

# Predictors of Running-Related Injuries Among 930 Novice Runners

## A 1-Year Prospective Follow-up Study

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**Background:** To identify persons at high risk of sustaining running-related injuries, an evidence-based understanding of the risk factors associated with injury is needed.

**Purpose:** To identify demographic and behavioral risk factors associated with running-related injuries.

**Study Design:** Observational prospective cohort study with a 1-year follow-up.

**Methods:** Exposures including sex, age, body mass index (BMI), behavior (Type A Self-Rating Inventory [TASRI]), running experience, other sports activity, previous running-related injuries, and other injuries not related to running were assessed prior to or at baseline. The outcome of interest was a running-related injury, defined as any musculoskeletal complaint of the lower extremity or back caused by running that restricted the amount of running (volume, duration, pace, or frequency) for at least 1 week. All participants quantified their running volume by global positioning system (GPS) and used a neutral running shoe. Time to first injury for each exposure variable was analyzed using a generalized linear model, with cumulative kilometers of the training sessions as the time scale.

**Results:** A total of 930 individuals were included in the study, of which 254 sustained a running-related injury during a total of 155,318 km of running. By calculating the cumulative injury risk differences (cIRDs) [95% confidence intervals] after 500 km of running, the TASRI Type B behavior (cIRD, 11.9% [−0.5%; 23.3%];  $P = .04$ ) was found to be a significant predictor of injury, while age between 45 and 65 years (cIRD, 14.7% [−2.1%; 31.5%];  $P = .08$ ) and previous injuries not related to running (cIRD, 11.1% [−0.2%; 22.4%];  $P = .05$ ) were considered clinically interesting, although not statistically significant. In addition,  $\chi^2$  test results across 4 BMI groups also revealed a borderline significant relationship ( $P = .06$ ). No significant or clinically relevant relationships were found for sex ( $P = .42$ ), previous running-related injury ( $P = .47$ ), running experience ( $P = .30$ ), and other sports activities ( $P = .30$ ).

**Conclusion:** The findings of the present study suggest BMI >30 kg/m<sup>2</sup>, age between 45 and 65 years, noncompetitive behavior, and previous injuries not related to running are associated with increased risk of injury among novice runners, while BMI <20 kg/m<sup>2</sup> was protective. Still, the role of the risk factors in the causal mechanism leading to injury needs to be investigated.

**Keywords:** running-related injury; novice; BMI; behavior; age

Running-related injuries (RRIs) occur more often among novice runners commencing a running regimen than among runners with a weekly running volume of >40 miles/week.<sup>14</sup> Because of the large number of inactive people choosing running as their preferred form of exercise when commencing a training regimen and because the risk of RRI among novice runners is high, it is important to identify persons at high risk of injury in this population.<sup>10</sup> Few studies have examined the risk factors for injury occurrence among novice runners.<sup>2-4,6,7,15</sup> Previous injuries,<sup>6</sup> high body mass index (BMI),<sup>3,6,15</sup> arch movement,<sup>6</sup> and training errors<sup>14,15</sup> have been associated with injury occurrence. Still, more work is needed to document these relationships and ascertain whether other exposures are associated with injury occurrence.

To improve the understanding of the risk factors associated with RRI, we designed the Danish Novice Running study (DANO-RUN). Using surveillance analyses, this study intends to identify the demographic and the behavioral risk factors that may predispose a runner to injury.

## METHODS

The study was designed as a prospective study with a 1-year follow-up. The study design, procedures, and informed consent procedure were presented to the Ethics Committee of Central Denmark Region (M-20110114). The committee waived the request of ethics approval since the study design was observational. The study was accepted by the Danish Data Protection Agency. The participants were mainly recruited from Jutland, Denmark, between July and August 2011 and followed for 1 year from the day they signed the informed consent at a baseline

investigation. Guidelines for reporting observational studies in epidemiology were followed according to the statement of strengthening the reporting of observational studies in epidemiology (STROBE).<sup>21</sup>

