness and self-efficacy from the questionnaire) over time was assessed using linear mixed effects models on raw values, and on percent change in both criterion and predictor variables adjusted for time as fixed effect and participant as random effect.

Residual maximum likelihood (REML) method was used for fitting all the models. In order to check the model assumptions, link tests and partial regression plots were used to assess linear model specification; independence, normality, and homoscedasticity of the residuals were also assessed. Standardized effect sizes were calculated for the overall regression models as Cohen's f^2 (cf. Selya et al., 2012) and for simple effects as Cohen's d from mixed models contrasts and standard errors, and interpreted according to the standard values: d = 0.20 and f^2 = 0.02 for small, d = 0.50 and f^2 = 0.15 for medium, and d = 0.80 and f^2 = 0.35 for large (Cohen, 1992). All analyses were performed using Stata 15.1 (StataCorp, College Station, TX, United States).

RESULTS

Sample Description

For reasons not related to the research protocol, three participants missed one administration of the Podium questionnaire assessment (two did not complete the 4th and one did not complete the 5th time measure).

Otherwise, all the data were complete. Sample characteristics presented in **Table 1** show that except for their statistically significant differences in height (p = 0.001), weight (p = 0.003), and BMI (p = 0.001), males and females in the sample were otherwise equivalent in athletic performance. Moreover, the two sexes showed almost identical relative marathon performance level around 208% the average of the top 10 marathon runners for each sex. Personal times for both groups were better than typical recreational endurance athletes, since the world's average finish time of a marathon in 2017 was 4:15:14 for men and 4:47:15 for women (Hanson et al., 2019). No injury occurred during the training or the competition. All runners completed the training according to inclusion criteria and declared to have reached their performance goal in competition. Many of them reached (or were closed to) their personal best time over the distance.

Psychological Variables

The adjusted means and 95% CI for each Podium scale over time are shown in **Figure 1**. Exploratory data analysis showed that the trends seen in the majority of the variables agreed with the reference values proposed by the questionnaire authors (Larumbe et al., 2015). In general, the lowest averages were found at the beginning of the study, and the peak average values were found at the end, except for cognitive anxiety (lowest value at time point 2) and motivation (lowest value at time

TABLE 1 | Sample characteristics.

	All	Women	Men	
	Mean (SD)	Mean (SD)	Mean (SD)	*p*
Age (year)	36.9 (4.7)	36.3 (5.6)	37.6 (3.9)	0.576
Weight (kg)	66.8 (14.9)	55.1 (4.5)	78.5 (11.8)	0.001
Height (m)	1.67 (0.1)	1.60 (0.06)	1.73 (0.09)	0.003
BMI (kg/m^2)	23.8 (3.0)	21.5 (1.8)	26.0 (2.2)	0.001
Endurance training experience (years), median (IQR)	3 (2–4)	4 (2.5–5)	2.5 (2–3.5)	0.257
Personal best marathon time (h, min)	04 h 13 min (38 min)	04 h 17 min (44 min)	04 h 08 min (32 min)	0.668
Relative Marathon Performance level (%)	208.3 (11.8)	208.4 (15.3)	208.1 (21.5)	0.990
HR (bpm) at AeT (Zone 2)	158 (10)	157 (11)	159 (9)	0.716
HR (bpm) at AnT (Zone 4)	176 (9)	177 (9)	175 (9)	0.550
HR_{max} (bpm)	184 (9)	184 (7)	185 (11)	0.810
VO_{2max} (mL/kg/min)	48.0 (6.4)	45.2 (4.3)	50.8 (7.1)	0.077
MAS (km/h)	14.2 (1.3)	13.6 (1.0)	14.7 (1.4)	0.107
RE testing velocity (% mean marathon speed)	104 (7)	105 (9)	104 (6)	0.618

BMI = body mass index; Relative Marathon Performance level = runner's personal best compared to the top 10 best marathon runners in the world; HR = heart rate; bpm: beats per minute; AeT = Aerobic Threshold, determined by Ventilatory Threshold 1; AnT = Anaerobic Threshold, determined by Ventilatory Threshold 2; MAS = Maximal Aerobic Speed, determined by Velocity at VO_{2max}; RE = Running Economy. p-values were calculated using two-tailed Student's t-test for independent samples; years of experience were compared using Wilcoxon rank-sum test.

