


Training volume and previous injury as associated factors for running-related injuries by race distance: A cross-sectional study

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ABSTRACT

Objective: This study aims to determine the relationship between weekly pre-competition running volume and the presence of running-related injuries (RRIs) by race distance. **Methods:** An online questionnaire was sent to 25,000 participants, 14 days following the running event. The questionnaire included the presence and topography of RRIs, previous injury in the last 12 months, running experience, training, and sociodemographic characteristics. Univariate and multivariable binomial regression was used to analyse the crude and adjusted relationship of RRI and training volumes. **Results:** 4380 surveys were analysed (10km, n=1316; 21km, n= 2168; 42km, n=896). The median age was 36 years. Previous injury was reported by 51.8% of the respondents. Median training volume in the previous month was 15 km/week (IQR 6-24), 30 km/week (IQR 15-40) and 45 km/week (IQR 30-60), for the 10km, 21km, and 42km distances, respectively. During the race, 14.1% reported a RRI, with 43.1% located at the knee. The multivariable analysis showed previous injury and distance as the main associated factors, whereas weekly training volume, age, and previous participation were protective. **Conclusion:** Race is an inciting event for developing a RRI. Running race distance is an important factor itself and should be incorporated with other modifiable risk factors in current injury models. **Keywords:** Running; Epidemiology; Athletic Injuries; Etiology; Sports.

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INTRODUCTION

Running is one of the most popular physical activities enjoyed by people around the world. Over the last decades, the number of runners and running races has increased worldwide (Fredericson and Misra, 2007), including in Chile. According to the Santiago Marathon Producers, the number of participants in this marathon increased from approximately 6,800 runners in 2007 to over 30,000 runners by 2016.

Even though running produces many health benefits, injuries can commonly emerge from its practice. The overall running-related injuries (RRIs) incidence varies from 19.4% to 79.3% (van Gent et al., 2007). These injuries are often related to musculoskeletal structural overload. Time-loss injury proportions between different runner populations range from 3.2% in competitive cross-country runners to 84.9% in novice recreational runners (Kluitenberg, van Middelkoop, Diercks, & van der Worp, 2015). The most commonly affected sites are located below and around the knee (Lopes, Hespanhol, Yeung, & Costa, 2012; van Gent, et al., 2007), but the proportion and location may differ between less and more experienced runners (Kluitenberg, et al., 2015; Videbæk, Bueno, Nielsen, & Rasmussen, 2015).

According to the Comprehensive Model for Injury Causation (Bahr and Krosshaug, 2005) and the Conceptual Model for the Determinants of RRIs (Malisoux, Nielsen, Urhausen, & Theisen, 2015), the running injury risk is increased by intrinsic and extrinsic factors. Internal risk factors include sex, age, body mass index, previous injury, physical fitness, and psychological factors, which predispose the running athlete to an injury. Conversely, the extrinsic factors are comprised of weekly training volume or other training characteristics, sport equipment, and environment, which heighten the runner's susceptibility to injury. However, factor exposure is often insufficient for producing an overuse injury, where an inciting event that increases specific loads, such as running a race, is ultimately necessary to trigger a running injury in context with exposure to those factors.

Several running injury studies reported previous injury in the previous 12 months as a prevalent risk factor for RRIs (Hespanhol, Pena Costa, & Lopes, 2013; Saragiotto et al., 2014; Videbæk, et al., 2015). However, the influence of other risk factors, such as training characteristics, on RRIs is controversial (Hulme, Nielsen, Timpka, Verhagen, & Finch, 2016; Oestergaard Nielsen, Buist, Sørensen, Lind, & Rasmussen, 2012; Saragiotto, et al., 2014). Weekly running volume is an important modifiable risk factor that has been widely studied, but few investigations have examined the risk of developing those injuries during a race (Rasmussen, Nielsen, Juul, & Rasmussen, 2013; van Poppel, de Koning, Verhagen, & Scholten-Peeters, 2016; van Poppel, Scholten-Peeters, van Middelkoop, Koes, & Verhagen, 2018). Rasmussen et al (2013) reported a 2.02 times greater probability (Relative Risk, or RR; $p < 0.01$) for suffering an injury during a marathon among finishers with an average weekly training volume below 30 km/week compared with a volume between 30-60 km/week. However, there is no robust evidence to support whether higher or lower chronic volumes are associated with RRIs during a race (Hulme, et al., 2016).

