

How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury

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Key words:

Load management, recovery, adaptation, maladaptation, stress, training, competition, calendar, congestion, saturation, psychosocial stressors, travel, external load, internal load, response, acute:chronic load ratio, spikes, injury, overuse, acute, wellbeing, fatigue, fitness, monitoring, measurement

Contributorship:

TS and MS made substantial contributions to overall and detailed conception, planning, drafting and critically revising the paper. J-MA, RBahr BC, HPD, TG, MG, MH, MRH, CJvR, KMK, RM, JWO, BMP and MR made substantial contributions to drafting and critically revising the paper. LE and RBudgett made substantial contributions to overall conception and planning of the paper.

Provenance and peer review:

Not commissioned; internally peer reviewed

Acknowledgements:

The authors would like to acknowledge the contribution and support of IOC Medical and Scientific Chair, Prof. Dr. Uğur Erdener, during the consensus meeting, and the International Olympic Committee for funding the meeting.

Competing Interests:

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Abstract

Athletes participating in elite sports are exposed to high training loads and increasingly saturated competition calendars. Emerging evidence indicates that poor load management is a major risk factor for injury. The International Olympic Committee convened an expert group to review the scientific evidence for the relationship of load (including rapid changes in training and competition load, competition calendar congestion, psychological load, and travel) and health outcomes in sport. We summarise the results linking load to risk of injury in athletes, and provide athletes, coaches and support staff with practical guidelines to manage load in sport. This consensus statement includes guidelines for (i) prescription of training and competition load, as well as for (ii) monitoring of training, competition and psychological load, athlete wellbeing and injury. In the process, we identified research priorities.

Introduction

Sport has evolved from games played principally for entertainment and leisure to a competitive, professionalised industry.[1] To meet commercial demands, event calendars have become longer and increasingly congested, with new single- and multi-sports events packed into the calendar year.

Inherent to the growth of sport and more strenuous competition programs, elite and developing athletes face increasingly greater pressures to stay competitive. Consequently, athletes and their support staff search relentlessly for ways to aggregate marginal gains over time and thus, improve performance. Although many factors can contribute, their main instrument is via their training regimen. Training and competition load stimulates a series of homeostatic responses and accompanying adaptation of the human body's systems.[2-5] The paramount principle in training theory is to utilise this process of biological adaptation to increase fitness and subsequently improve performance (Figure 1).[4, 5] Elite and developing athletes push their training volume and intensity to the limits to maximise their performance improvement.