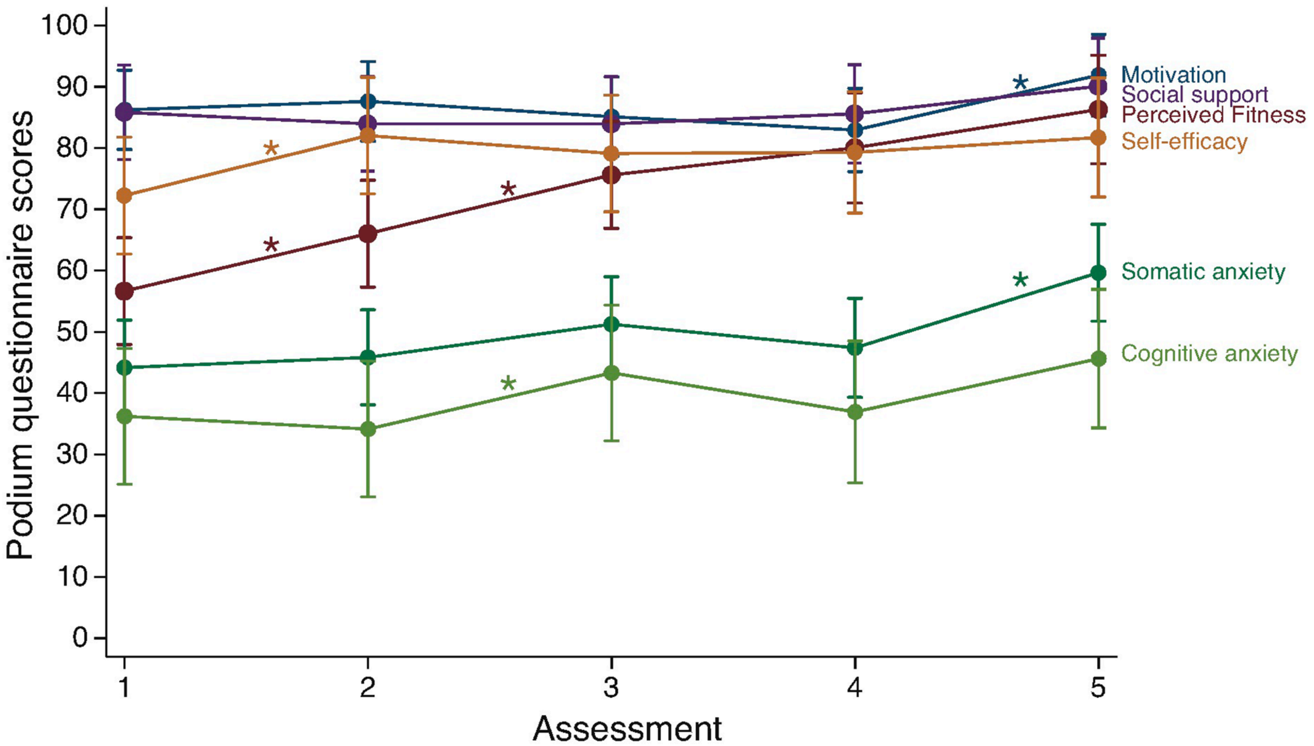

FIGURE 1 | Psychological variables assessed five times over 16 weeks. Assessments were performed at 116, 88, 60, 32, and 11 days prior to competing in the marathon. Data represent mean and 95% confidence intervals adjusted for participant's random effects. Asterisks represent statistically significant changes ($p < 0.05$).

point 4). Study means over time and reference IQR values for the questionnaire ranged: Perceived Physical Fitness, 56.7–86.3 (reference IQR: 57–80); Self-efficacy: 72.3–81.8 (reference IQR: 63–83); Somatic Anxiety, 44.2–59.7 (reference IQR: 30–57); Cognitive Anxiety, 34.2–45.6 (reference IQR: 27, 50); Motivation, 82.9–91.9 (reference IQR: 70–86); Social support, 83.9–90 (reference IQR: 70–86). Spaghetti plots presenting individual data are included as **Supplementary Figure 1**.