Data gathered during large-scale athletic events, such as an organized running race, may serve as an evidence-based platform for self-care recommendations that can be delivered to the general population (Ooms, Veenhof, & de Bakker, 2013), especially in events with different race distances (e.g. 10km, 21km and 42km). The purpose of this study was to determine the relationship between weekly pre-competition running volume and the presence of RRIs in runners competing at a sectioned marathon event within their respective registered running distances (10km, 21km and 42km).

MATERIALS AND METHODS

Participants

Data were collected through an online cross-sectional survey answered by runners who participated in the Santiago Marathon (SM) held in Santiago, Chile in April 6th, 2014. Individuals were allowed to participate if they were 18 years or older and had competed in one of the three SM running distances. Informed consent was confirmed when individuals clicked on the survey link, thus authorizing investigators to use their de-identified data for further analysis. This study was approved by the Research Ethic Committee at Universidad del Desarrollo, no. 2014-52.

Outcome measures

The survey allowed data collection in several different categories. Socio-demographic and anthropometric data included age, educational level, weight and height. Health data included co-morbidities, previous musculoskeletal running-related injuries in the last 12 months, the topographic/anatomical area of such injuries, and whether they developed RRIs during the race. Running practice data included the SM registered distance, number of previous competitive running event participations in the selected registered distance, and years of running experience. Training data included the approach to monitoring the subject's training (i.e., self-guided or professionally coached), running surface (hard, soft, or mixed), weekly training duration (hours) and volume (kilometres) in the previous one and two month(s) prior to the race, maximum single daily running volume achieved within six weeks prior to the competition and an account of participation in other sports. The main exposure factor for the current study was "training volume", whereas the primary outcome was the presence of self-reported RRIs by runners sustained during the race. Training volumes were measured according to participants' retrospective reports that reflected the longest training distance in the six weeks before the marathon race and their weekly average running volumes (in kilometres) during each of the following periods: at one month prior to the race (during March; M1); and at two months prior to the race (during February; M2). These values were transformed to categorical variables through quartile analysis by distance. A running-related injury was defined as "any injury to muscles, tendons, joints and/or bones caused by running. The injury had to be severe enough to cause or be expected to cause a reduction in distance, speed, duration, or frequency of running for at least 7 days. Conditions such as muscle soreness, blisters, and muscle cramps were not considered as injuries".

Procedure

An email invitation was distributed by race organizers 14 days after the race to all registered runners who participated in one of three different distances (10km, 21km, and 42km). A questionnaire consisting of 21 questions was accessed through a link on the participant email. Three days after the race organizers delivered the original survey invitation, a second invitation and link was emailed to the same population. All survey responses were collected online by survey software (Plan Gold, SurveyMonkey, www.surveymonkey.com). The survey remained accessible to potential participants for one month after the first email invitation.

Analysis

Descriptive analyses identified the central tendency and dispersion values, along with data normality according to the Shapiro Wilk test. Since no quantitative data were normally distributed, they were presented with median and interquartile range (IQR); ordinal and nominal data were presented with frequency and percentages. The inferential comparisons for socio-demographics characteristics, running practices, previous injury, training volumes, and the proportion of RRIs between injured and non-injured participants were performed for each distance using the Mann Whitney-U test for quantitative data and the Chi-square

test for ordinal and nominal data. A univariate binomial regression analysis was conducted to assess different associated factors with RRI. Multivariable binomial regression with a stepwise approach (backward elimination, using 0.10 of significance level for removal from the model) was used to analyse the relationship between RRI and training volumes adjusted for potential control factors. The significance level was set at $\alpha = .05$. All statistical analyses were performed using 13.0 STATA software.

