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### Monitoring endurance athletes

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## CHAPTER 4

# **A delay between high load and increased injury rate: using an individual approach in high-level competitive runners**

(Submitted)

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**ABSTRACT**

The objective was to investigate the relation between training parameters and the occurrence of injuries in a group of high-level competitive runners. For this purpose a prospective cohort study was used in which twenty-three high-level competitive runners were followed for 37 weeks. Information about training parameters (training load, training volume and training intensity) and injuries were collected. Training parameters were obtained as absolute values and as relative values scaled to a person's average value. Cox regression analyses were performed to study the influence of training parameters in the preceding five weeks on injury occurrence. The results showed that high relative training load three weeks before the injury, a high cumulative relative training load and volume over the previous five weeks and a high training intensity three and five weeks before were related to injury. Also increases in intensity three and five weeks before increased the injury rate. Relative training parameters scaled to an individual's average more often showed a significant relation to injury compared to absolute values. These findings suggest that there is a delay between the moment of overload and onset of an injury, as training parameters of 3-5 weeks before showed relations with injury rate. Scaling training parameters to a personal average may increase the likelihood of finding associations.

**Keywords:** Athletic injury; Etiology; Longitudinal study; Primary prevention

## INTRODUCTION

The yearly incidence of time-loss injuries is high in middle distance runners (64%), long distance runners (32%) and marathon runners (52%) [11], most of which are overuse injuries. Time-loss injuries lead to reduced training and the inability to compete, which is detrimental to the career of competitive athletes. Prevention of these injuries is therefore important. Steps toward successful prevention can be made by identifying risk factors and injury mechanisms [27]. Some have argued that overuse injuries are predominantly caused by training errors [7]. Studying training parameters preceding an overuse injury may therefore shed light on how injuries can be prevented.

A number of studies have been performed on the relation between training parameters and injury incidence in novice runners. It has been shown that a progression of more than 30% in weekly running distance over a two week period increased the rate of running injuries [17,18]. Also running more than three kilometres during the first week of a running program increased the injury risk of novice runners with high BMI [15].

Less is known about the relation between training parameters and injuries in high-level runners. Studies in highly trained runners have only used aggregate data on training load that was collected retrospectively. Two studies showed that a large training distance and high training frequency were related with injury occurrence in runners participating in a 10.000 meter national championship road race [9] and also with the prevalence of shin splints in elite master runners [12]. Another study showed that the distance covered in a month was related to the number of injury days in the next month [14]. Finally, research in female competitive athletes [10] and collegiate cross-country runners [21] found no relation between average weekly training distance and injury prevalence. However, because there was no longitudinal collection of training data in these studies on competitive athletes, contrary to the studies on novice runners, no information regarding training parameters preceding the onset of injury could be obtained. Also taking an average of training parameters over a total season ignores the time-varying nature of training parameters; they are not the same at all times. Not taking this into account may preclude finding an association between changes in training parameters and injury or influence the direction of these associations. For example, it may be speculated that a well-trained runner

runs larger distances and is less likely to get injured compared to a recreational runner. This could lead to finding a reversed relation between volume and injury. Using absolute values may sometimes be unavoidable, for example in large community based studies, but the setting of high-level competitive sports provides an opportunity to obtain more data and to obtain information about individual training load. Such an individualized approach may therefore increase the chance of finding associations between training parameters and injury.

Studies on the relation between training parameters and injury have been performed in elite athletes in sports, such as soccer and Australian Rules Football. For example, the weekly load and the variability of training (i.e. monotony) were prospectively monitored in elite soccer players and related to injuries [3]. Higher load and higher monotony resulted in increased injury risk. Thereafter, studies tried to account for the time varying nature of training parameters. Studies in Australian Football players and cricket fast bowlers, for example, found that training load in the previous weeks were indicative for injury occurrence [8,23]. Similar studies on competitive runners are lacking at the moment.

The aim of the present study was to investigate the relation between training parameters and the occurrence of injuries in a group of high-level competitive runners. Training parameters (load, volume and intensity) were obtained both as absolute and as relative (scaled to an individual's average) values to study which had the highest predictive values. The values of training parameters in the preceding five weeks, the cumulative values over the preceding five weeks and changes in these parameters between weeks were determined to study the temporal relation with injury occurrence.