Change Over Time

Only perceived fitness ($p < 0.001, f^2 = 1.19$) and somatic anxiety ($p = 0.001, f^2 = 0.32$) showed statistically significant increases over time associated to large effect sizes. The cumulated effect of time had an initial moderate effect size on perceived fitness (baseline to 2nd measure: Cohen's $d = 0.59$), and statistically significant large or very large effects until the end of the macrocycle (baseline to 3rd, 4th, and 5th measures: $d = 1.19$, 1.51, and 1.89, respectively, $p < 0.001$ for all). A large effect size compared to baseline was also observed at the end of the study in somatic anxiety (baseline to 5th measure: $d = 0.99$, $p < 0.001$), but only a moderate effect was found at the 3rd measure ($d = 0.45$). Cognitive anxiety only showed a low-moderate cumulated effect at the end of the study (baseline to 5th measure: $d = 0.41$). Self-efficacy showed a modest initial increase that was sustained until the end (baseline to 2nd, 3rd, 4th, and 5th measures: $d = 0.52$, 0.36, 0.38, and 0.51, respectively). Otherwise, the observed effects were small in all variables including motivation and social support.

Percent Change

The analysis of percent change between consecutive time points revealed that perceived fitness increased significantly between baseline and time point 2 (34.3%, 95% CI = 16.3–52.4, $p < 0.001$), and between 2 and 3 (19.3%, 95% CI = 1.3–37.4, $p = 0.035$), see **Table 2**. A similarly high increment was also found in self-efficacy between baseline and time point 2 (39.03%, 95% CI = 11.75–66.3, $p = 0.005$). However, motivation did not show any significant increase between consecutive time points until the last assessment (4.65%, 95% CI = 4.65–26.9, $p = 0.005$). Social support did not show any significant increase between consecutive time points. Both anxiety measures showed and increase at the end of the microcycle, although the change was statistically significant only for somatic anxiety (31.1%, 95% CI = 2.8–59.4, $p = 0.031$). Cognitive anxiety showed a significant increase between time points 2 and 3 (64.5%, 95% CI = 7.8–121.2, $p = 0.026$).

Physiological Performance Parameters

Change Over Time

All four physiological variables (**Figure 2**) presented statistically significant changes over time (AeT speed: $p < 0.001, f^2 = 1.04$; AnT speed: $p < 0.001, f^2 = 0.498$; RE mL: $p < 0.001, f^2 = 0.349$; RE kcal: $p = 0.024$, $f^2 = 0.197$). Cumulated effects were initially moderate-large in AeT speed (baseline vs. time point 2: + 0.31 km/h, $d = 0.70$, $p = 0.021$) and were progressively larger until reaching a peak at the end (4 vs. 5: + 0.77 km/h, $d = 1.76$, $p < 0.001$). Very similar effects were found in AnT speed both at the beginning (baseline vs. time point 2: + 0.37 km/h, $d = 0.70$, $p = 0.020$) and toward the end (4 vs. 5: + 0.58 km/h, $d = 1.13$, $p < 0.001$). RE mL measures showed moderate or low effects, with a relative fall at the 3rd assessment, from baseline to time points 2 ($d = 0.47$, $p = 0.216$), 3 ($d = 0.29$, $p = 0.682$) and 4 ($d = 0.47$, $p = 0.032$), and reached the effect peak at the end ($d = 1.07$, $p < 0.001$). A similar trend was found for RE kcal from baseline to time points 2 ($d = 0.45$, $p = 0.265$), 3 ($d = 0.28$, $p = 0.700$), 4 ($d = 0.47$, $p = 0.280$), and 5 ($d = 0.84$,

TABLE 2 | Percent change in study variables between time points ($n = 16$).

	−116 to −88			−88 to −60			−60 to −32			−32 to −11		
	$M_{\%dif}$	95% CI	p	$M_{\%dif}$	95% CI	p	$M_{\%dif}$	95% CI	p	$M_{\%dif}$	95% CI	p
Podium questionnaire												
Perceived fitness	34.33	16.31 to 52.36	<0.001	19.35	1.33 to 37.38	0.035	7.45	−11.81 to 26.72	0.448	9.24	−10.75 to 29.23	0.365
Self-efficacy	39.03	11.75 to 66.31	0.005	−2.29	−29.57 to 24.99	0.869	−0.5	−29.67 to 28.66	0.973	10.31	−19.96 to 40.57	0.504
Motivation	3.26	−6.76 to 13.28	0.523	−2.64	−12.66 to 7.38	0.605	0.53	−10.18 to 11.24	0.922	15.77	4.65 to 26.88	0.005
Social support	−2.29	−14.48 to 9.9	0.713	5.59	−6.6 to 17.77	0.369	3.63	−9.4 to 16.66	0.585	8.55	−4.97 to 22.07	0.215
Somatic anxiety	24.62	−0.88 to 50.12	0.058	15.44	−10.06 to 40.94	0.235	−6.98	−34.25 to 20.28	0.616	31.14	2.84 to 59.43	0.031
Cognitive anxiety	28.06	−28.66 to 84.78	0.332	64.51	7.79 to 121.23	0.026	13.12	−45.59 to 71.83	0.661	39.84	−21.09 to 100.76	0.2
Physiological variables												
AeTSpeed	3.17	1.57 to 4.77	<0.001	1.32	−0.28 to 2.93	0.105	2.18	0.47 to 3.89	0.013	1.02	−0.75 to 2.8	0.259
AnTSpeed	3.25	1.38 to 5.13	0.001	1.49	−0.38 to 3.37	0.119	0.05	−1.96 to 2.05	0.962	0.39	−1.7 to 2.47	0.717
REmL	−2.72	−5.96 to 0.52	0.100	1.59	−1.65 to 4.83	0.336	−2.55	−6.01 to 0.92	0.149	−2.94	−6.54 to 0.65	0.108
REkcal	−2.44	−5.43 to 0.54	0.108	1.36	−1.62 to 4.34	0.371	−0.82	−4.01 to 2.37	0.614	−2.63	−5.94 to 0.67	0.119

