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Risk factors for lower extremity injuries among male marathon runners

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The aim of this study is to identify risk factors for lower extremity injuries in male marathon runners. A random sample of 1500 recreational male marathon runners was drawn. Possible risk factors were obtained from a baseline questionnaire 1 month before the start of the marathon. Information on injuries sustained shortly before or during the marathon was obtained using a post-race questionnaire. Of the 694 male runners who responded to the baseline and post-race questionnaire, 28% suffered a self-reported running injury on the lower extremities in the month before or during the marathon run. More than six times race participation in the previous 12 months [odds ratio (OR) 1.66; confidence interval (CI) 1.08–2.56], a history of running injuries (OR 2.62; CI 1.82–3.78), high education level (OR 0.73; CI 0.51–1.04) and daily smoking (OR 0.23; CI 0.05–1.01) were associated with the occurrence of lower extremity injuries. Among the modifiable risk factor studies, a training distance <40 km a week is a strong protective factor of future calf injuries, and regular interval training is a strong protective factor for knee injuries. Other training characteristics appear to have little or no effect on future injuries.

Running is a popular form of recreational exercise all over the world. Besides the positive health effects of this form of exercise, analysis of previous studies of recreational and competitive runners reveals a yearly incidence of injuries in runners of 26–92.4% (Nicholl & Williams, 1982a; Kretsch et al., 1984; Lysholm & Wiklander, 1987; Bovens et al., 1989; Walter et al., 1989; Satterthwaite et al., 1999; Steinacker et al., 2001). There particularly is a high incidence of lower extremity injuries for those taking part in marathon runs (Nicholl & Williams, 1982a; Kretsch et al., 1984; Marti et al., 1988; Walter et al., 1989; Satterthwaite et al., 1996). Several studies have suggested a number of factors that may increase the risk of injuries for runners. A review from Macera (1992) concluded that among the modifiable risk factors studied, weekly running distance is the strongest predictor for future injuries. Most studies showed an increasing injury rate with increasing weekly running distance beyond approximately 32 km/week (Koplan et al., 1982; Jacobs & Berson, 1986; Bovens et al., 1989; Macera et al., 1989; Walter et al., 1989). Previous running injuries are also reported to be a strong predictor for future injuries in several studies (Kretsch et al., 1984; Macera et al., 1989, 1991; Walter et al., 1989; Wen et al., 1998). However, few studies investigated lower extremity injuries and their risk factors in long-distance runners. As frequently seen in studies in the 1980s, the methodological quality of these studies is quite low, especially with respect to the statistical analysis. Only one more recent study of Wen et al. (1998), which studied the possibility of alignment as being a risk factor for running injuries, determined the possible risk factors independently from the injury and additionally applied a multivariate analysis. In order to enhance the prevention of running injuries, it is of interest to enlarge the knowledge concerning potential risk factors, especially modifiable risk factors. Therefore, the aim of this study was to examine prospectively the relationship between possible risk factors and lower extremity injuries occurring shortly before or during a marathon run.

Methods

Study participants

The Rotterdam marathon was held on April 10, 2005 over a standard-length course (42.2 km) through Rotterdam. The daily mean temperature in Rotterdam was 7.6 °C (range 4.3–11.0 °C), and the daily mean relative atmospheric humidity was 86%. Of the approximately 6000 recreational male runners who signed in for the Rotterdam marathon, a random sample of 1500 recreational runners was drawn. The questionnaires were added to every fourth start package that was sorted out on start number by the mail-order firm. One month before the start of the marathon, a baseline questionnaire was sent by a mail-order firm to the 1500 randomly selected recreational runners. These were asked to return the questionnaire by mail before April 10, 2005. Immediately after the Rotterdam marathon, a second questionnaire was sent to all included runners. Those not returning the post-race questionnaire were sent a reminder letter. Residual non-responders were then contacted by telephone and asked to return the completed questionnaire.

Athletes were included in this study if they met the following criteria: (1) they had to be a male resident of the Netherlands, (2) they were recreational/amateur runners and (3) they returned both the baseline questionnaire before running the marathon and the post-race questionnaire after the marathon run. Recreational runners were runners who signed in for the Rotterdam marathon and were not competitive with the professional runners in the Rotterdam marathon race.

