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Original article

Risk models for lower extremity injuries among short- and long distance runners: A prospective cohort study

Dennis van Poppel[a,*], Gwendolijne G.M. Scholten-Peeters[a,b], Marienke van Middelkoop[c], Bart W. Koes[c], Arianne P. Verhagen[a,c]

[a] Avans University of Applied Sciences, Research Group Diagnostics, Breda, The Netherlands
[b] MOVE Research Institute Amsterdam, Faculty of Behavioural and Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands
[c] Erasmus Medical Center University, Dept General Practice, Rotterdam, The Netherlands

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ABSTRACT

Background: Running injuries are very common. Risk factors for running injuries are not consistently described across studies and do not differentiate between runners of long- and short distances within one cohort.
Objectives: The aim of this study is to determine risk factors for running injuries in recreational long- and short distance runners separately.
Design: A prospective cohort study.
Methods: Recreational runners from four different running events are invited to participate. They filled in a baseline questionnaire assessing possible risk factors about 4 weeks before the run and one a week after the run assessing running injuries. Using logistic regression we developed an overall risk model and separate risk models based on the running distance.
Results: In total 3768 runners participated in this study. The overall risk model contained 4 risk factors: previous injuries (OR 3.7) and running distance during the event (OR 1.3) increased the risk of a running injury whereas older age (OR 0.99) and more training kilometers per week (OR 0.99) showed a decrease. Models between short- and long distance runners did not differ significantly. Previous injuries increased the risk of a running injury in all models, while more training kilometers per week decreased this risk.
Conclusions: We found that risk factors for running injuries were not related to running distances. Previous injury is a generic risk factor for running injuries, as is weekly training distance. Prevention of running injuries is important and a higher weekly training volume seems to prevent injuries to a certain extent.

1. Introduction

Running is an increasingly popular form of physical activity in Western countries (Van Gent et al., 2007; Aschmann et al., 2013). In 2008, about 11.5% of the population in the US ran, and 3.4% of this group ran two times a week or more on average (Messier et al., 2008). Between 2000 and 2010 the number of half marathon runners in Switzerland increased from 2904 to 8690 female runners and from 9333 to 21583 male runners (Aschmann et al., 2013). In 2012 almost 2 million Dutch people participated in running activities (Van Hespen et al., 2012). This is about 11% of the total Dutch population. Although several health benefits are attributed to running activities (Taunton et al., 2003; Verhagen, 2012), injuries also occur frequently (Van Poppel et al., 2016; Kluitenberg et al., 2015a; Malisoux et al., 2014; Saragiotto et al., 2014). In the Netherlands about 32% of the runners get injured each year (Van Hespen et al., 2012). Most running injuries occur in the lower extremities (Chang et al., 2012; Lopes et al., 2012; Van Poppel et al., 2014; Kluitenberg et al., 2015b) with an incidence varying from 19.4 to 79.3% (Van Gent et al., 2007). This wide variation in incidence is likely due to differences in study-populations and definition of injuries (Kluitenberg et al., 2015a). The most common site of running injuries is the knee (Van Poppel et al., 2014; Kluitenberg et al., 2015b; Van Middelkoop et al., 2008a).

Several studies evaluated risk factors for running injuries (Lopes et al., 2012; van der Worp Maarten et al., 2015). The most important risk factors found are: a history of previous injuries and an increased training volume per week in male runners (Van Gent et al., 2007; Saragiotto et al., 2014; van der Worp Maarten et al., 2015). The common belief is that factors like body mass index (BMI), running experiences, types of shoes and training characteristics (duration, frequency of running, training distance, running speed, warm-up and exercise habits before running) are also associated with increased risk of

* Corresponding author. Avans University of Applied Sciences, Research Group Diagnostics, PO Box 90116, 4800 RA Breda, The Netherlands.
E-mail address: d.vanpoppel@avans.nl (D. van Poppel).