## **METHODS**

Twenty-three high-level competitive middle- and long-distance runners (16 male, 7 female) were followed for 37 weeks during which they reported data on training parameters and injuries (Table 1). Permission for the study was obtained from the medical ethical committee of University Medical Center Groningen, the Netherlands (METc 2011/186). The funding organization had no role in the collection of the data, the analyses and interpretation of the data. Neither had they the right to approve or disapprove the publication of the manuscript.

**Table 1.** Baseline characteristics of runners

	<b>Male</b>	<b>Female</b>	<b>Total</b>
<b>Number</b>	16	7	23
<b>Age</b> (years; mean $\pm$ SD)	22.5 $\pm$ 6.3	21.4 $\pm$ 4.4	22.2 $\pm$ 5.7
<b>Height</b> (cm; mean $\pm$ SD)	185 $\pm$ 5	172 $\pm$ 7	181 $\pm$ 8
<b>Body weight</b> (kg; mean $\pm$ SD)	68.6 $\pm$ 6.0	58.3 $\pm$ 4.0	65.4 $\pm$ 7.2
<b>Percentage body fat</b> (%; mean $\pm$ SD)	8.5 $\pm$ 2.3	17.6 $\pm$ 4.2	11.3 $\pm$ 5.2
<b>VO<sub>2</sub>max</b> (ml/min/kg)	66.7 $\pm$ 5.9	62.7 $\pm$ 7.4	65.5 $\pm$ 6.5

cm = centimeter; kg = kilogram; ml = milliliter; min = minutes; SD = Standard Deviation; VO<sub>2</sub>max = maximal oxygen uptake

The runners kept a daily training log in which information about training duration, training intensity and sustained injuries was reported. The coach added information about the training schedule, inability to execute the planned training sessions and observed injuries of the runners to the same training log.

Information regarding injuries was obtained from the training logs. An injury was defined as any musculoskeletal problem of the lower extremity or back that led to an inability to execute training or competition as planned for at least one week [2]. Recovery was defined as being able to comply with the normal training schedule. Collection of recovery data was continued after the follow-up period, up until the last injury in the study cohort had been resolved. Injury and recovery data were extracted from the information in the training log which was a combination of self-reported information and information provided by the coach.

Training parameters (duration and intensity) were recorded in the training log after each training session and race. All types of training were included (e.g. technique training, strength training etc.) Duration (volume) was registered in minutes and intensity was measured using the session Rating of Perceived Exertion (sRPE) 30 minutes after the session [5] on a scale from 6-20 [1]. Training load was calculated by multiplying session volume (in minutes) by sRPE and it was expressed in arbitrary units [5].

Descriptive data on subject characteristics, injuries, and training parameters were calculated and presented as frequency (nominal variables), mean with standard deviations (normally distributed continuous variables) or median with range (non-normally distributed variables). Cox regression analyses

were performed on the data with the first sustained injury as outcome. The time variable was the training week. Training variables were included as time-varying covariates. Because of the sample size, only uni-variable analyses were performed, as it has been shown that at least 10 events for each included independent variable are needed in a Cox regression analysis to ensure sufficient power [20].

Volume, intensity and training load were included as time varying covariates. These training parameters were expressed in two ways: as absolute values and as relative values. Absolute values were the total time (duration), average sRPE score (intensity) and total number of arbitrary units (training load) for a training week. Cumulative values were obtained from 1 to 5 previous weeks by summing the values of the separate weeks. Changes in training parameters were calculated for the previous five weeks by dividing the value of a certain week with the value of the prior week and were expressed as a percentage. Relative values were obtained by dividing absolute values by the personal average weekly values over a season that was calculated for each runner by taking the average value over the runner's entire season, excluding the periods with adapted training as a result of injury. Changes in training parameters were only calculated for absolute values, because results are similar to changes in relative values.

Hazard Ratios (HR) with 95% confidence intervals (95% CI) were calculated for each training variable. A p-value of  $\leq 0.05$  was considered significant and a p-value of  $\leq 0.10$  was considered a trend. Because these training variables were calculated over the preceding 5 weeks, injury data of the first five weeks (week 1-5) could not be included because it was not possible to calculate training variables for these weeks. The Cox regression was therefore performed over a 32 week follow-up period (week 6-37). The proportional hazards assumption was assessed by Schoenfeld residual tests and by inspecting the Schoenfeld residual plots for non-random patterns. Variables that not met the proportional hazards assumption were transformed dichotomous variables and tested again [6]. Analyses were performed in R statistics (version 3.1.0) with the Survival package (version 2.37.7) [25].