Questionnaires

From the baseline questionnaire, we obtained information about possible risk factors for running injuries categorized into demographic factors, training-related factors, race event factors, lifestyle factors and previous running injuries. Demographic factors included age, sex, height, weight and education. In the training-related section, participants were asked about training distance, frequency and duration (average from last 3 months' total), running experience, type of training underground, training type (long-distance, interval) and shoes. Race event factors included earlier race participations, warming up, cooling down and stretching activities. Lifestyle aspects included other sport participation, special nutrition, smoking, medication and alcohol usage.

From the second questionnaire, we obtained information regarding injuries occurring during the marathon (location of injury, pain intensity and other complaints). We also asked participants to report their warming-up and cooling-down strategy, nutrition intake and brace use with respect to the marathon run.

The researchers developed the questionnaire and it was pilot-tested on a group of runners during the half marathon 6 months before the investigated marathon race. Questions were mostly multiple-choice or yes/no format. Questions about training and race factors were generally in short-answer format.

The outcome measure for this study was a self-reported running injury occurring 1 month before or during the marathon run. The injury definition was elaborated on the injury definition of Macera et al. (1989). A running injury was defined as a self-reported "injury on muscles, joints, tendons and/or bones of the lower extremities (hip, groin, thigh, knee, lower leg, ankle, foot, and toe) that the participant attributed to running." The problem had to be severe enough to cause a reduction in the distance, speed, duration or frequency of running.

Statistical analysis

Descriptive statistics were used for baseline characteristics. Continuous variables such as age, height, weight, training duration, frequency and distance, running experience, years of race participation and race participations in the last year were categorized in tertiles.

Using running injuries as the dependent variable, univariate regression analyses were performed on demographic, training, race event, lifestyle and previous running injury factors for each factor independently. Factors with a P-value ≤ 0.20 on the Wald test in the univariate models were entered in a multivariable logistic regression model. Backward stepwise elimination was used for the multivariable logistic analysis of prediction of runners at risk for injuries, and $P \leq 0.10$ was used as a cut-off level for elimination of non-significant predictors from the prognostic model.

Subgroup analyses were planned for the most frequently occurring running injuries. For these analyses, factors with a univariate P-value ≤ 0.20 on the Wald test were entered into category-specific regression models because fewer cases were involved in the analysis. Secondly, factors with a P-value ≤ 0.20 in the categorical models were entered into the full multivariable model. For these subgroup location-specific analyses, the factor "other incident injury than that location" was also included in the analysis.

Calibration of the logistic model was assessed using the Hosmer–Lemeshow goodness-of-fit test (Hosmer & Lemeshow, 1989), and discrimination was assessed using the area under the receiver operating characteristic (ROC) curve to evaluate how well the model distinguished patients who were injured from those who were not injured (Zweig & Campbell, 1993; Koch & Hau, 2005).

Odds ratios (ORs) are presented with 95% confidence intervals (CI). Possible risk factors were those with $P \leq 0.1$ on bivariate analyses. All statistical analyses were performed using SPSS for Windows, version 11.0, 2001.

Results

A total of 726 runners responded to the baseline questionnaire. One female runner returned the questionnaire because she bought the start package, including the questionnaire, from a registered male and was excluded for this reason. The final study population consisted of 694 (95.7%) male runners who also responded to the second questionnaire. The baseline characteristics of the study population are represented in Table 1. The mean age of the study population was 44 years with a standard deviation of 9.6 years, which was representative for the entire male marathon population (42.8 $\pm$ 9.3 years). Almost half of the runners ran less than four times a week in the 3 months preceding the marathon. However, 21.3% of the respondents ran more than 60 km a week in the 3 months preceding the marathon. More than half of the runners had suffered a running injury during the 12 months preceding the baseline questionnaire.