RESULTS

The survey was sent to 25,000 runners registered in the 2014 SM event. From those, 5615 participants completed the survey, representing a 22.5% response rate. From the total responses, 29 were not included because the participants were younger than 18 years old. After data reduction, 4380 surveys were available for analysis. Figure 1 shows a flowchart of the recruitment and selection process of participants.

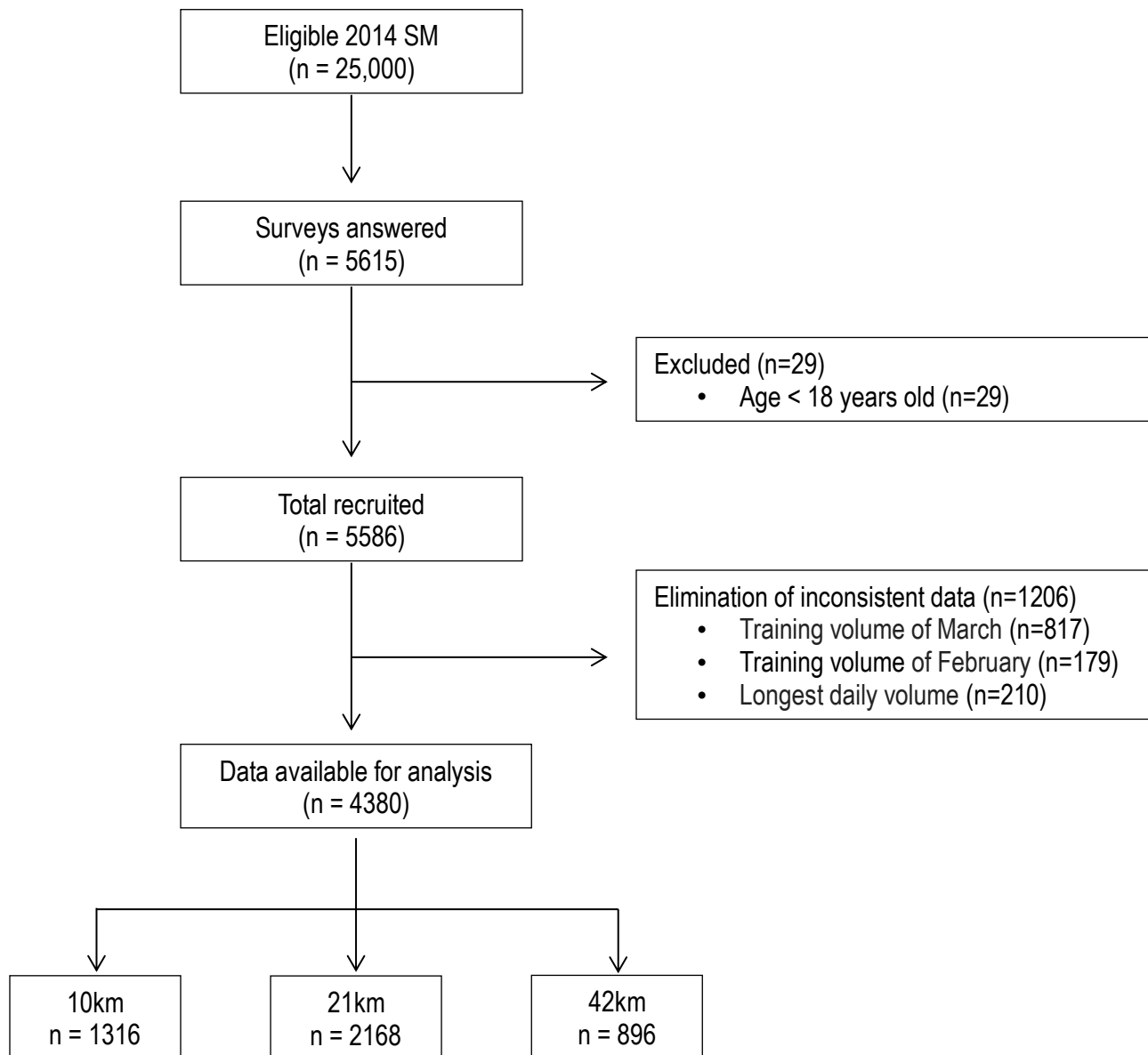


Figure 1. Flowchart of 2014 Santiago Marathon's participants

Characteristics of participants are presented in Table 1. Of all participants, the mean age was 36 years, 53.8% reported have completed more than 18 years of formal education, 40% were categorized as overweight or obese, and 24.7% reported to have at least one comorbidity, with allergies (59.8%) among the most common. Previous injury in the last 12 months (at least one) was reported by 51.8% of all participants, where the most frequent sites were located at the knee (44.4%), followed by ankle (38.7%), lower leg (13.7%) and lower back (13.5%). One third of the participants reported that they had never participated in a running race of the same distance at which they were registered, whereas the largest proportion of participants reported from 1 to 4 previous participations at the pre-registered distance. The majority of the 10km and 21km runners reported 1 to 4 years of running experience, whereas the 42km runners reported more than 4 years of experience.