**Table 2.** Overview of injuries and training load

	Male	Female	Total
<b>Injuries</b>			
Runners with no injuries during season	10	2	12
Runners with one injury during season	4	5	9
Runners with two injuries during season	2	0	2
Injury location (back/hip/knee/ calf-Achilles/ankle-foot)	0/1/2/4/1	1/1/0/1/2	1/2/2/5/3
Time to recovery (days; median(range))	24 (8-50)	122(12-306)	26 (8-306)
<b>Training parameters (excl. weeks injured)</b>			
Weekly training load during season (AU)	6695±1913	7894±3427	7060±2453
Weekly training duration (hours)	8.4±2.2	9.2±3.2	8.6±2.5

AU = Arbitrary Units

## RESULTS

The total number of training hours of the 23 athletes during the 32 weeks was 5370. In total 13 injuries were sustained during this period (Table 2), resulting in an injury density of 2.4 injuries per 1000 hours. Injury density was 2.0 injuries per 1000 hours in males and 3.5 in females. Two runners sustained two injuries, leaving 11 primary injuries. Most injuries were located in the calf/Achilles tendon. The median time to recovery was 26 days and the mean time to recovery was 75 days.

Training parameters expressed as absolute value did not meet the proportional hazards assumption and were therefore transformed to a dichotomous variable based on the median value.

Absolute training load in previous weeks showed no relation to injury, but relative training load of three weeks before showed a significantly higher HR (HR = 4.11 [95% CI 1.0-16.9],  $p = 0.049$ ). A high cumulative relative training load over the previous five weeks also showed a significantly higher HR (HR = 9.66 [95% CI 1.01-92.73],  $p = 0.0049$ ), but not when it was calculated for absolute training load. Changes in training load were not related to injury.

Training volume in previous weeks showed no relation to injury although a trend was visible for the relative training volume one and four weeks before injury occurrence. A high cumulative relative training volume over the previous five weeks was related to an increased injury rate (HR = 1.73 [95% CI 1.01-2.95],  $p =$

0.046), and a trend was visible for the cumulative relative training volumes calculated over one to four preceding weeks. No relation was found for cumulative absolute training volume and changes in training volume.

Both absolute (three weeks before) and relative training intensity (three and five weeks before) were related to an increased injury rate. A high relative training intensity in the week before injury showed a trend towards a decreased injury rate. No significant relation was found for cumulative training intensity and injury. A decrease in training intensity two weeks before and an increase in training intensity three and five weeks before were related to a higher injury rate.

## **DISCUSSION**

In this study the relation between training parameters and injury rate in high-level competitive runners was analyzed. A high relative training load three weeks before the injury, high cumulative relative training load and volume over the previous five weeks and a high training intensity three and five weeks before were related to injury. These findings suggest that there is a delay between the moment of overload and onset of an injury, as training parameters of 3-5 weeks before showed relations with injury rate. Also a continued high volume and training load seem to increase the injury rate. Changes in training load and volume were not related to injury, but changes in training intensity were. Finally, relative values more often showed a significant relation to injury compared to absolute values.

The injury incidence of 2.4 injuries/1000h in the current study was comparable to previous studies on competitive long distance runners that found incidences of 2.5 injuries/1000h [14] and 1.7 injuries/1000h [22]. Injury incidence was lower than reported in a meta-analysis on novice (17.8 [95% CI 16.7-19.1]) and recreational (7.7 [95% CI 6.9-8.7]) runners [29]. Most injuries were reported in the calf/Achilles tendon region. The incidence of Achilles tendinopathy is high middle- and long-distance runners [4,13], and it has been suggested that Achilles tendinopathy may be related to high running pace [16].