## Study Population

To locate individuals interested in commencing a running regimen, e-mails were distributed to local companies and among employees and students at hospitals and at a university. All persons who received an e-mail with information about the study were allowed to forward it to family, friends, or others they assumed to have an interest in taking up running. After 3 weeks, a total of 1530 persons had signed up for the study. Only healthy novice runners were eligible for inclusion in the study. We used a modified version of the definition used by Buist et al<sup>5,7</sup> to define a novice runner, that is, a person who had not been running on a regular basis the last year. The cutoff to define a regular basis was set at 10 km of the total running volume in all training sessions during the last year. Thus, persons running  $3 \times 2$  km the last year were eligible to participate, while persons running a total of  $3 \times 5$  km during 1 year were excluded. Other exclusion criteria were age younger than 18 or older than 65 years, injury in the lower extremities or back 3 months preceding the baseline investigation, no e-mail address or access to the Internet, participation in other sports for more than 4 hours/week, necessity for the use of insoles while running, pregnancy, previous strokes, heart diseases, or pain in the chest during training. Those who were unwilling to run using a neutral running shoe or use a global positioning system (GPS) watch to quantify the training characteristics were also excluded.

## Baseline Investigation

Eligible persons were invited for a baseline investigation after completing an online questionnaire. At the baseline investigation, the participants were informed about the study before providing signed informed consent. Participants' heights were measured by a ruler and their weights by a calibrated personal scale (SC 330; Tanita Corporation, Tokyo, Japan). Hereafter, the participants received a pair of neutral running shoes (Supernova Glide 3 Male or Female; Adidas, Herzogenaurach, Germany) and a GPS watch (Forerunner 110 M; Garmin International Inc, Olathe, Kansas). Over a distance of 1000 m in various terrains, a GPS watch of this type measures 8 to 62 m shorter than a gold standard differential GPS watch. In the worst-case scenario, the 95% limits of agreement between the 2 GPS watches are  $-42$  to 31 m

over a 1000-m distance.<sup>15</sup> Finally, the participants were instructed to upload their training data to their personal training diary (available at <http://www.vilober.dk/>). They were told to upload every training session (running only) saved on the GPS watch to the home page. In cases of missing GPS data, they were told to manually enter the time and distance. At all times, the participants had to run wearing the provided neutral running shoes.

## Follow-up Period

After baseline, in every running session, the participants were expected to use their neutral running shoes. The participants received no running program and decided for themselves when and where to run. No restrictions were given with regard to the volume, duration, or intensity of each running session. Participants were told that they would receive the shoes and GPS for free only if they completed a total of 52 training sessions during the 1-year follow-up.

## Outcome Variable

An RRI was defined as any musculoskeletal complaint of the lower extremity or back caused by running, which restricted the amount of running (volume, duration, pace, or frequency) for at least 1 week. This definition was a modified version of that used by Buist et al.<sup>7</sup> If a participant sustained an RRI during the follow-up period, he or she was instructed to contact the research group via his or her personal training diary. The participant was then contacted by telephone to make an appointment for a clinical examination. At the examination, the participant was examined and diagnosed by a physical therapist, preferably no later than 1 week after the initial contact. The injury was classified as an RRI or an injury related to other causes. Injuries related to other causes were not considered as an RRI. If an additional examination was needed, participants were referred to the Division of Sports Traumatology at Aarhus University Hospital, Denmark.

## Potential Risk Factors for RRI

Exposures of interest included sex, age, behavior, previous running experience, sports activity, previous injuries not related to running, and previous RRI. Prior to the baseline investigation, all of these exposures were assessed from the questionnaire completed. In addition, BMI was calculated based on measurements of weight and height at the baseline investigation. For all exposures, the group that had the lowest risk of injury was chosen as the reference group

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One or more of the authors has declared the following potential conflict of interest or source of funding: Adidas, Herzogenaurach (Germany), and Garmin International Inc (Olathe, Kansas, USA) provided the research group with discounts on running shoes and GPS watches. The Danish Rheumatism Organization provided financial support.

(“reference”), and the group with no difference was chosen as a random reference group (“reference random”).