Table 1. Description of socio-demographic, health characteristics and running experience based on the registered distance of 2014 Santiago Marathon

	n	Total n=4380	10km n=1316	21km n=2168	42km n=896
Age (years)^a	4380	36 (29-43)	34 (28-43)	35 (29-43)	38 (32-45)
Educational level^b	4380				
Under 12 years		426 (9.7)	124 (9.4)	200 (9.2)	102 (11.4)
Between 12 and 18 years		1599 (36.5)	505 (38.4)	794 (36.6)	300 (33.5)
Over 18 years		2355 (53.8)	687 (52.2)	1174 (54.2)	494 (55.1)
Body mass index (kg/m²)^b	3949				
Underweight		31 (0.8)	16 (1.4)	10 (0.5)	5 (0.6)
Normal weight		2305 (58.4)	647 (55.3)	1133 (57.9)	525 (64)
Overweight		1456 (36.8)	423 (36.1)	756 (38.6)	277 (33.7)
Obese		157 (4)	84 (7.2)	59 (3)	14 (1.7)
Previous injury (12 months)^b	4380	2267 (51.8)	595 (45.2)	1170 (54)	502 (56)
Knee		1007 (44.4)	315 (52.9)	506 (43.2)	186 (37.1)
Ankle		877 (38.7)	204 (34.3)	477 (40.8)	196 (39)
Lower leg		310 (13.7)	58 (9.7)	168 (14.4)	84 (16.7)
Thigh		246 (10.9)	46 (7.7)	128 (10.9)	72 (14.3)
Hip		173 (7.6)	34 (5.7)	90 (7.7)	49 (9.8)
Lower back		307 (13.5)	77 (12.9)	163 (13.9)	67 (13.3)
Number of previous participations^b	4380				
None		1459 (33.3)	374 (28.4)	770 (35.5)	315 (35.2)
Between 1 and 4		1953 (44.6)	518 (39.4)	1026 (47.3)	409 (45.6)
More than 4		968 (22.1)	424 (32.2)	372 (17.2)	172 (19.2)
Running experience (years)^b	4380				
Less than 1 year		704 (16.1)	415 (31.5)	263 (12.1)	26 (2.9)
Between 1 and 4 years		2226 (50.8)	662 (50.3)	1187 (54.8)	377 (42.1)
More than 4 years		1450 (33.1)	239 (18.2)	718 (33.1)	493 (55)

^a Median (interquartile range); ^b Frequency (%).