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running injuries but no statistically significant association has been found yet (Van Poppel et al., 2014, 2016; Malisoux et al., 2014; Van Middelkoop et al., 2008b; Knapik et al., 2016). This may be due to the fact that most research on risk factors for running injuries has been performed in homo- and heterogeneous groups of runners, varying from military personnel to recreational runners, running 5 km to marathon distances (42,195 km) (Van Gent et al., 2007; Knapik et al., 2016). Training related characteristics such as volume, frequency, duration and intensity of training differ between runners of different distances (Ristolainen et al., 2010). Half marathon runners had, compared to marathon runners, significantly less running experience (7.9 years versus 10.5 years), run less weekly training kilometers (minimum weekly distance 16.2–45.2 km versus 22.8–63.3 km), and run less weekly running hours (3.9 versus 4.8 h) (Ristolainen et al., 2010). Some gender-specific risk factors were also found (van der Worp Maarten et al., 2015). Overall, women are at lower risk of developing running related injuries (van der Worp Maarten et al., 2015). Previous injuries, running experience (0–2 years), restarting running and having a weekly running distance of more than 40 miles are associated with greater injury risk in men than in women. Age, previous sports, running on concrete surface, participating in marathons, weekly running distance (30–39 miles), and wearing running shoes for 4–6 months were associated with an increased risk of running injuries in females than in males (van der Worp Maarten et al., 2015). More females started running, mainly 10 km and half marathons, and the male/female ratio changed from 3:2 to 2:5 (Aschmann et al., 2013). In general, risk factors vary between different studies as the result of heterogeneity of the study population, definition of injury, type of runners (recreational or elite) and running distance (Kluitenberg et al., 2015a, 2015b).

No previous studies prospectively evaluated the incidence of running injuries and possible different risk factors for running injuries in recreational short- and long distance runners. Therefore, the aim of this study is to assess the risk factors for running injuries among recreational runners on several running distances during the race and determine whether risk factors differ between the various distances.

2. Methods

2.1. Design

A prospective cohort study with a 12-month follow-up. Runners were invited to participate in the study and were followed-up for 12 months by using web-based questionnaires. The Medical Ethical Committee of the Erasmus Medical Centre (MEC-2009-319) approved this study.

2.2. Study participants

Participants (> 18 years) of four different yearly national running events in The Netherlands were invited. These running events were the Amgen Singelloop Breda (twice: October 2009 and October 2011), ABN AMRO Marathon Rotterdam (April 2012), and the Lage Landen Marathon Eindhoven (October 2012). The runners could run a variety of distances including the marathon (42,195 km), half marathon (21,095 km), 15 km, 10 km and 5 km runs. Since there was a low turnout on the 15 km distance, these runners were combined with the 10 km group, forming a moderate distance group: short distance (5 km), moderate distance (10 and 15 km), half marathon and marathon.

Participants were invited if they subscribed digitally as individual recreational runners at least 4 weeks before the start of the running event and provided a valid email address. Professional runners were excluded. Also, business runners, as in teams of runners from a company, were excluded.

2.3. Procedure

Participants received information via email about the study accompanied by a link to an online baseline questionnaire which was developed and used previously (Van Middelkoop et al., 2008a, 2008b; Zillmann et al., 2013). All participants who returned the baseline questionnaire and agreed with the informed consent, were included in the study and received a follow-up questionnaire one week after the event (and 3, 6, 9 and 12 months after the event). Non-responders received a reminder within one week. For this manuscript we only use the baseline data and the data of one week after the event.

2.4. Baseline determinants

At baseline, runners were asked to complete questions about a) sociodemographic characteristics (e.g. age, gender, height, weight, education, lifestyle (e.g. smoking, alcohol)), b) training related characteristics (e.g. type of training, weekly training frequency, weekly running distance) and c) other running related risk factors, based on the literature (e.g. years of running experience, running terrain, and previous running injuries during the last year).

Categorical determinants with the answer options: always, often, sometimes, rarely, or never, were dichotomized into 'often' (always, often) and 'sometimes' (sometimes, rarely, never), in accordance with a previous study (Van Middelkoop et al., 2008b). BMI was calculated based on height and weight and included in the analysis as a continuous variable. The variable ‘previous injuries in 12-months preceding the event’ was dichotomous (yes/no).

A priori we defined 22 determinants relevant for the analysis: age, gender (male/female), BMI, alcohol use (yes/no), daily smoking (yes/no), education level (high/low), specific feeding supplements (yes/no), injuries in the previous 12 months (yes/no), participation in an organized running group (yes/no), running experience (years), training on firm underground (yes/no), weekly training hours, frequency and kilometers, average running speed, long distance training, interval training (yes/no), stretching before and after the training (yes/no), warming up before and after the training (yes/no) and running distance in the event (5 km, 10/15 km, half marathon or marathon).