Age was categorized into 3 groups: 18 to 30 years, 30 to 45 years (reference), and 45 to 65 years. Data on weight were missing for 2 participants, and, therefore, their self-reported weights assessed from the questionnaires were used to calculate their BMI. The BMI was categorized into 4 exposure groups: <20, 20 to 25 (reference), 25 to 30, and >30. The Type A Self-Rating Inventory (TASRI) was used to assess behavior.<sup>8</sup> Participants were dichotomized into either a type A behavior, which corresponds to a competitive, impatient, hyperactive personality, or a type B behavior (reference random), which corresponds to a relaxed, laid-back personality. Because the participants were all novice runners at baseline, previous running experience was categorized as no experience = had never ran on a regular basis before (reference) and experienced = ran on a regular basis before but not in the 12 months preceding the baseline measurements. These definitions are similar to those used by Buist et al.<sup>6</sup> The levels of sports activity were categorized into 3 groups: no other sports activity (reference random), sports activity with axial load, and sports activity without axial load (axial load = weightbearing). Participants were also dichotomized into groups based on their previous RRI status: no previous RRI (reference) or previous RRI. No previous injury not related to running was also dichotomized into yes or no (reference).

### Statistical Analyses

Time to RRI was analyzed using cumulative kilometers of the training sessions as the time scale. Each participant was considered the unit of analysis. Participants were censored in case of RRI, pregnancy, disease, lack of motivation, unwillingness to attend the clinical examination in case of RRI, or end of follow-up at 1 year, whichever came first. The RRI proportion as a function of follow-up kilometers was estimated using the Kaplan-Meier method. The cumulative injury risk difference (cIRD) and 95% confidence interval (CI) of sustaining an injury up to a running volume of 500 km were analyzed with a generalized linear regression model using the pseudo values method.<sup>11</sup> In some studies, forward and backward elimination of possible risk factors associated with injury occurrence have been performed in the regression analyses. However, this approach may lead to estimates in the final model, which are biased away from the null, confidence intervals that tend to be narrow, and *P* values to be small.<sup>18</sup> As a consequence, forward or backward elimination of risk factors was not used in the present study. Instead, we presented crude analyses and adjusted the potential confounders hypothesized a priori to influence the estimates in the associations between the exposure of interest and RRI. Predictors of injury were defined as exposures that revealed a statistically and clinically significant relationship to injury occurrence. Relationships were considered statistically significant at  $P \leq .05$ . In addition, relationships between the 2 exposure groups (with a corresponding *P* value ranging from .15 to .05) were considered clinically interesting if the estimate of the risk differences

TABLE 1  
Demographic and Behavioral Characteristics:  
Counts and Frequencies of Participants  
in Each of the Exposure Variables<sup>a</sup>

Variable	All (n = 930)	Injury Free (n = 676)	Injured (n = 254)
Sex			
Male	468 (50.3)	338	130
Female	462 (49.7)	338	124
Age			
18-30 y	266 (28.6)	208	58
30-45 y	469 (50.4)	339	130
45-65 y	195 (21.0)	129	66
BMI			
<20 kg/m <sup>2</sup>	41 (4.4)	35	6
20-25 kg/m <sup>2</sup>	369 (39.7)	276	93
25-30 kg/m <sup>2</sup>	345 (37.1)	247	98
>30 kg/m <sup>2</sup>	175 (18.8)	118	57
TASRI at baseline			
Type A behavior	207 (22.2)	160	47
Type B behavior	723 (77.8)	516	207
Running experience			
No	561 (60.3)	416	145
Yes	369 (39.7)	260	109
Sports activity			
No	582 (62.6)	425	157
Yes, without axial load	174 (18.7)	124	50
Yes, with axial load	174 (18.7)	127	47
Previous RRI			
No	765 (82.3)	574	191
Yes	165 (17.7)	102	63
Previous non-RRI			
No	579 (62.3)	437	142
Yes	351 (37.7)	239	112

<sup>a</sup>All variables were measured or reported prior to or at the baseline investigation. Data presented for all participants and stratified by injury status during the project. Numbers in parentheses are frequencies. RRI, running-related injury; BMI, body mass index; TASRI, Type A Self-Rating Inventory.

between the 2 exposure groups exceeded 10% or -10%, corresponding to a number needed to treat >10 persons, and if the lower limit or upper limit of the confidence interval (with a range slightly crossing 0) was close to 0. The evaluations of “close to 0” were admittedly based on subjective judgment. All analyses were performed using STATA version 12 (StataCorp, College Station, Texas). Since this study was exploratory, no power analyses were performed.