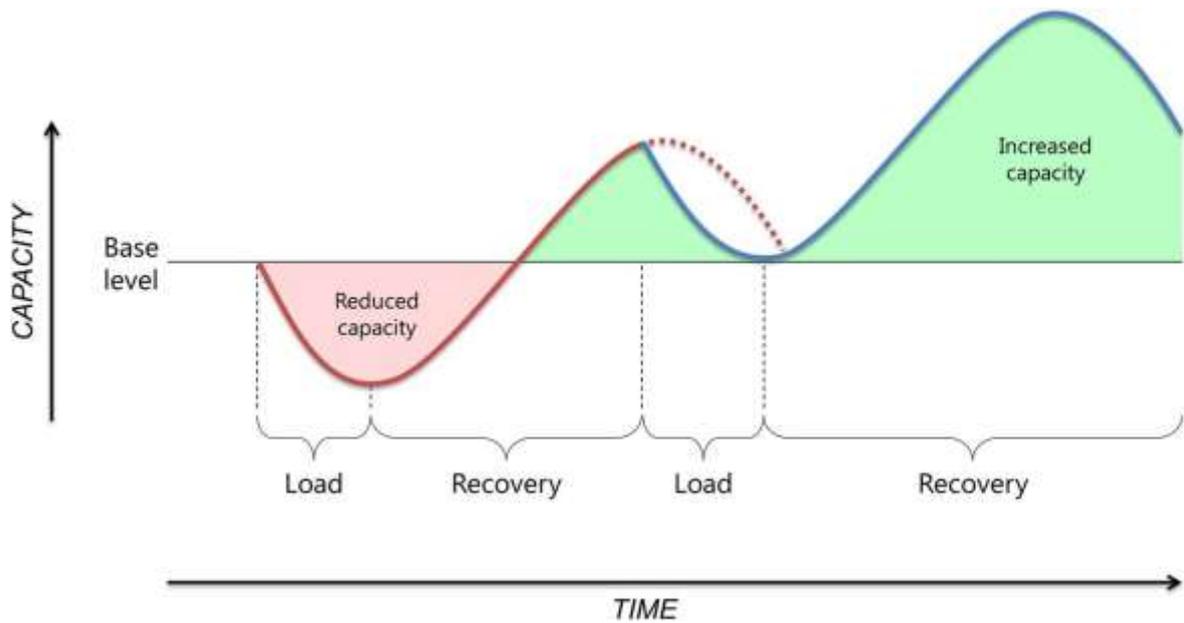


Figure 1. Biological adaptation through cycles of loading and recovery (adapted from Meeusen, 2013[6])

Health professionals who care for elite athletes are concerned that poorly managed training loads combined with the increasingly saturated competition calendar may damage the health of athletes.[7-9] It was suggested nearly three decades ago that the balance between external load and tissue capacity plays a significant causative role in injury.[10, 11] Although injury aetiology in sports is multifactorial and involves both extrinsic and intrinsic risk factors,[12, 13] evidence has emerged that load management is a major risk factor for injury.[14] Insufficient respect of the balance between loading and recovery can lead to prolonged fatigue and abnormal training responses (maladaptation),[15-18] and an increased risk of injury and illness (Figure 2).[14, 19]

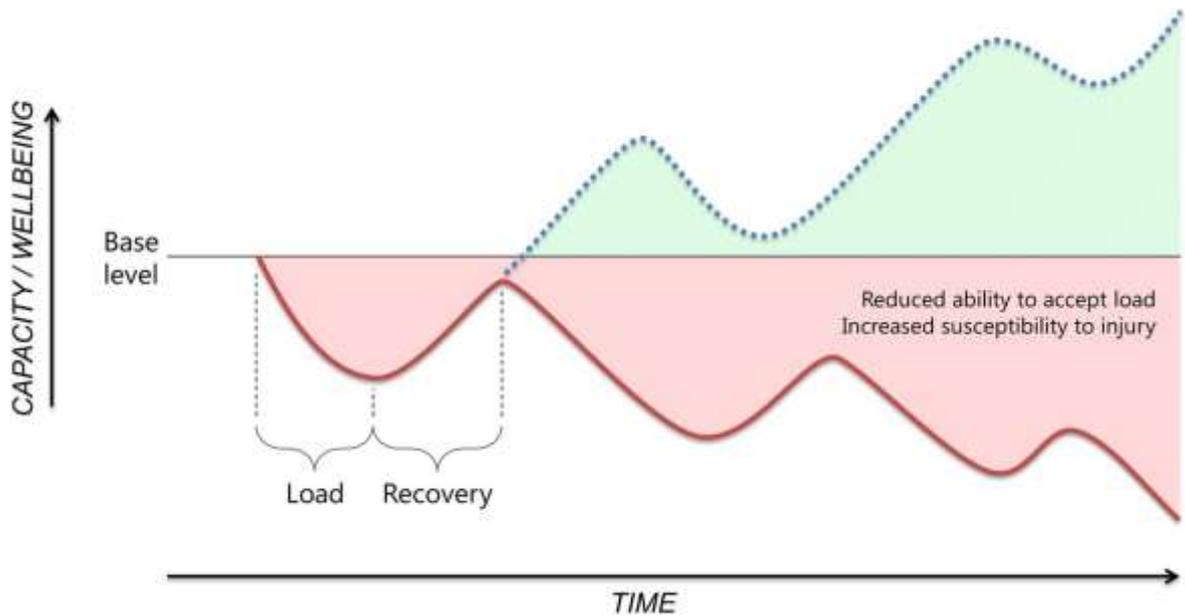


Figure 2. Biological maladaptation through cycles of excessive loading and/or inadequate recovery (adapted from Meeusen, 2013[6])

We consider the relationship between load and health as a wellbeing continuum,[16] with load and recovery as mutual counteragents (Figure 3). Sport and non-sport loads impose stress on athletes, shifting their physical and psychological wellbeing along a continuum that progresses from homeostasis through the stages of acute fatigue, functional and non-functional overreaching, overtraining syndrome, subclinical tissue damage, clinical symptoms, time-loss injury or illness, and – with continued loading – ultimately death. Death is rare in sport, and typically coupled with underlying disease (e.g., underlying structural heart disease triggering a fatal arrhythmia). For athletes, deterioration (clinically and in performance) along the continuum usually stops at time-loss injury or illness. At that point, the athlete is forced to cease further loading.