Time points are presented as days prior to competing in the marathon. Values represent percent change between time points: Mean, 95% confidence interval (CI), and statistical significance of the estimate. AeTSpeed = aerobic threshold speed (km/h); AnTSpeed = anaerobic threshold speed (km/h); REmL = running economy (mL/kg/km); REkcal = running economy (kcal/kg/km).

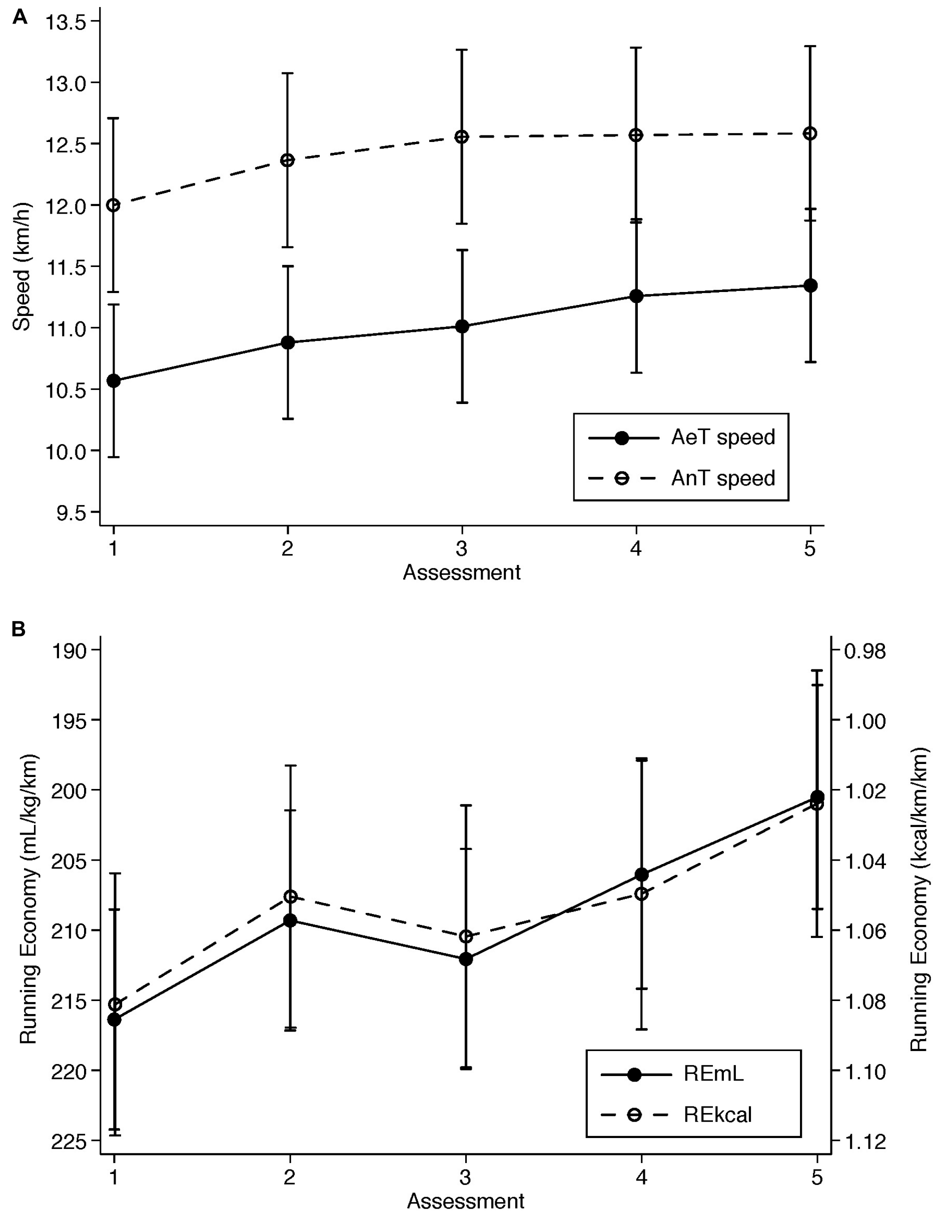

FIGURE 2 | Ventilatory thresholds speeds **(A)** and running economy **(B)** measured five times over 16 weeks. AeT speed: Aerobic threshold speed; AnT speed: Anaerobic threshold speed; REmL: running economy measured as oxygen cost, mL/kg/km; REmL: running economy measured as energy cost, kcal/kg/km. Assessments were performed at 116, 88, 60, 32, and 11 days prior to competing in the marathon. Data represent mean and 95% confidence intervals adjusted for participant's random effects.

$p = 0.004$). Spaghetti plots for physiological variables are included as **Supplementary Figure 2**.

Percent Change

The analysis of percent change revealed that statistically significant increases (see **Table 2**) between consecutive time points were only found in AeT speed, from baseline to time point 2 (3.17%, 95% CI = 1.57–4.77, $p < 0.001$) and from time point 3 to 4 (2.18%, 95% CI = 0.47–3.89, $p = 0.013$), and in AnT speed, from baseline to time point 2 (3.25%, 95% CI = 1.38–5.13, $p = 0.001$).

Percent Change Prediction Between Consecutive Time Points

Perceived Physical Condition

The longitudinal regression coefficients of the raw data adjusted for time and participants showed that only AeT (6.17, 1.99–10.35, $p = 0.004$, $R^2 = 0.14$) and AnT (6.42, 2.8–10.04, $p = 0.001$, $R^2 = 0.14$) speeds were associated with perceived fitness over time, while RE measurement did not show any predictive value.

However, adjusted for participant and multiple assessment effects, none of the assessed relative changes in physiological variables showed statistically significant predictive value on changes in perceived physical condition. From each independent model, we only found not statistically significant and small effects for AeT speed (f^2 = 0.02), REmL (f^2 = 0.03), and REkcal AeT (f^2 = 0.04); the effect for AnT speed was trivial (f^2 = 0.006). **Figure 3** depicts the strength of longitudinal associations examined in the study.