### RESULTS

A total of 933 novice runners were included in the DANO-RUN study, of which 3 were excluded due to missing data on the injured leg ( $n = 1$ ) or injuries sustained prior to baseline ( $n = 2$ ). Of the remaining 930 persons (468 males and 462 females; mean age,  $37.2 \pm 10.2$  years; mean BMI,  $26.3 \pm 4.4$  kg/m<sup>2</sup>), 254 sustained an injury during the 1-year follow-up. Description of the baseline characteristics and the count in each stratum for all participants, injured participants, and injury-free participants are presented in Table 1.

TABLE 2  
Crude Analysis on Different Exposures to Injury:  
cIRD for Running Injury After 500 km  
According to Exposure Variables <sup>a</sup>

Variable of Interest	cIRD at 500 km	Standard Error	95% CI	P Value
<b>Sex</b>				
Females (ref)	0			
Males	-4.4%	5.5	-15.2%; 6.4%	.42
<b>Age</b>				
18-30 y	-1.6%	5.5	-12.3%; 9.2%	.77
30-45 y (ref)	0			
45-65 y	14.7%	8.6	-2.1%; 31.5%	.08
$\chi^2 = 0.14^b$				
<b>BMI</b>				
<20 kg/m <sup>2</sup>	-14.1%	9.0	-31.6%; 3.5%	.12
20-25 kg/m <sup>2</sup> (ref)	0			
25-30 kg/m <sup>2</sup>	2.7%	6.6	-10.2%; 15.7%	.68
>30 kg/m <sup>2</sup>	10.3%	7.1	-3.7%; 24.3%	.15
$\chi^2 = 0.06^b$				
<b>TASRI</b>				
Type B behavior (ref)	0			
Type A behavior	-11.9%	5.9	-23.3%; -0.5%	.04
<b>Running experience</b>				
Experienced (ref)	0			
No running experience	6.0%	5.8	-5.4%; 17.3%	.30
<b>Sports activity</b>				
No (ref)	0			
Yes, with axial load	-0.7%	7.0	-14.3%; 12.8%	.92
Yes, without axial load	-2.4%	8.4	-18.9%; 14.2%	.78
$\chi^2 = 0.96^b$				
<b>Previous RRI</b>				
No (ref)	0			
Yes	5.2%	7.2	-8.9%; 19.3%	.47
<b>Previous non-RRI</b>				
No (ref)	0			
Yes	11.1%	5.8	-0.2%; 22.4%	.05

<sup>a</sup>cIRD, crude cumulative injury risk difference; BMI, body mass index, TASRI, Type A Self-Rating Inventory; CI, confidence interval; ref, reference group.

<sup>b</sup>Probability calculated based on a Wald test across categories.

During follow-up, the participants ran a total volume of 155,318 km. Of the 676 persons not sustaining an RRI, 197 were censored before the end of follow-up for reasons including too much training uploaded without the GPS watch (n = 59), lack of motivation (n = 37), pregnancies (n = 25), and other reasons (n = 76). The crude cIRD between exposures of interest and RRI are presented in Table 2, and the Kaplan-Meier survival graphs in Figure 1.

A dose-repose relationship was found across the 4 BMI groups: the risk of RRI increased with an increase in BMI ( $P = .06$ ), with obese individuals facing the highest risk (cIRD, 10.3% [95%CI, -3.7%; 24.3%];  $P = .15$ ) compared with persons of a normal BMI. To reduce their BMI from >30 to the normal BMI range to avoid 1 injury, 9.7 persons were needed. None of the 11 males with a BMI <20 sustained an RRI, while injuries were observed among 6 of the 30 women in the lowest BMI category. Still, no significant differences were found in the effect of BMI between females and males, among those with a BMI <20 (cIRD between

sexes, -16.7% [-50.1%; 16.7%];  $P = .33$ ) or among the persons with a BMI of 25 to 30 (cIRD between sexes, -2.2% [-23.1%; 27.6%];  $P = .86$ ) or a BMI >30 (cIRD between sexes, -5.0% [-50.1%; 16.7%];  $P = .33$ ).

No difference in injury survival after 500 km of running was found between individuals with no previous RRI compared to those with a previous RRI (cIRD, 5.2% [-8.9%; 19.3%];  $P = .47$ ). On the contrary, an almost significant relationship was found for previous injuries not related to running: persons with previous injuries not related to running had sustained 11.1% ([-0.2%; 22.4%],  $P = .05$ ) more injuries than healthy persons.