Abbreviations: Km = kilometres; m = meters; kg = kilograms

The weekly volume reported during the previous (M1) and the second (M2) month, and the longest daily volume varied according to the registered distance. Statistically significant differences were found ($p < 0.05$) between 10km, 21km and 42km runners, for all reported training volumes. The comparison of training volumes (quartiles) and running characteristics was included as additional data file (see supplemental material S1). Six hundred and twenty runners (14.1%) sustained a RRI during the race. The most common sites were the knee (43.1%) and ankle/foot (30.7%) segments, whereas the least common was the lower

back (5%). By distance, the proportions of injury were 10% (n=131), 14.7% (n=318) and 19.1% (n=171) for 10km, 21km and 42km, respectively ($p < 0.001$). All distances exhibited the knee and ankle/foot segments as the most frequent injury sites. In general, non-injured runners were older, had lower proportions of previous injury, accumulated less weekly training volume, and had more previous racing experience than injured runners. The median comparisons of M1 and M2 volumes were statistically significant ($p < 0.05$) for 21km and 42km runners, whereas 10km and 21km only showed significant differences ($p < 0.05$) for the longest training distance during the six weeks before the race. Previous injury was significantly associated ($p < 0.05$) with RRIs for all distances, except for 42km runners. The comparisons of training volumes, previous injury, running experience, and socio-demographics characteristics of injured and non-injured runners are represented in Table 2.

Table 2. Comparison of training volumes and other exposure factors in injured (RRI +) and non-injured (RRI -) runners based on the registered distance of 2014 Santiago Marathon

	Total (n = 4380)			10km (n = 1316)			21km (n = 2168)			42km (n = 896)		
	RRI (+)	RRI (-)	p value	RRI (+)	RRI (-)	p value	RRI (+)	RRI (-)	p value	RRI (+)	RRI (-)	p value
Age (years) ^a	33 (28-41)	36 (30-44)	<0.01	32 (27-40)	35 (28-43)	0.03	32 (28-40)	36 (30-43)	<0.01	35 (29-43)	39 (33-45)	<0.01
BMI (kg/m ²) ^a	24.5 (22.8-26.1)	24.5 (22.8-26.1)	0.51	25.0 (23.1-27.7)	24.5 (22.5-26.4)	0.04	24.5 (22.8-26.1)	24.5 (22.8-26.1)	0.73	24.1 (22.6-25.5)	24.2 (22.6-25.7)	0.62
Previous injury (yes) ^b	413 (66.6)	1854 (49.3)	<0.01	91 (69.5)	504 (42.5)	<0.01	218 (68.6)	952 (51.5)	<0.01	104 (60.8)	398 (54.9)	0.16
M1 volume (km/week) ^a	21 (10-40)	25 (13-40)	0.05	10 (5-22)	15 (6-24)	0.16	20 (14-35)	30 (15-40)	<0.01	40 (21-52)	45 (30-60)	<0.01
M2 volume (km/week) ^a	25 (10-40)	25 (10-40)	0.85	10 (4-25)	10 (5-20)	0.29	20 (10-35)	25 (15-40)	<0.01	45 (27-60)	50 (30-60)	0.02
Longest daily volume (km/day) ^a	15 (10-21)	15 (10-21)	0.51	8 (5-10)	10 (6-12)	0.03	15 (10-18)	16 (13-20)	<0.01	30 (21-32)	30 (23-32)	0.13
Previous participation (none) ^b	266 (42.9)	1193 (31.7)	<0.01	42 (32.1)	332 (28.0)	0.33	146 (45.9)	624 (33.7)	<0.01	78 (45.6)	237 (32.7)	<0.01
Years of running experience (>2 years) ^b	358 (57.7)	2354 (62.6)	0.02	43 (32.8)	500 (42.2)	0.04	176 (55.4)	1224 (66.2)	<0.01	139 (81.3)	630 (86.9)	0.06

^a Median (interquartile range); ^b Frequency (%). ^a Mann Whitney-U test; ^b Chi-square test

Abbreviations: BMI = body mass index; kg = kilograms; km = kilometres; RRI = running-related injury; M1 = March volume; M2 = February volume.