2.5. Follow-up measurement

The follow-up questionnaire (one week after the event) obtained information regarding the running event itself (running distance and performance), new running injuries during these events, location of injuries, and pain intensity measured with an 11-point Numeric Rating Scale (NRS). (Van Middelkoop et al., 2007; Gallasch and Alexandre, 2007).

2.6. Outcome

The outcome of interest was the presence of new running injuries during the running events as reported during the one-week follow-up. Running injuries were defined as self-reported complaints of muscles, joints, tendons or bones in the lower extremity (hip, groin, thigh, knee, lower leg, ankle, foot and toe) due to running activities by which the running intensity or frequency was reduced, or medical consultation was needed (Van Poppel et al., 2014, 2016; Van Middelkoop et al., 2008b; Mintken et al., 2009).

2.7. Statistical analysis

2.7.1. Descriptive analysis

If participants subscribed to more than one of the running events (e.g. Singelloop, 2009, 2012), we only included the data of the first running event in which the participant took part. We calculated descriptive statistics (frequencies) for baseline characteristics, including

Table 1
Characteristics of the running cohorts.

Determinants[a]	5 km n = 383	10-15 km n = 1374	Half marathon n = 927	Marathon n = 1055	Total n = 3768
Demographic determinants					
Gender: males (%)[#]	89 (23.5)	695 (50.6)	642 (69.3)	828 (78.5)	2270 (60.2)
Age in years, mean (SD), range[#]	39.1 (12.4), 16-73	41.8 (11.4), 16-77	43.2 (11.4), 17-75	45 (9.6), 19-83	42.8 (11.2), 16-83
BMI, mean (SD)[#]	23.8 (3.1)	23.6 (2.6)	23.2 (2.4)	23.1 (2.2)	23.4 (2.5)
Education level, higher education (%)	300 (78.3)	1045 (76.1)	716 (77.2)	795 (75.4)	2857 (76.3)
Daily smoking: yes (%)	291 (76)	60 (4.4)	38 (4.1)	32 (3.0)	161 (4.3)
Alcohol use: yes (%)	29 (7.6)	1152 (83.8)	725 (82.5)	847 (80.3)	3080 (81.7)
Special feeding supplements: yes (%)[#]	33 (8.6)	163 (11.9)	218 (23.5)	558 (52.9)	979 (26.0)
Previous injury 12 months: yes (%)[#]	175 (45.7)	536 (45.0%)	520 (56.1)	626 (59.3)	1976 (52.2)
Training related determinants					
Trainings distance, km/week, mean (SD), range[#]	12 (7), 2-50	20 (11.2), 1-81	31.7 (14.4), 1-87	46.5 (17.6), 1-100	29.5 (18.4) 1-100
Training frequency, times/week, mean (SD) range[#]	2.3 (0.7), 1-6	2.4 (0.8), 1-12	2.9 (0.9), 1-7	3.7 (1.1), 1-12	2.9 (1.1), 1-12
0–2 (%)	241 (62.9)	768 (55.9)	295 (31.8)	83 (7.9)	
Running speed during training km/hr, mean (SD), range[#]	8.9 (1.8), 5-16	10 (1.7), 5-25	10.8 (1.4), 5-17	11.0 (1.4), 5-21	10.4 (1.7) 5-25
Running experience, years, median (IQR), range[#]	2 (1–7), 0-45	4 (2–11), 0-48	5 (3–12), 0-51	8 (4–18), 0-56	5 (2–13) 0-56
0–2 year, n (%)	226 (59.0)	551 (40.1)	207 (22.3)	147 (13.9)	
Hard training underground: often (%)[#]	308 (80.4)	1184 (86.2)	813 (87.8)	969 (91.8)	3298 (87.5)
Long-distance training: often (%)[#]	306 (79.9)	1241 (90.3)	864 (93.2)	994 (94.2)	3430 (91.0)
Interval training: often (%)[#]	120 (31.3)	497 (36.2)	417 (45.0)	441 (41.8)	1484 (39.4)
Warming-up before training: often (%)[#]	206 (53.8)	651 (47.4)	424 (45.7)	417 (39.5)	1711 (45.4)
Stretching before training: often (%)[#]	194 (50.7)	700 (50.9)	453 (48.9)	423 (40.1)	1783 (47.3)
Cooling down after training: often (%)[#]	220 (57.5)	666 (48.5)	385 (41.4)	363 (34.4)	1650 (43.8)
Stretching after training: often (%)[#]	262 (68.4)	918 (66.8)	577 (62.2)	549 (52.0)	2323 (61.6)
Organized running in groups: yes (%)[#]	114 (29.8)	458 (33.3)	395 (42.6%)	498 (47.2)	1477 (39.2)
Shoe advice: yes (%)[#]	279 (72.8)	945 (79.4)	806 (86.9)	965 (91.5)	3177 (84.3)