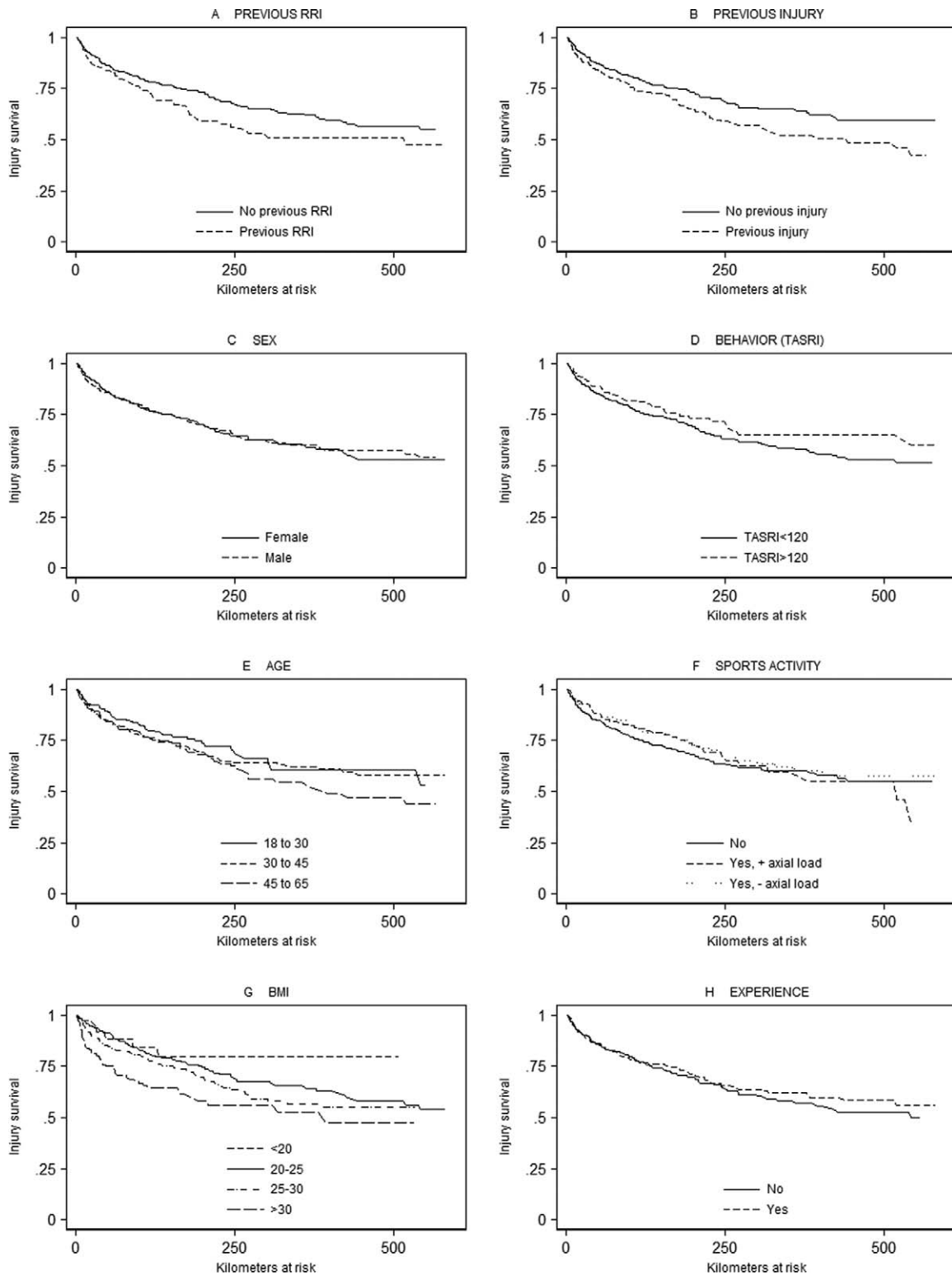
The results of the crude analysis between sex and RRI were not affected after adjusting for previous running experience; after adjusting, males still had 4.5% ([-1.5%; 6.3%],  $P = .41$ ) fewer injuries than females. The difference between persons at the age from 45 to 65 compared with 30 to 45 was 14.7% ([-2.1%; 31.5%],  $P = .08$ ). The change in estimate between the crude and the adjusted analysis was less than 0.1% after adjusting for previous RRI and previous injury not related to running. Injury risk was lessened among runners with type A behavior both in the crude analysis and after controlling for sex (adjusted cIRD, -11.7% [-23.1%; -3.3%];  $P = .04$ ). Based on the adjusted result, 17 persons were needed to change their behavior from type B to type A to avoid 2 injuries. When including sex as an effect-measure modifier on the association between behavior and RRI, a nonsignificant difference of 3.9% ([-18.8%; 26.5%],  $P = .74$ ) was found.