Self-Efficacy

Similar to the longitudinal prediction of fitness data, the analysis of self-efficacy raw data coefficients adjusted for time and participants showed that only AeT (7.23, 2.7–11.76, p = 0.002, R^2 = 0.04) and AnT (6.56, 2.4–10.72, p = 0.002, R^2 = 0.09) speeds were significant predictors, while no predictive value was found in either RE measurement.

Changes in self-efficacy were only predicted by changes in perceived fitness (1.14, 95% CI = 0.88–1.41, $p < 0.001$, f^2 = 1.33) with a statistically significant and very large effect. The prediction of change in self-efficacy from change in physiological performance parameters did not show any statistically significant effect. AeT speed and AnT speed showed a trivial effect size (f^2 = 0.004 and f^2 = 0.001, respectively), and changes in running economy measures showed a small effect size (REmL: f^2 = 0.028; REkcal: f^2 = 0.24).

Motivation

Both change in self-efficacy and change in perceived physical condition were significant predictors of change in motivation. However, change in self-efficacy showed a positive large effect (0.19, 95% CI = 0.11–0.27, $p < 0.001$, f^2 = 0.36), while change in perceived fitness showed a positive moderate association (0.21, 95% CI = 0.07–0.35, p = 0.003, f^2 = 0.17).

Anxiety

Relative increases in self-efficacy were significantly associated with moderate relative decreases in somatic anxiety (−0.32, 95% CI = −0.55 to −0.08, p = 0.008, f^2 = 0.13) although the small association with cognitive anxiety (f^2 = 0.04) was not found statistically significant. The association between increases in perceived fitness and decreases in anxiety was found small but statistically significant both for somatic (−0.4, 95% CI = −0.76 to −0.04, p = 0.03, f^2 = 0.09) and cognitive (−0.81, 95% CI = −1.6 to −0.02, p = 0.044, f^2 = 0.08) anxiety variables. Similarly, small associations were found between increases in motivation and decreases in both somatic (−0.66, 95% CI = −1.32 to −0.01, p = 0.048, f^2 = 0.07) and cognitive (f^2 = 0.05) anxiety, although the latter effect was not found statistically significant.