SD: standard deviation; IQR: interquartile range; BMI: body mass index; kg: kilogram; m: meter; km: kilometers; h: hour.
[#] Significant differences between groups.
[a] Cumulating numbers do not match because of incidental missing data.

means and standard deviations. In case the data did not show a normal distribution, we presented medians and interquartile ranges. We used the Independent Samples T-test to analyze differences between responders and non-responders.

2.7.2. Risk model development

Before developing a multivariate logistic regression model we evaluated multicollinearity between potential determinants; if a correlation between two determinants was ≥0.8 only one of the determinants was chosen for the multivariate analyses. First, the multivariate analysis was performed in the total cohort (method Backward Wald, $p < 0.1$ for exclusion). Secondly, we calculated risk models for each distance separately. Results were expressed in Odds Ratios (ORs). In case of missing variables, participants were excluded from the multivariate analysis. We complied with the 1 in 10 rule (one determinant per every 10 injuries) in the analysis, and selected the appropriate number of determinants a priori, based on the literature (Peduzzi et al., 1996).

2.7.3. Potential risk predictors

An overview of all 22 determinants is given in Table 1. For the 5 km runners we could enter 5 to 6 variables in the regression model. We choose to enter the variables that were found relevant in a previous study (age, previous injury, weekly training distance, interval training and participation in organized running groups) (Van Poppel et al., 2014). Among 10–15 km runners 21 (all except running distance) variables could be entered into the regression analysis. Finally, we included 18 determinants in the analysis of the half marathon group (age, gender, BMI, alcohol use, daily smoking, education level, specific feeding supplements, injuries in the previous 12 months, participation in an organized running group, running experience, training on firm underground, weekly training hours, frequency and kilometers, average running speed, long distance training, interval training). The same determinants were used in the analysis for the marathon runners.

2.7.4. Model performance

Lastly, performance measures of the model were calculated: explained variance (R^2) and the area under the curve (AUC)). The AUC represents the ability of the risk model to distinguish between patients with or without an injury at the 1 week follow-up and ranges from 0.5 (no discrimination) to 1.0 (perfect discrimination) (Peduzzi et al., 1996). An AUC ≥ 0.7 is considered good discrimination and an AUC between 0.6 and 0.7 as moderate discrimination.

Data were analyzed using the Statistical Package for Social Sciences (SPSS version 23, Inc, Chicago, Illinois).

3. Results

3.1. Participants

In total 17,891 participants received an invitation to participate by email, of which 3768 runners (21.1%) returned the baseline questionnaire. In total 383 participants ran 5 km, 1189 participants ran 10 km, 185 ran 15 km, 927 participants ran the half marathon and 1055 participants the marathon. Added numbers do not match up completely because of some missing data.

3.2. Baseline

The mean age of the runners was 42.8 years, with a range from 16 to 83 years; 60.8% were male and the average BMI was 23.4 (see Table 1). The percentage of males was highest in the marathon group (78.5%) and lowest in the 5 km group (23.2%). Also the percentage of runners using food supplements was highest in the marathon group (52.9%) and lowest in the 5 km group (8.6%). Almost half of the runners replied with a “yes” when asked whether they had suffered running injuries during the 12 months before the baseline questionnaire.