Other sports activity was categorized into 3 categories, with no sports activity as the reference group; the differences in risk of injury were almost similar among persons participating in sports activities with (cIRD, -0.7% [-14.3%; 12.8%];  $P = .92$ ) or without axial loading (cIRD, -2.4% [-18.9%; 14.2%];  $P = .78$ ).

## DISCUSSION

The purpose of this prospective cohort study was to explore the demographic and behavioral predictors of injury occurrence among novice runners wearing the same running shoes and using the same GPS watch to quantify the volume in each running session. Of the 930 runners included in the analysis, 254 runners sustained an injury during the 1-year follow-up period. Age, BMI, TASRI, and previous injury not related to running were found to be predictors of RRI. Exposures not associated with RRI included sex, running experience, sports activity, and previous RRI.

Previous injury often has been associated with the occurrence of new injury among runners,<sup>9,19,22</sup> but Buist et al<sup>6</sup> noticed that it was unclear whether the term *previous injury* referred to an RRI or an injury in general. They suggested that in future studies previous injuries should be further specified as RRI and other types of injuries. In the present study, based on the responses given in the baseline questionnaire, previous injuries were divided into groups. Despite the fact that the accuracy of self-reported information on previous injury and previous RRI is highly questionable,



**Figure 1.** Kaplan-Meier survival graphs for (A) previous running-related injury dichotomized into yes/no; (B) previous injuries not related to running dichotomized into yes/no; (C) sex dichotomized into female/male; (D) behavior measured by Type A Self-Rating Inventory (TASRI) dichotomized into <120 (type B: relaxed, laid-back personality) and >120 (type A: competitive, impatient, hyperactive personality); (E) age categorized into 18-30, 30-45, and 45-65 years; (F) sports activity categorized into *no*, *yes—sports activity with axial load*, and *yes—sports activity without axial load*; (G) body mass index (BMI) in kg/m<sup>2</sup> categorized into <20, 20-25, 25-30, and >30; and (H) previous running experience dichotomized into yes/no. All exposures were assessed prior to or at baseline of 0 kilometers at risk. RRI, running-related injury.

self-reported information was used. After a notable difference after 200 km (Figure 1), no difference was found among persons with previous RRI compared to those without after 500 km of running ( $P = .47$ ). Persons with previous injuries not related to running sustained more injuries during follow-up compared with healthy individuals ( $P = .05$ ). Unfortunately, previous injuries not related to running may be considered as a nonmodifiable risk factor and, therefore, hard to influence before commencing a running program.<sup>19</sup>