Until now, no studies on running injuries in high-level athletes have analysed the relation between training load and injury. The present findings suggest that a high relative training load is related to running injury. In line with the present findings, previous studies on competitive athletes found a relation between training volume and injury [9,12,14]. However, others found no relation between

volume and injuries [10,21]. Reasons for these differences may be found in the studied populations or employed methods. All previous studies used an average load in their analysis, whereas the present study took the time-varying character of training load into account. This enabled finding relations between training patterns and injury. Also a relation was found between a high training intensity and injury. This relation was previously observed in novice runners. The relation between training intensity and injury rate was significant for three and five weeks before, but a continued high intensity over several weeks was not related to injury as indicated by the analysis on cumulative load. The intensity in the previous week even showed a reversed pattern, high intensity showed a trend towards a reduced injury rate. It is possible that runners who got injured already experienced some 'signs' and therefore reduced their training intensity. This does however not match with the trend observed for training volume that showed that high volume was related to injury rate.

A notable finding in the present study is that there appears to be a lag between the moment of high load and the moment of onset of injury. A similar observation has been made in a study on cricket injuries [19]. That study showed increased injury risk three to four weeks after the high workload. This delay is similar to the delay that was found in the present study. According to Orchard et al. [19], a hypothesis that explains this finding may be that during high load damage occurs to immature tissue while mature tissue allows for maintaining function in the period after the high load. However when the mature tissue is broken down as a result of natural tissue turn over, it is replaced by the damaged tissue and the risk of injury increases.

An increase in training intensity three weeks before and a decrease in training intensity two weeks before were related to an increased injury rate. This second finding, of a relation between a decrease in intensity and injury, seems counterintuitive. One explanation for this may be that the relation between a high training intensity three weeks before and injury automatically implies that the intensity two weeks before is lower compared to the previous week in injured subjects. Another explanation is, as described above, that subjects reduced their training intensity because they already experienced some 'signs'.

**Table 3.** Results of the Cox regression with the training variables as predictor of injury.

	<b>Absolute load</b>			<b>Relative load</b>		
	Training load (HR for high load ( $\geq$ 6650 AU per week) compared low load (< 6650 AU))	Training volume (HR for high volume ( $\geq$ 505 minutes per week) compared low volume (< 505 minutes))	Training intensity (HR for high intensity ( $\geq$ 13.3 average sRPE per week) compared low intensity (<13.3 average sRPE score))	Training load (HR for 100% increase compared to individual training load)	Training volume (HR for 100% increase compared to individual training volume)	Training intensity (HR for 10% increase compared to individual training intensity)
<b>Load previous wks</b>						
Previous wk	1.33 (0.41-4.29)	1.33 (0.48-3.72)	0.82 (0.29-2.30)	2.45 (0.65-9.19)	5.29 (0.99-28.27) <sup>a</sup>	0.64 (0.38-1.05) <sup>a</sup>
2 wks before	0.83 (0.25-2.83)	1.53 (0.49-4.87)	2.50 (0.70-8.91)	2.21 (0.53-9.29)	2.87 (0.53-15.68)	1.02 (0.58-1.79)
3 wks before	1.48 (0.42-5.21)	1.07 (0.31-3.67)	5.63 (1.22-25.97) <sup>b</sup>	4.11 (1.00-16.90) <sup>b</sup>	3.17 (0.69-14.67)	2.19 (1.30-3.69) <sup>b</sup>
4 wks before	1.77 (0.52-5.97)	2.51 (0.71-8.85)	2.12 (0.66-6.85)	2.85 (0.89-9.07) <sup>a</sup>	3.00 (0.89-10.19) <sup>a</sup>	1.24 (0.94-1.64)
5 wks before	1.65 (0.51-5.32)	1.12 (0.37-3.36)	1.75 (0.58-5.30)	1.88 (0.79-4.51)	1.59 (0.63-3.89)	1.61 (1.05-2.47) <sup>b</sup>
<b>Cumulative load previous wks</b>						
previous wk	1.33 (0.41-4.29)	1.33 (0.48-3.72)	0.82 (0.29-2.30)	2.45 (0.65-9.19)	5.29 (0.99-28.27) <sup>a</sup>	0.64 (0.38-1.05) <sup>a</sup>
previous 2 wks	1.13 (0.35-3.63)	1.23 (0.40-3.84)	1.15 (0.38-3.45)	2.93 (0.58-14.89)	2.29 (0.89-5.87) <sup>a</sup>	0.80 (0.54-1.18)
previous 3 wks	1.88 (0.55-6.43)	1.31 (0.37-4.63)	1.81 (0.62-5.29)	4.21 (0.78-22.74)	1.82 (0.94-3.52) <sup>a</sup>	1.03 (0.75-1.40)
previous 4 wks	1.69 (0.52-5.48)	2.71 (0.80-9.15)	1.90 (0.65-5.58)	6.97 (0.92-52.75) <sup>a</sup>	1.81 (0.99-3.31) <sup>a</sup>	1.05 (0.85-1.29)
previous 5 wks	1.75 (0.55-5.54)	1.74 (0.56-5.43)	1.82 (0.63-5.25)	9.66 (1.01-92.73) <sup>b</sup>	1.73 (1.01-2.95) <sup>b</sup>	1.08 (0.92-1.28)