Of the 694 respondents of the post-race questionnaire, 648 started the race, 46 did not start and the remaining one respondent is unknown. Of those who started, 35 did not finish. Of the runners who did not start, 30 did not because of a running injury. A comparison of age, body mass index (BMI), running experience, weekly running distance, frequency and previous running injuries of the runners who completed both questionnaires compared with those who did not showed no significant differences ($P > 0.05$).

A total of 195 runners (28.1%) reported a new running injury occurring in the month before or during the Rotterdam marathon. Of these injuries, 15.6% ($n = 108$) occurred in the month before the marathon and 17.0% ($n = 118$) of the runners suffered a new running injury during the marathon.

Table 1. Baseline characteristics ($n = 694$)

	Mean (SD)	n	%
Demographic characteristics			
Age (years), mean (SD)	43.8 (9.6)		
Height (cm)	182.1 (6.7)		
Weight (kg)	78.1 (8.8)		
BMI (kg/m^2)	23.5 (2.1)		
BMI > 25		105	15.1
Education level (high)		324	46.7
Training-related factors			
Weekly distance (km)	50.2 (18.3)		
Weekly distance (km) > 60		148	21.3
Weekly hours	5.7 (2.9)		
Weekly frequency	3.6 (1.1)		
Running experience (years)	10.8 (8.9)		
Weekly distance per weekly hours (km/h)	9.4 (2.6)		
Weekly distance per weekly frequency	14.0 (4.3)		
Special training program (yes)		454	65.4
Athletics association (yes)		318	45.8
Hard training underground (always)		669	96.4
Tartan training underground (always)		85	12.2
Gravel training underground (always)		10	1.4
No hard training underground (always)		156	22.5
Long-distance training (always)		682	98.3
Interval training (always)		301	43.4
Warming-up (always)		344	49.6
Stretching before training (always)		359	51.7
Cooling-down (always)		300	43.2
Stretching after training (always)		434	62.5
Knee brace use (yes)		10	1.4
Ankle brace use (yes)		6	0.9
Use of several shoes (yes)		600	86.5
Alternately wearing shoes (yes)		397	57.2
Shoe advice (yes)		616	88.8
Race events			
Earlier races (yes)		667	96.1
History of race participation (years)	9.0 (8.0)		
Times of race participation last year	6.5 (7.6)		
Participation race within framework of the marathon (yes)		325	46.8
Races 0–5 km (yes)		13	1.9
Races 6–10 km (yes)		169	24.4
Races 11–22 km (yes)		608	87.6
Races 22–42 km (yes)		295	42.5
Warming-up before race (always)		429	61.8
Stretching before race (always)		405	58.4
Cooling-down after race (always)		240	34.6
Stretching after race (always)		355	51.2
Use of same shoes race and training (yes)		618	89.0
Knee brace use race (yes)		9	1.3
Ankle brace use race (yes)		6	0.9
Lifestyle factors			
Participation other sports (yes)		416	59.9
Daily smoking (yes)		22	3.2
Alcohol use ($\geq$10 glasses/week)		185	26.7
Special feeding supplements (yes)		585	84.3
Non-musculo-skeletal comorbidities (yes)		124	17.9
Medication use (yes)		70	10.1
Running injuries			
Injury previous 12 months (yes)		376	54.2

BMI, body mass index.

Most of the incident injuries occurred in the knee (28.7%), calf (27.2%) and thigh (15.9%).

The median pain intensity of the 195 injured runners in rest directly after the marathon run was 2 [interquartile range (IQR) = 3], and the median pain intensity during exercise was 4 (IQR = 5), both on a pain scale from 0 to 10, with higher scores indicating more pain.