Among novice runners, BMI has previously been found to be significantly associated with RRI. In a 10-week prospective study by Nielsen et al,<sup>15</sup> runners not sustaining RRI had a mean BMI of  $24.8 \pm 3.6$ , whereas participants sustaining injuries had a mean BMI of  $27.6 \pm 4.5$ . This finding was in agreement with Buist et al,<sup>3</sup> who found an increased risk of 31.8% of sustaining an RRI among novice runners with a BMI  $>25$  kg/m<sup>2</sup> compared with those with a BMI  $<25$  kg/m<sup>2</sup>. We hypothesized a U-shaped pattern, suggesting persons with normal BMI to be at lowest risk while underweight (BMI  $<20$  kg/m<sup>2</sup>), overweight (BMI = 25-30 kg/m<sup>2</sup>), and obese (BMI  $>30$  kg/m<sup>2</sup>) were expected to be at greater risk of RRI. Unlike our hypothesis, persons with a BMI  $<20$  kg/m<sup>2</sup> faced the lowest risk of injury. In the present study, only 6 participants had a BMI  $<18$  kg/m<sup>2</sup>. Based on this, it was not possible to identify the risk profile among persons with very low BMI ( $<18$  kg/m<sup>2</sup>). More work is therefore needed to ascertain whether a very low BMI is associated with increased risk of injury. Based on the results of the present and other studies,<sup>3,15</sup> it must be concluded that increasing BMI is associated with increased risk of injury. However, the increased risk of injury among novice runners with BMI  $>30$  kg/m<sup>2</sup> is in contrast to the findings among recreational runners presented in a systematic review by van Gent et al.<sup>19</sup> Based on their review, BMI  $>26$  kg/m<sup>2</sup> was protective of injury occurrence. The reason for the differences in injury risk between overweight or obese novice runners and overweight or obese recreational runners remains unknown. One factor that may explain the high frequency of injuries among the obese individuals in the present study was the choice of running shoes. All participants received the same running shoes with a medium level of shock absorption. Obese individuals may have been less susceptible to injury if the shock absorption in the running shoes was greater than the absorption level of the shoes they were provided with. However, no evidence exists that supports the assumption that obese individuals are at decreased risk of injury when running using a highly absorptive shoe.<sup>16</sup>

The TASRI is a tool used to assess the personality and behavior among runners.<sup>8</sup> Fields et al<sup>8</sup> suggested that a competitive personality (type A behavior) may lead to suppression of minor symptoms that may or may not increase the risk of an overuse injury. In a 1-year prospective study of 40 recreational runners, a type A behavior including time urgency, ambitiousness, and competitiveness was associated with an increased risk of injury. Conversely, Buist et al<sup>6</sup> found that type A behavior was not related to the hazard of sustaining an injury among novice runners. The findings in the present study contradict those of Fields et al<sup>8</sup> and

Buist et al<sup>6</sup> since the risk of injury was lessened among individuals with a type A behavior.

In the present study, increased age was associated with an increased risk of injury. This finding is in contrast to that of Buist et al<sup>6</sup> who found no increase in hazard per 10-year increase in age among males or females. They included age as a continuous variable, as opposed to the present study where age was considered as a categorical variable with 3 strata. The discrepancy between the findings in the 2 studies may therefore be explained by different definitions of age. Most likely, persons with an age  $>45$  years are more susceptible to sustain injuries in the lower extremities compared to younger persons. Because previous injury was also associated with the occurrence of RRI, we adjusted for previous RRI and previous injury not related to running, but this adjustment had little effect on the estimates.

Despite the strengths of the prospective design,<sup>1,22</sup> the valid estimation of the running exposure,<sup>15</sup> the length of the follow-up period, and the sample of more than 900 novice runners included in the present study, our results should be interpreted with caution. We performed analyses on simple associations to identify individuals at high risk of RRI. We did not identify any causal mechanisms leading to RRI. Several authors have suggested the cause of sports injury in general to be multifactorial.<sup>13,17,19</sup> Even though some similarities between sports injury and RRI may exist, models and framework for the causal mechanisms specifically leading to RRI are greatly needed. From a causal perspective, training errors may be of particular interest, as excessive progression on 1 or more training-related variables may be a main cause of a majority of all RRIs.<sup>14</sup> More work is needed to identify the association between training volume, pace, duration, frequency, and occurrence of RRI. Despite the influence of other variables of interest on RRI occurrence, the association between several risk factors and RRI discussed in this article suggests that advice and education of novice runners may be necessary. Still, further analyses are necessary to determine to which degree these risk factors are effect measure modifiers on the association between training volume, pace, and duration and injury occurrence. Traditionally, other covariates have been included in the analysis as confounders.<sup>6,20</sup> However, it seems plausible to assume that some covariates may modify the amount of training tolerated by the runner before injury occurrence.<sup>12</sup> If this is true, it may be of greater importance to include the important risk factors as BMI, behavior, previous injury not related to running, and age as effect measure modifiers rather than as confounders, when investigating the causal mechanisms leading to RRI.

## CONCLUSION

The findings of this study suggest BMI  $>30$  kg/m<sup>2</sup>, age between 45 and 65 years, a noncompetitive behavior, and previous injuries not related to running to be associated with increased risk of injury among novice runners. Still, the roles of these risk factors in the causal mechanisms leading to RRI need to be investigated.

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