3.3. Follow-up

At the follow up (one week after the event) in total 2763 runners

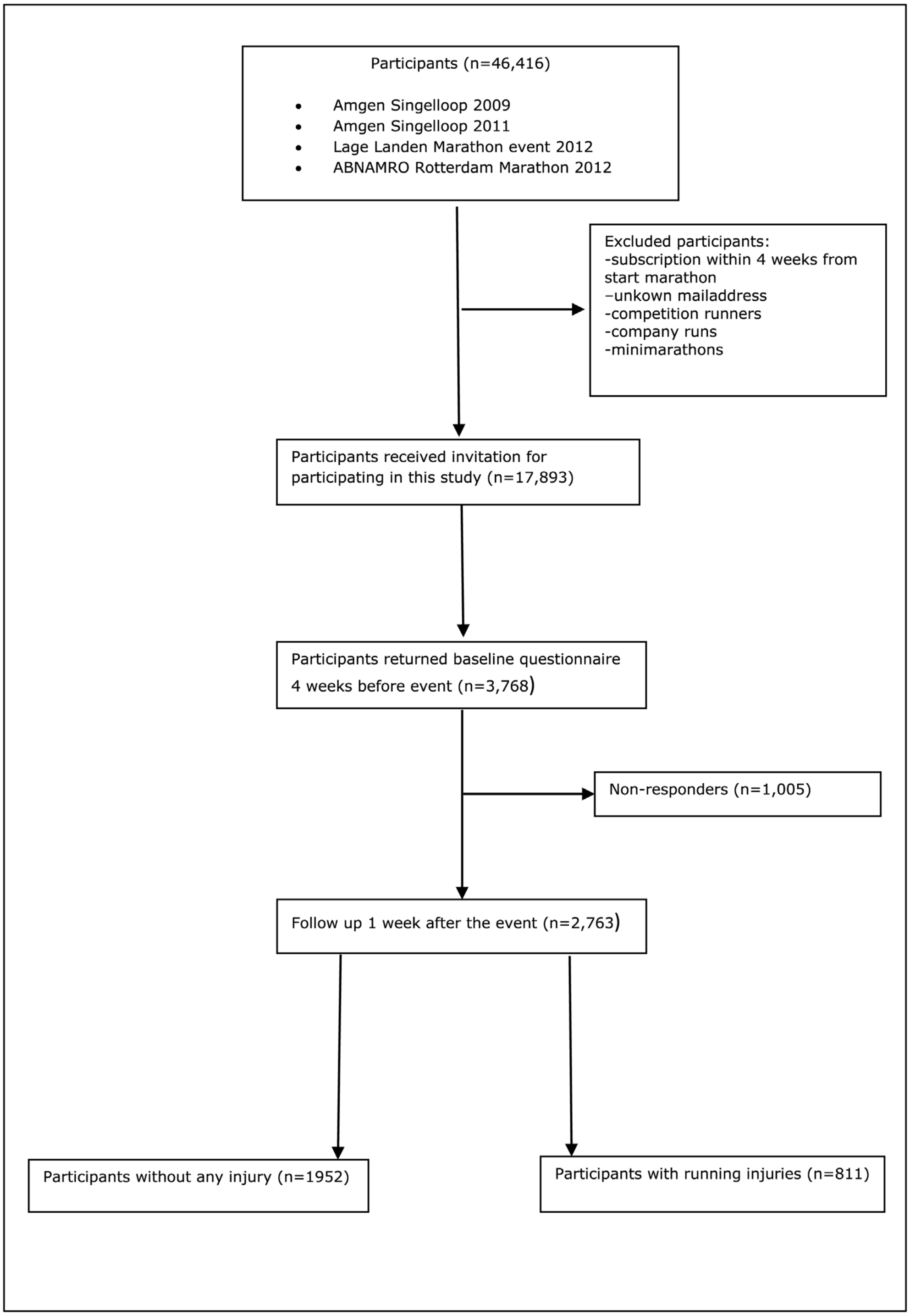

Fig. 1. Flow chart participant.

(73.3%) responded to the follow-up questionnaire (see Fig. 1). We found statistically significant differences between responders and non-responders at follow-up for some variables. Non-responders were notably younger, had a higher BMI, ran shorter distances more often and there were more female responders compared to the rest of the group (see Table 2). Although statistically significant, the differences between the groups were small.

In total 2566 participants (92.9%) started and finished, 46 participants did not finish, and 151 persons did not start due to sickness or injuries. We received data on 194 injuries incurred in 2721 runners between answering the baseline questionnaire and the follow-up (i.e. after the baseline questionnaire but before the event or during the event). Overall, 811 runners (21.5%) reported one or more running injuries at the follow-up; 5 km: 17.5% (67/250), 10–15 km: 18.7% (257/981), half marathon: 23.1% (214/708) and marathon: 25.2% (266/762).