Non-musculo-skeletal comorbidities during the marathon were seen in 97 (14%) marathon partici-

Table 2. Univariate odds ratios (ORs) and multivariable risk model (backward elimination) for incident injuries vs no injury

Variables	Univariate analysis		Multivariable analysis	
	OR (95% CI)	*P*-value	OR (95% CI)	*P*-value
High education level	0.76 (0.55–1.07)	0.11	0.73 (0.51–1.04)	0.08
Long distance training				
Always	0.32 (0.10–1.07)	0.06		
Interval training				
Always	0.76 (0.54–1.07)	0.12		
Weekly distance per weekly frequency				
0–10	095 (0.64–1.42)	0.81		
11–15	Reference			
≥16	1.38 (0.86–2.22)	0.18		
History of race participation (years)				
0–3	1.21 (0.79–1.85)	0.39		
4–10	Reference			
≥11	1.47 (0.96–2.24)	0.08		
Times of race participation last year				
0–2	1.29 (0.84–1.97)	0.25	1.33 (0.86–2.06)	0.20
3–6	Reference		Reference	
≥7	1.55 (1.02–2.36)	0.04	1.66 (1.08–2.56)	0.02
Warming-up before race				
Always	0.79 (0.55–1.12)	0.18		
Daily smoking				
Yes	0.25 (0.06–1.07)	0.06	0.23 (0.05–1.01)	0.05
Non-musculo-skeletal comorbidities				
Yes	1.45 (0.96–2.19)	0.08		
Injury previous 12 months				
Yes	2.51 (1.76–3.56)	0.00	2.62 (1.82–3.78)	0.00

Only entered variables shown.
CI, confidence interval.

pants. The most reported complaints were gastro-intestinal tract ($n = 33$), locomotor apparatus (arms, neck, shoulder and back) other than lower extremities ($n = 30$) and the skin ($n = 10$). Of all participants, 10.2% used pain medication shortly before or during the marathon run while 6.5% used pain medication after the marathon run.

Warming-up exercises before the start of the marathon were performed by 46% of the runners and more than 50% of the runners carried out some stretching exercises before the start. Directly after the marathon, 20% carried out some running exercises while almost 40% performed stretching exercises after the run.

Risk factors

Ten of the possible 48 potential risk factors (Table 2) were univariately associated with lower extremity injuries ($P < 0.20$). A multiple logistic regression model was used to assess the combined effect of these risk factors on the occurrence of lower extremity injuries. The final multivariable logistic model after backward elimination is represented in Table 2. More than six times race participation in the last year (OR 1.66; CI 1.08–2.56) and previous running injuries (OR 2.62; CI 1.82–3.78) were associated with the occurrence of lower extremity injuries. High education level (OR 0.73; CI 0.51–1.04) and daily smoking (OR 0.23; CI 0.05–1.01) were protective factors for the occurrence of running injuries. The Hosmer–Lemeshow goodness-of-fit ($P = 0.87$) showed no lack of fit of the final model to the data (a large *P*-value indicating that there is not a large discrepancy between observed and expected injuries). The index of predictive discrimination for this model, namely the area under the ROC curve, was 0.65, reflecting moderate ability of the model to discriminate between runners who do and do not have a running injury.

Knee injuries

The occurrence of knee injuries was univariately associated with 11 of the potential 49 risk factors. The final multivariable logistic model is represented in Table 3. A previous running injury in the last 12 months (OR 3.67; CI 1.79–7.49) and a running experience of more than 15 years (OR 2.56; CI 1.22–5.34) were risk factors for the occurrence of knee injuries shortly before or during the marathon. Always performing interval training (OR 0.49; CI 0.26–0.93) was a protective factor for the occurrence of knee injuries. The accuracy of the model was moderate with an area under the curve (AUC) of 0.72, and the Hosmer–Lemeshow goodness-of-fit ($P = 0.60$) showed no lack of fit of the final model to the data.

Table 3. Multivariable risk model (backward elimination) for incident *knee* injuries vs no knee injury

	OR	95% CI	*P*-value
Interval training (always)	0.49	0.26–0.93	0.03
Injury previous 12 months	3.67	1.79–7.49	0.00
Running experience			0.03
0–4 years	1.43	0.63–3.26	0.40
15+	2.56	1.22–5.34	0.01

CI, confidence interval; OR, odds ratio.

Table 4. Multivariable risk model (backward elimination) for incident *calf* injuries vs no calf injury

	OR	95% CI	*P*-value
High education level	0.60	0.33–1.10	0.10
Training distance (km)			0.04
0–40	0.36	0.17–0.78	0.01
60+	0.57	0.27–1.19	0.14
Athletics association	0.58	0.31–1.09	0.09
Incident injury at another localization	2.57	1.42–4.67	0.00

CI, confidence interval; OR, odds ratio.