DISCUSSION

The major contribution of the present study is to depict the evolution of different psychological and physiological variables together in recreational marathon runners over the last 4 months before a marathon race. Since all runners successfully achieved their performance goals at the finish line, the results of this study would characterize the normal evolution of these variables in recreational marathon runners following a systematic training program without major incidents.

Perceived physical fitness increased constantly from an average score of 56.7 at the beginning of the study to 86.3 right before the race. It is difficult to determine a cause-effect relationship between physiological improvements and psychological changes, since multiple covariates might have a role in self-perceiving physical fitness (e.g., experience as a runner, number of marathons run, communication with the coach, comparison to other runners, performance expectations, etc.). Isolating the effect of physiological variables on perception from the effect of other cofounders would be impossible within the present applied research design. Despite this limitation, our findings showed evidence that some systematic improvements in AeT and AnT speeds, but not in RE, were associated to better physical fitness perception. However, when we tried to parallel the changes in both sets of variables we only found not statistically significant small effect sizes.

Despite our results may not be generalized to other runners and training programs, as a practical example, we have found that improving any threshold speed by one km/h was roughly associated to 6% better physical fitness perception. The R^2 value of 0.14 reflected a moderate link that just corroborates previous results (e.g., Delignières et al., 1994; Jensen et al., 2018) (r = 0.38) from meta-analytic efforts using other populations (Germain and Hausenblas, 2006). However, percent change analysis between time points did not confirm these results (**Figure 3**). Therefore, the influence of the physiological performance parameters on perceived fitness should be taken as a long-term relationship rather than an immediate effect.

Average self-efficacy scores were high, ranging from 72 to 82 out of 100. High perception of self-efficacy would reflect the runner's belief that he or she is ready to perform at the best possible level, while excessive or poor self-efficacy states would lead the runners to be unsuccessful. Therefore, the observed high, but not excessive, self-efficacy scores reflect an optimal mental disposition that should be the norm for runners during the last microcycle and especially right before competing.

Our data partially failed to confirm the hypothesis that improving physical condition would improve self-efficacy. Although the long-term trend showed that improving any threshold speed by one km/h was roughly associated to 6 or 7% better perceived self-efficacy, the analysis of shorter-term relative changes did not confirm these results. However, we did find a strong relationship between perceived fitness and self-efficacy. Approximately, an increase of 10 percent in perceived fitness from any time point to the next was associated with a 11.4% percent increase in self-efficacy during the same period.

Our results showed that motivation remained high during the course of the study, as the average values ranged from 82.9 to 91.9 out of 100. We also found that the sample of runners exhibited also high levels of perceived social support (average range 84–90 during the study), although this variable is not linked to our hypotheses and may not be reproducible in other groups. A deeper analysis of motivation and social support was out of the scope of this study. However, according to the definition of the scales by the questionnaire authors (Larumbe et al., 2015),