The univariate analysis revealed no significance differences between RRIs and training volumes, when all distances were analysed together. However, the analysis of RRIs and training volumes varied by distance. The OR for M1 and M2 volumes were significant for 21km and 42km runners. The OR for longest daily volume was significant only for 21km runners. Taking 10km distance as reference, the risk of RRIs was OR=1.55 [1.3-1.9], $p < 0.01$ for 21km and OR=2.13 [1.7-2.7], $p < 0.01$ for the 42km race. The analysis of other potential control factors showed significant associations ($p < 0.05$) between

the presence of RRIs with previous injury, age, previous participation, and more than 2 years of running experience. No significant association was found with Body Mass Index (BMI) (see supplemental material S2). The multivariable analysis showed that M1 volume, previous injury, age, previous participation, distance (21km and 42km), and the longest daily volume were associated with RRIs during the race. Running experience (> 2 years) and BMI were removed from the model. Table 3 shows the results of the multivariable binomial regression analysis.

Table 3. Results of multivariable binomial regression analysis between running-related injury and training volume, adjusted by control factors

	OR	Standard error	95% CI	p-value
M1 volume (km/week)	0.99	0.003	0.98 – 0.99	< 0.01
Previous injury (last 12 months)	2.06	0.191	1.72 – 2.47	< 0.01
Age (years)	0.97	0.005	0.96 – 0.98	< 0.01
Previous participation (at least one)	0.73	0.067	0.61 – 0.88	< 0.01
Distance				
10km (reference)	---	---	---	---
21km	1.82	0.221	1.44 – 2.31	< 0.01
42km	3.68	0.643	2.61 – 5.18	< 0.01
Longest daily volume (km/day)	0.98	0.007	0.96 – 0.99	0.02

Abbreviations: OR = Odds Ratio; 95% CI = 95 percent of Confidence Interval; M1 = March volume; km = kilometres

DISCUSSION

The results of the current study revealed findings similar to other studies (Hespanhol, et al., 2013; van Gent, et al., 2007) regarding the prevalence (14.1%) and location of RRIs, where the knee was the most commonly reported site. The proportion of injury was higher for the runners with a longer registered distance, where 42km runners showed 3 times more risk of developing a RRI compared with 10km runners in the multivariable model. These findings are consistent with previous studies conducted in half-marathon and marathon runners (van Poppel, et al., 2016; van Poppel, et al., 2018), which appears to be logically plausible, because the 42km runners likely experience greater exposure to overload stress compared middle-distance runners. Post-race follow-up studies may enhance the understanding of RRIs associated with these types of events (Marienke van Middelkoop, Kolkman, van Ochten, Bierma-Zeinstra, & Koes, 2007).

Weekly running volume was a protective associated factor, where for middle and marathon distances (21km and 42km) accumulating a greater amount of training kilometres (chronic load) decreased the likelihood of developing RRIs. The overall median of M1 volume for non-injured runners was 25 km/week compared with 20 km/week for those injured. The distance analysis revealed that weekly volume was only a protective factor for 21km and 42km runners. This result might be explained because of the profile of runner who participates in 10km races, with less year of experience and more recreational (Besomi, Leppe, Di Silvestre, & Setchell, 2018). Our findings are consistent with Rasmussen et al (2013), who reported that the relative risk of suffering an injury rose by RR= 2.02 [95% CI: 1.26; 3.24; p < 0.01] among runners with an average weekly training volume below 30 km/week compared with runners with an average weekly training volume of 30-60 km/week. According to our findings, we recommend that middle distance (21km) and marathon runners achieve a minimum running volume before a competition and we suggest at least 30 km/week and 45 km/week for 21km and 42km runners, respectively.