Calf injuries

In the subgroup analysis, the occurrence of calf injuries was univariately associated with seven of the 49 potential risk factors. Table 4 represents the final multiple logistic regression model for calf injuries. Having an incident injury at another localization was a risk factor for incident calf injuries (OR 2.57; CI 1.42–4.67). A high education level (OR 0.60; CI 0.33–1.10), a training distance <40 km a week (OR 0.36; CI 0.17–0.78) and membership of an athletics association (OR 0.58; CI 0.31–1.09) were all protective factors for calf injuries. The AUC was 0.69, reflecting a moderate accuracy of the model. The Hosmer–Lemeshow goodness-of-fit ($P = 0.44$) showed no lack of fit of the final model to the data.

Discussion

This cohort study has identified several risk factors for the occurrence of marathon-related injuries on the lower extremities in male runners. More than six times race participation in the previous year and a history of running injuries were risk factors for the occurrence of running injuries. However, this study also revealed that a high education level and daily smoking are protective factors for marathon-related lower extremity injuries. We also found that a high education level, a training distance of <40 km a week and membership of an athletics association were protective factors for the occurrence of calf injuries shortly before or during the marathon run. For knee injuries, runners with a history of running injuries and/or a running experience of more than 15 years were at a higher risk.

In this study, 28% of the runners suffered a running injury on the lower extremities in the month before or during the marathon run. The incidence rate found in this study is comparable with the incidence rates found in other studies (Nicholl & Williams, 1982a; Maughan & Miller, 1983; Jakobsen et al., 1989). The knee and calf were found to be the most predominant sites of injuries, which have also been reported in several other studies (Maughan & Miller, 1983; Bovens et al., 1989; Walter et al., 1989; Satterthwaite et al., 1996; Wen et al., 1998; Taunton et al., 2003).

Risk factors

In this study, a multivariable analysis of several modifiable risk factors was performed. Previous studies on running injuries were mostly retrospective and only represented a univariate analysis. However, several studies have reported numerous risk factors for injuries in long-distance runners.

The rates of injuries among runners in this study do not increase with increasing age. Previous studies have reported higher age as a significant risk factor (Nicholl & Williams, 1982b; Wen et al., 1998; Satterthwaite et al., 1999; Taunton et al., 2003) but higher age is also reported as a protective factor for the occurrence of running injuries (Nicholl & Williams, 1982a; Kretsch et al., 1984; Satterthwaite et al., 1999). However, in the majority of the literature, age was not associated with running injuries and this is supported by the present study.

A history of running injuries was reported to be a significant risk factor for the occurrence of running injuries shortly before or during the marathon. This result was confirmed in other studies reporting relative risks of 1.7–2.7 (Macera et al., 1989, 1991; Walter et al., 1989; Wen et al., 1998). This could suggest a possible role of unfavorable individual structural and biomechanical characteristics of injury-sensitive runners, or an insufficient healing of the primary lesion, or both (Marti et al., 1988). The increased risk of previous injuries may have also been influenced by the severity of the primary injury, inadequate rehabilitation and/or premature return to sports activity.

A high education level (vocational college/university) is shown to be a protective factor for running injuries. However, the association between running injuries and education level has not been investigated so far. Nevertheless, a high education level is often seen as a protective factor for the occurrence of musculo-skeletal complaints (Reynolds et al., 2000). Runners with a high education level may be more capable of dealing with upcoming injuries and therefore do not develop the more serious injuries that are reported in the questionnaire.

The present study indicates that daily smoking helps to prevent running injuries, but there is no evidence in the existing literature to support this finding, although Satterthwaite et al. (1999) found a negative association between smoking and the occurrence of blisters. However, blisters were not included in this study and so it remains difficult to explain these findings. We cannot give a possible physiological explanation for this finding. However, we think that daily smoking is a proxy variable for a non-measured variable in our study.