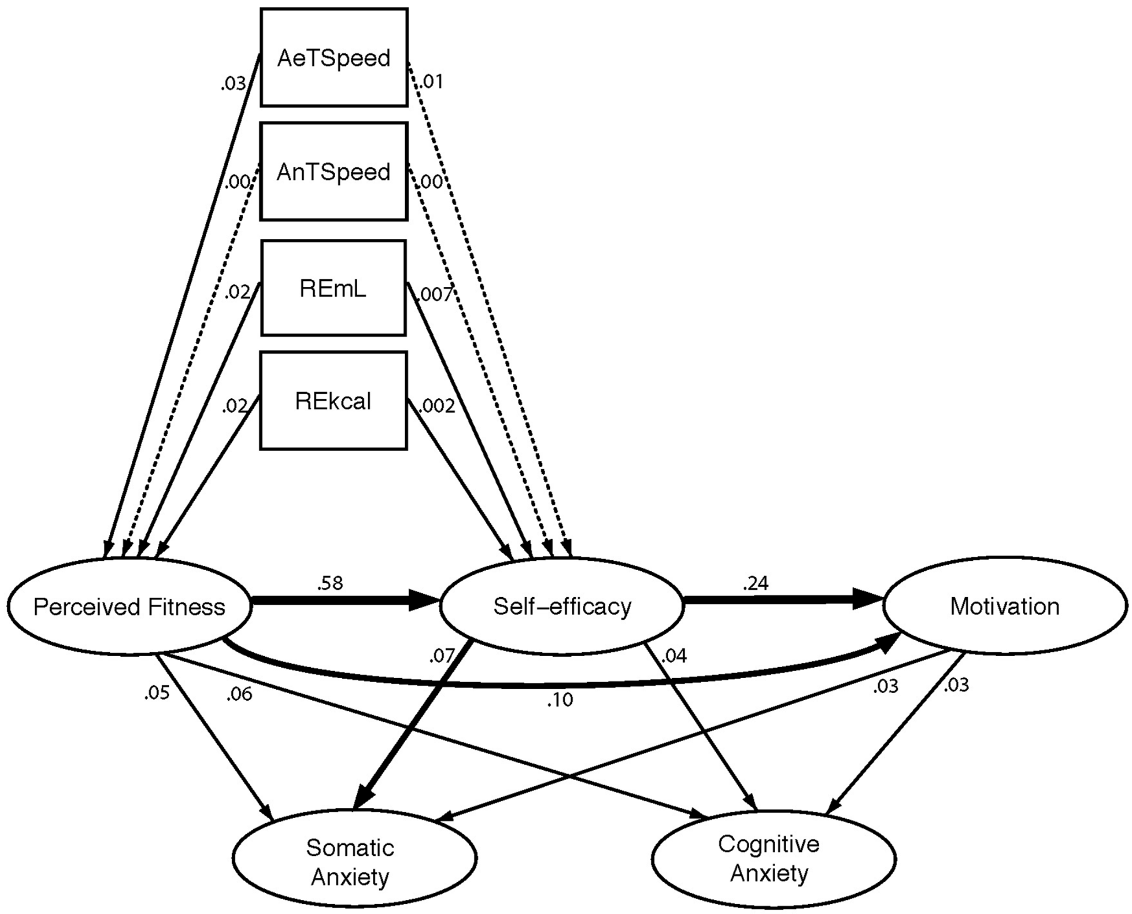

FIGURE 3 | Summary of longitudinal R^2 values found in the study. Numbers represent the effect (R^2) of the predictor adjusted for participant and multiple measurement effects using separate linear mixed effects models for each association tested. Arrows represent the direction of the prediction. Thinness of the arrows represents the magnitude of the effect size (f^2).

the motivation score would reflect the internal feeling of commitment and willingness to run, whereas the perceived social support score would reflect either external support or pressure from the interpersonal environment. Both variables showed high values in our sample, reflecting high internal and external sources of motivation for running. Interestingly, the large association between relative changes in motivation and relative changes in self-efficacy scores confirms that self-beliefs of efficacy play a key role in the self-regulation of motivation (Bandura, 1994). In practice, based on our results, a relative increase around 50 percent in either self-efficacy or perceived physical condition would be necessary to produce a 10 percent increase in motivation.

Both anxiety measures showed relative low levels at the beginning of the study: cognitive anxiety averaged 34.2 and somatic anxiety averaged 44.2 out of 100. Levels close to the race day were 45.6 and 59.7, respectively. Overall, in agreement with the existing literature (e.g., Bandura, 1994), medium-term improvements in perceived fitness, self-efficacy and motivation were associated with improvements (decreases) in anxiety, although the effects were predominantly small. However, we found a shift in somatic anxiety from day-32 to day-11 that has been already linked to training load-derived stress (Rehm et al., 2013), and it is also associated with alterations of the immune system, as well as commonly referred gastrointestinal symptoms (Pugh et al., 2018). Interestingly, the increase in somatic anxiety during the last assessment happened in absence of a significant increase in cognitive anxiety (worries). The results achieved in our sample would reflect that the preparation program developed according to the runners' expectations.

In summary, the general trend observed in the data, where all variables peaked at the end, would mostly reflect that the last training macrocycle before competing is usually planned and executed to provide the athlete with the most adequate preparation, both physically and mentally. These increments in motivation, social support, perceived fitness, and self-efficacy are usually perceived as positive. However, our data showed that some moderate levels of both somatic and cognitive anxiety should also be expected to be normal as a consequence of an optimal preparation.