Previous injury was the main factor associated with the presence of RRIs during a race of different distances, but it was not significant for 42km runners. Runners can sustain a number of injuries during a one-year-period, which are often subsequent because a previous injury (index injury) is associated with an increased risk (Liam A Toohey, Drew, Cook, Finch, & Gaida, 2017). However, this relationship is likely higher in less experienced runners (10km and 21km). Moreover, epidemiological researchers face a substantial challenge in quantifying subsequent injuries (Finch, 2014; L. A. Toohey, Drew, Fortington, Finch, & Cook, 2018). Future investigations should study the influence of longer time frames on RRIs during running races, considering recently developed models of pain adaptation, which describe key elements for positive and negative aspects of the adaptation. Despite that adaptation achieving a short-term outcome in protecting the individual from further pain, injury, or both, authors suggest the adaptation may have more long-term consequences that could lead to further problems, due to increased or modified load, or decreased movement duration and variability (Hodges and Tucker, 2011). Protective factors, such as age and previous experience, were additionally associated with RRIs. This is consistent with the literature, including studies that evaluate injury risk during a race or a training session (Fredericson and Misra, 2007; van Gent, et al., 2007; van Poppel, et al., 2018; Videbæk, et al., 2015). Because previous injury is a non-modifiable risk factor, it is important that health professionals consider an adequate rehabilitation and recovery process to restore neuromuscular impairments that patients might experience after a running injury.

Current conceptual models that are used to explain injury development can clarify these results (Bahr and Krosshaug, 2005; Malisoux, et al., 2015). A predispose runner is characterized by younger age, having experienced previous injury in the last 12 months, and with no previous race history at the present registered running distance. This suggests that a susceptible runner would be one who cannot accumulate an adequate training load prior to the competition. Finally, for the longer distances (21km and 42km), the inciting event would be the race. This model is a good way to understand the development of any musculoskeletal injury, and more studies should further examine the race itself as a trigger factor. Recently, Windt and Gabbett (2016) developed an updated injury aetiology model, which includes how workloads alter injury risk. Within this model, internal risk factors were differentiated into modifiable and non-modifiable factors, where workloads were earmarked as a contribution to injury in three ways: (1) exposure to external risk factors and potential inciting events; (2) fatigue, or negative physiological effects; and (3) fitness, or positive physiological adaptations. Exposure is determined solely by total load, while positive and negative adaptations are controlled both by total workloads, as well as changes in load (e.g., the acute: chronic workload ratio). Future research should incorporate this theory and other workload-related factors to study the nature of a running injury in a more comprehensive way (Jungmalm, Grau, Desai, Karlsson, & Nielsen, 2018) and incorporating other approaches to study overuse injuries (Clarsen, Rønsen, Myklebust, Flørenes, & Bahr, 2014).

Limitations and future research

A major limitation of our study was the loss of the sex variable, due to a failure in the recording system by the production company, which did not allow identifying or classifying the participants in an appropriate manner. It is possible that sex differences may have influenced these results, but we were not able to test this hypothesis (Van Der Worp et al., 2015). Despite this limitation, this large-scale study analyses injury-associated factors among different race distances, which is consistent with current prospective studies (M. Van Middelkoop, Kolkman, Van Ochten, Bierma-Zeinstra, & Koes, 2008; van Poppel, et al., 2016). Further prospective investigations should be conducted incorporating longer follow-up periods to better understand the contribution of training variables in the development of injuries during a race. Objective methods, such as mobile applications or global positioning satellite systems may be considered to enhance the accuracy of measurements, especially those related to weekly running volume (Diderisken, Soegaard, & Nielsen, 2016).

Such could decrease the recall bias typically found on this kind of design, especially when runners are consulted about their training load during the previous month and the previous two months.

CONCLUSION

The race itself appears to be an inciting event for developing RRI. Race running distance is an important factor itself and health professionals as well as training coaches should take this into account for the preparation and goals programming of their patients or runners. Previous injury remains the most important risk factor that can modify the risk of developing a running injury. Other protective and modifiable factors, such as training volume, should be further studied in prospective designs in order to generate better and more comprehensive models to explain RRI.

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The experiments comply with the current laws of the country in which they were performed.

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