As mentioned in the introduction, weekly training distance is the most frequently cited risk factor for running injuries. However, we did not find an increased risk for injuries with increased weekly running distance. Following previous studies, runners would be at greater risk when running more than 60 km a week (Macera et al., 1989; Walter et al., 1989). Nevertheless, Kretsch et al. (1984) suggested that marathon entrants need to average at least 60 km/week in the 2–3 months before the race to minimize the risk requiring treatment on race day. In our study population, 27% of the runners with a weekly running distance of more than 60 km a week were injured against 30.5% injured runners with a weekly running distance of 0–40 km a week. Hence, the association between weekly running distance in the 3 months before the marathon and the occurrence of running injuries remains unclear.

A high education level, a training distance <40 km a week and a membership of an athletics association are found to be protective factors for the occurrence of calf injuries. These last two factors are modifiable and indicate that the risk on calf injuries may be reduced. The factor membership of an athletics association may be covered by several other training factors; however, these factors did not remain in the model.

The occurrence of knee injuries in this study was associated with previous running injuries and a running experience of more than 15 years and a lack of interval training. Several studies showed a previous injury to be a significant predictor for the occurrence of a new injury and this study indicates that this is true for knee injuries also. Satterthwaite et al. (1999) already reported an association between knee injuries and participation in a marathon for the first time. Our findings suggest the opposite: more experienced runners who probably have more experience on marathon runs are at greater risk for knee injuries. A relationship with higher age can be suggested; however, the factor age does not survive in the multivariate model. Nevertheless, more than 40% of the experienced injured runners in our study are 50 years old or older vs 20% of the less experienced injured runners. This could suggest that these older runners might experience symptoms of early osteoarthritis. This should be in correspondence with the study of Lievense et al. (2003) showing some evidence for the fact that long-distance running predisposes for hip osteoarthritis. However, for knee osteoarthritis no such evidence has been found yet (Lane et al., 1986; Cymet & Sinkov, 2006).

Strength and limitations of the study

The strength of this study was its prospective study design. Injury information was obtained prospectively and extensive information was available concerning runners' characteristics, running experience and training patterns. One limitation of this study was that all outcomes and risk factors were self-reported and thus may not be completely reliable. Unfortunately, because we have no information from a physical examination, possible risk factors such as runners' strength, running pattern and alignment could not be taken into consideration. Running injuries were also self-registered. We chose not to mention the duration of an injury in our definition. However, it could have been useful to register the duration of a self-reported running injury as an index for injury severity. Furthermore, we chose a significance level of 0.1. Hence, we defined variables associated with running injuries whose OR was not included in the 95% confidential interval. However, in our guidelines, these variables are associated with running injuries.

The response rate of the baseline questionnaire was 48.4%, which is somewhat lower than we had expected. A comparably relative high non-response was found in other athletics-based studies as well (Egermann et al., 2003; Kazemi et al., 2005; McKean et al., 2006). For the baseline questionnaire, it was impossible to post reminders and to telephone the non-responders because of the anonymous mailing by a mail-order firm. Nevertheless, the response rate of the post-race questionnaire was very high; i.e. 95%. The 1-year prevalence of running injuries found in the present study might have been influenced by selection bias. Subjects who were already injured or recently had a running injury might have been more willing to participate, in which case the prevalence rates could have been overestimated.

The intention of this cohort study was to draw a random sample out of 10 000 male and female athletes. However, through a communication problem with the mail order-firm, the random sample was only performed within the male runners group. As a consequence, this study is about male recreational runners only.

Perspectives

Several risk factors were taken into account in this prospective cohort study. A high education level was found to be protective for running injuries and a history of running injuries in the previous 12 months is shown to be a risk factor. This result is also confirmed in several other studies and so great care should be taken regarding subjects with a history of running injuries, especially in the 12 months before the marathon event. Prior injuries should be sufficiently healed before participating in a marathon run. Among the modifiable risk factors studied, <40 training kilometers a week is a strong risk factor for future calf injuries and always performing interval training is a strong protective factor for knee injuries. Other training characteristics seem to have little or no effect on the injury rate.

Key words: running, injuries, marathon, risk factors.

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