3.4. Risk models

3.4.1. Total cohort

In total 2369 runners were included in the multivariable analysis, of which 709 (out of 811) had a running injury. We found no correlations

Table 2
Characteristic of responders versus non-responders.

	Responders T1 N = 2763	Non-responders N = 1005
Gender, male	1698 (61.5%)	572 (56.9%)[a]
Age, mean (SD)	43.5 (11.1)	40.8 (11.2)[a]
BMI, mean (SD)	23.3 (2.4)	23.5 (2.6)[a]
Running distance[a]		
5 km	253 (9.2%)[b]	130 (12.9%)[c]
10 km	1000 (36.2%)	374 (37.2%)
Half marathon	713 (25.8%)	214 (21.3%)
Marathon	780 (28.2%)	275 (27.4%)

[a] Means statistical significant difference ($p < 0.05$).
[b] % runners within responders.
[c] % runners within non-responders.

between determinants above 69%, so no determinants were removed from multivariable regression analysis.

Multivariable regression analysis resulted in a risk model including 4 determinants (see Table 3): two of which were risk factors (increasing the risk of an injury): previous injuries (OR 3.7; β 1.30) and running distance during the event (OR 1.3; β 0.27), two others were protective: older age (OR 0.99; β −0.013) and more training kilometers per week (OR 0.99; β 0.012). The Hosmer & Lemeshow test is not significant, indicating a good fit of the model. The overall risk model has an explained variance (Nagelkerke's R^2) of 12%, AUC of 68.4% (66.2–70.6), and it correctly classifies 70% of the runners.

3.4.2. Analyses per running distance

Since the running distance was a significant risk factor we also calculated a risk model per running distance (see Table 3). We found a 5 km risk model including 4 determinants: age (OR 0.97: β −0.026), previous injury (OR 4.1: β 1.400) and weekly training distance (0.95, β −0.057). Among 10–15 km runners we found a 10 km risk model including 5 determinants: age (OR 0.98; β −0.018), BMI (1.1; β 0.074), previous injury (OR 3.8; β 1.325), weekly training distance (0.97; β −0.026) and training frequency (OR 1.3; β 0.279) which correctly classified 72.7% of the runners (R^2 = 13.4%). For the half marathon and marathon runners, the regression analysis revealed a model including 2 determinants: previous injuries (OR 3.3; β 1.204 half marathon runners and OR 4.3; β 1.448 in marathon runners) and weekly training distance (OR 0.98; β −0.013 in both risk models).

For all risk models the Hosmer & Lemeshow test was not significant, indicating a good fit and all risk models correctly classify 66–76% of the runners. Furthermore, the AUC for all risk models was moderate.

4. Discussion

We found an incidence of running injuries between 17.5% (5 km) and 25.2% (marathon) depending on the running distance. Running distance during the event appeared to be a significant risk factor for developing running injuries. The distance specific risk models were quite comparable; two factors were present in all risk models: previous injury increased the risk of running injuries and higher number of weekly training kilometers decreased the risk.

4.1. Comparison with other studies

For the marathon the incidence of running injuries is in line with previous studies among marathon runners (Van Middelkoop et al., 2008a; Rubin, 1987). This is the first study that developed risk models for running injuries across different running distances in one cohort. Our hypothesis that risk factors for running related injuries vary, depending on the running distances, seems to not be confirmed. We rather found comparable distance specific risk models.

A review described that lower age is a protective factor and older age is associated with an increased risk for running injuries (van der Worp Maarten et al., 2015). A possible explanation for our contradictory finding could be that relatively older runners are fitter or better prepared than younger ones. Probably, if they would have had running injuries earlier, they would have stopped their running activities (healthy volunteer bias) (Rubin, 1987). Also, knowledge of their body could be better than in younger runners so overuse is less likely to appear (Rubin, 1987). Another explanation could be that peak ground reaction forces (GRF) in older runners seem to be lower than in younger runners and therefore they may be at lower risk. When GRF are higher, loading of joints and muscles is increased and possibly overuse injuries are less likely to appear (Sattertwhaite et al., 1999).