	Training load (HR for 100% increase compared to the week before)	Training volume (HR for 100% increase compared to the week before)	Training intensity (HR for 100% increase compared to the week before)
<b>Load increase</b>			
previous wk	0.83 (0.34-2.05)	0.83 (0.24-2.85)	0.85 (0.59-1.23)
2 wks ago	0.66 (0.29-1.48)	0.81 (0.41-1.58)	0.57 (0.36-0.92) <sup>b</sup>
3 wks ago	0.81 (0.50-1.30)	0.67 (0.32-1.44)	1.29 (1.02-1.65) <sup>b</sup>
4 wks ago	0.97 (0.70-1.35)	0.98 (0.75-1.28)	0.82 (0.63-1.05)
5 wks ago	1.70 (0.82-3.54)	0.85 (0.24-2.97)	1.53 (1.25-1.89) <sup>c</sup>

<sup>a</sup> p<.10; <sup>b</sup> p<.05; <sup>c</sup> p<.001; AU = Arbitrary Units; CI = confidence interval; HR = Hazard Ratio; sRPE = session Rating of Perceived Exertion; wk = week

The finding of no relation between volume and injury rate is contrary to previous studies in novice runners [17,18]. Possibly experienced runners are more accustomed to changes in training volume, because it is common in their training schedules, whereas novice runners may not have experienced this before.

Monitoring a large group of high-level athletes is difficult, simply because there are not many high-level athletes in one region. Therefore, a limitation of this study is that only uni-variable analyses could be performed because of the relatively small sample size. Future studies on larger samples in multiple regions are needed to perform multivariable analyses, which could give insight in the combined effects of training load on injury occurrence. A further limitation of the present study is the inclusion of only the first injury in the analysis. More complex statistical procedures have been described to include multiple injuries in the analyses [26]. However, in the present study this would only have led to the inclusion of 2 additional injuries. Strengths of the current study are the prospective design and the detailed and complete information that was obtained.

Injury prevention is important for competitive athletes as injuries lead to reduced training and inability to compete. The present study showed that high weekly training load, volume and intensity may lead to a higher injury rate. However, reducing training load in order to prevent injuries is often not an option for competitive athletes as it may lead to reduced performance. Training schedules are designed with a focus on performance. The present study may give some insights into how training load influences the injury risk. This may be taken into account when designing a training schedule. For example, scaling training parameters to an individual's average seems to increase the usability of the data. It has also to be considered that injuries do not seem to develop directly after period of high load. A survey among trainers and medical staff working with elite athletes found that they most often sought the cause of injuries in training [24]. According to these professionals, excessive training was the most common training error. This stresses the need for more knowledge of the relation between training load on the one hand and both injury risk and performance on the other hand. However, an exclusive focus on physical factors should be avoided. Psychological and social factors also play an important role in the onset of overuse injuries [28]. Future studies should take the influence of training on

performance into account in order to find a balance between performance improvement and injury prevention.

### **Conclusions**

The relation between training load and injury was studied in high-level competitive athletes. It was found that injury rate is increased several weeks after a week with high training load or training intensity. Prolonged high load or volume and changes in intensity may also increase the injury rate. Injury prevention in competitive athletes needs a different approach than used for recreational athletes, because a high level of performance is key. The present findings provide some first insights into the relation between training load and injury that may be taken into account when designing training schedules. Scaling training parameters to a personal average may result in better prediction of injuries.

### **Practical Implications**

- Injury rate is increased several weeks after a week with high training load or intensity. Therefore care should be taken several weeks after a high training load.
- When designing training schedules it should be taken into account that a prolonged high load or volume as well as increases in intensity lead to a higher injury rate.
- Scaling training parameters to a runner's individual average may give more insight in a runner's susceptibility to injury.

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