Physiological performance parameters, especially RE, failed to predict medium-term changes in either perceived fitness or perceived self-efficacy. There are several arguments to explain these results: (a) the residual (or cumulated) effect of fatigue from the training regimen could have impacted negatively the perception of achieving a better physical condition regardless of the physiological changes that objectively happened on the body; (b) as mentioned above, it is impossible in practice to expose regularly the subjects to the real tasks to be performed (i.e., finishing the marathon) in order to produce the perception of physical improvement over time, and therefore marathon runners' perceived fitness will always hold a large uncertainty component; (c) looking at RE values in **Figure 2B**, improvements do not necessarily follow a linear continuous upward trend, but an undulating pattern with ups and downs that make hard to self-assess physical condition; (d) in addition, the magnitude of the relative changes (**Table 2**) indicates that relative changes in perception have much larger magnitude than relative changes in physiological parameters, which indicates that self-perceptions are more inconsistent and are exposed to multiple sources of variation compared to the analyzed physiological variables.

Additionally, RE does not have a direct impact on the finish time like the pace at Zone 2 does. On the one hand, it is very difficult for the athletes to perceive whether they are economical during a short effort, which is the format how RE is usually measured for practical reasons. The human being cannot perceive when the "fuel reserve tank" is being used until the person is already in that situation, which usually takes 20–35 km of the marathon (Joyner, 1991). On the other hand, since the athletes also train according to physiological references (e.g., heart rate, pace), the intensity zones are easier to recognize and therefore to associate to perceptions of physical fitness and self-efficacy.

Nevertheless, all main three psychological variables (perceived fitness, self-efficacy, and motivation) were strongly associated, and linked according to the theoretical framework. This results also confirms the models proposed by Larumbe Zabala et al. (2009), where self-efficacy, perceived fitness, motivation, and anxiety were part of either positive or negative psychological disposition for running the marathon.

Limitations

Since our sample size was intended to detect moderate effect sizes around a half standard deviation, smaller but practically significant effect sizes may have not been properly addressed. For that reason, the extension of this study and the addition of larger number of subjects and more diverse samples would significantly enhance the description of the expected normal psychological state of marathon runners along their preparation cycles.

We did not consider the possibility that the analyzed associations could occur based on the cumulated perception of change (e.g., improvement over the season). Although this approach seems plausible, it would have required a different data analysis plan by comparing the cumulated change over time instead of percent change between time points. However, this approach would require setting an arbitrary baseline (e.g., at the beginning of a season, when all runners decide to enroll a training program, etc.), which in practice would have added more limitations than advantages to the study design.

Practical Applications and Future Studies

The presented data support the use of the perceived fitness scale of Podium questionnaire as a subjective measure of progress during the preparation for a marathon. In view of our results, we suggest sport psychology consultants and coaches using this scale to monitor regularly the perception of physical fitness and contrasting the information with physiological and performance tests, since our results suggest that these two sources of information may disagree. In our practical experience, disagreement between athlete's perception and objective tests would usually be attributed to an improper coach-athlete communication, lack of objective information about performance, excessive time between tests, non-realistic or inadequate goal setting, excessive comparison against other athletes, incidence of injuries and their recovery processes, or alterations in other psychological variables.

For future research regarding the Podium questionnaire variables, we suggest to examine the psychological response of runners to different situations, in order to characterize different profiles and suggest interventions. More specifically, further investigation should examine a cause-effect framework on the dynamics over time of all combinations of excess and/or deficiency in commitment, feeling of preparedness, and anxiety response. It should be expected these states to affect the responses of the subjects at different time point assessments. Consequently, these different response profiles should be associated to training and personal circumstances, in order to attribute the most probable causes for each profile and determine the most appropriate interventions.

Since only non-injured athletes participated in the study, physical performance and its perception were not affected by the occurrence of injuries. Therefore, further studies should explore the effect of injuries on perception of physical fitness, self-efficacy and anxiety levels, using preferably a longitudinal approach.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

This study was carried out in accordance with the recommendations of the European University of Madrid Ethics Committee with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. Ethical approval was granted by the European University of Madrid, Spain with number CIPI/035/15.

AUTHOR CONTRIBUTIONS

EL-Z and JE-L contributed to the conception and design of the study. JE-L, CC, and AA performed the field assessments. CC organized the database. EL-Z performed the statistical analysis and wrote the first draft of the manuscript. EL-Z, JE-L, and AQ wrote sections of the manuscript. All authors contributed to the manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2020.00545/full#supplementary-material

FIGURE S1 | Spaghetti plots of Podium questionnaire variables during the course of the study. Each line represents one study participant.

FIGURE S2 | Spaghetti plots of physiological performance parameters during the course of the study. Each line represents one study participant.

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