In this study age was only included in the final risk models for the shorter distances and in the overall risk model. Older age was a significant protective factor although odds ratios are small (OR 0.97–0.99) This is due to the fact that age is a continuous variable. This could be clinically meaningless, nevertheless it contributes statistically to the whole risk model.

Gender was not included in any of the risk models; which is in contrast with a recent systematic review (van der Worp Maarten et al., 2015), which showed that male gender is a risk factor for running injuries. However, a recent cohort study showed that female recreational runners have a different type of knee loading in comparison to males (Kline Paul and Blaise Williams, 2015). If these findings were true, in the runners studied here, we suggest that knee loading is not a meaningful injury risk factor.

Table 3
Multivariate regression models (backward wald[a]) for running injuries.

Variables	5 km (n = 220, 66 injuries)	10 -15 km (n = 818, 224 injuries)	Half marathon (n = 683, 206 injuries)	Marathon (n = 673, 230 injuries)	Total (n = 2369, 709 injuries)
Running distance during the event (categorical)					1.3 (1.2–1.5)
Age (continuous, year)	0.97 (0.95–0.99)	0.98 (0.97–0.99)			0.99 (0.98–1)
Previous injury (yes/no)	4.1 (2.2–7.6)	3.8 (2.7–5.3)	3.3 (2.3–4.8)	4.3 (2.9–6.1)	3.7 (3.0–4.5)
Weekly training distance (continuous, km)	0.95 (0.9–0.99)	0.97 (0.95–0.99)	0.98 (0.97–1)	0.98 (0.97–0.99)	0.99 (0.98–1)
BMI		1.1 (1.0–1.2)			
Weekly training frequency (continuous, nr)		1.3 (0.99–1.7)			
Performance measures					
Nagelkerke R square	15.6%	13.4%	9.6%	13.8%	12.1%
Hosmer -Lemeshow	0.89	0.92	0.12	0.85	0.70
Percentage correctly classified	76.7%	72.2%	70%	66.7%	70.2%
AUC (95% CI)	0.71 (0.64–0.79)	0.70 (0.66–0.73)	0.67 (0.62–0.71)	0.68 (0.64–0.72)	0.68 (0.66–0.71)

Data presented as OR (95% CI) unless otherwise specified; OR > 1.00 is a risk factor; OR < 1.00 is a protective factor; CI, confidence interval.
[a] Exclusion multivariate model $p < 0.10$.

4.2. Strengths and limitations

Strength of this study is the large population of runners included. Moreover, no previous studies have assessed risk factors in one cohort in four different distances. This study also has some limitations. One of the limitations is the diagnosis of running injuries since we used the self-reported complaints definition (Van Middelkoop et al., 2008b; Mintken et al., 2009). There was no physical examination in this study to objectify an injury. Also, participants might have applied the criteria for an injury differently in answering the questions. This could have led to an overestimation of running related injuries because complaints of muscle soreness could be interpreted as an injury according to our definition. On the other hand, there could also be an underestimation while participants did not report any injuries because of the absence of impairments in training or competition and/or medical consultation in regard to the definition from the recent consensus (Sinclair and Selfe, 2015).

Another limitation is that all determinants were obtained by self-reported questionnaires and the validity of the questionnaire is unknown. Therefore, it is possible that we have missed potential relevant risk factors such as psychosocial factors. Self-report studies are inherently biased by the person's feelings at the time they filled out the questionnaire (Timpka et al., 2014). Despite these limitations, the results of this study may contribute to the growing body of knowledge of running injuries, especially at other distances than marathon runners only.

5. Conclusion

We found that risk models for short- and long distance runners did not differ much. Previous injury is the most important generic risk factor for running injuries, as is weekly training distance. To prevent running injuries three risk factors seem to be important: age, previous injuries and weekly training volume. Previous injuries cannot be modified, although it became clear that it is important to prevent running injuries as this factor is a major contributor to the risk models. Runners should pay attention to their weekly training volume, as a higher weekly volume seems to be protective. There might be an optimum weekly training volume (per running distance of the event), but we were unable to assess that. Future research might also consider individual athletes' relative changes in training loads or the training load compared to the distance ran, rather than the absolute load.

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Conflicts of interest

None of the authors have conflicts of interest.

All authors had access to the data and a role in writing the manuscript.

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