As these biological stages (Figure 3) form a continuum, it is difficult to clearly separate them. For example, the onset of subclinical tissue damage, symptoms and injury may happen *early or late* in the continuum. With adequate recovery following a load, however, the process is reversed, tissues remodel and homeostasis is restored, at a higher level of fitness and with an improved performance potential.

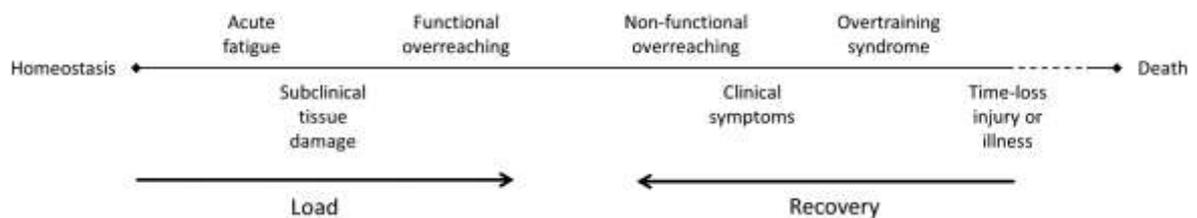


Figure 3. Wellbeing continuum (adapted from Fry and colleagues, 1991[16])

A key concept for those responsible for managing load is to appreciate that maladaptations are triggered not only by poor management of training and competition loads, but also by interaction with psychological non-sport stressors, such as negative life-event stress and daily hassles.[16, 20-22] Inter- and intra-individual variation (e.g., age, sex, sport, fitness, fatigue, health, psychological, metabolic, hormonal and genetic factors)[23] greatly complicate load management in athletes. There can be no “one size fits all” training or competition program. Ultimately, the timeframe of recovery and adaptation – and hence susceptibility to injury – varies within and among athletes.

The International Olympic Committee convened a consensus meeting from 24-27 November 2015 where experts in the field reviewed the scientific evidence for the relationship of load (including rapid changes in training and competition load, competition calendar congestion, psychological load and travel) and health outcomes in sport. We searched for, and analysed, current best evidence, aimed at reaching consensus, and provide guidelines for clinical practice and athlete management. In the process, we identified urgent research priorities.

Terminology and definitions

A consensus regarding definition of key terms provided the basis for the consensus group, and may also serve as a foundation for consistent use in research and clinical practice. An extensive dictionary of all key terms is provided in appendix A (online).

The term “load” can have different definitions. In general, “load” refers to “a weight or source of pressure borne by someone or something”.[24] Based on this definition and variation in the sports medicine and exercise physiology literature, the consensus group agreed upon a broad definition of “load” as “*the sport and non-sport burden (single or multiple physiological, psychological or mechanical stressors) as a stimulus that is applied to a human biological system (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual).*” Load can be applied to the individual human biological system over varying time periods (seconds, minutes, hours to days, weeks, months and years) and with varying magnitude (i.e., duration, frequency and intensity).

The term “external load” is often used interchangeably with “load”, referring to any external stimulus applied to the athlete that is measured independently of their internal

characteristics.[25, 26] Any external load will result in physiological and psychological responses in each individual, following interaction with, and variation in several other biological and environmental factors.[23, 27] This individual response is referred to as “internal load” and is discussed next.

Monitoring of load and injury

Monitoring athletes is fundamental to defining the relationship between load and risk of injury in care of athletes and also in research. This includes accurate measurement and monitoring of not only the sport and non-sport loads of the athletes, but also athletes’ performance, emotional wellbeing, symptoms and their injuries.

The benefits of scientific monitoring of athletes include explaining changes in performance, increasing the understanding of training responses, revealing fatigue and accompanying needs for recovery, informing the planning and modification of training programs and competition calendars, and, importantly, ensuring therapeutic levels of load to minimise the risk of non-functional overreaching (fatigue lasting weeks to months), injury, and illness.[26, 28, 29]

Monitoring external and internal loads

There are many different measures of load (Table 1), but the evidence for their validity as markers of adaptation and maladaptation to load is limited. No single marker of an athlete’s response to load consistently predicts maladaptation or injury.[18, 23, 26] Load monitoring involves measuring both external and internal load, where tools to measure the former can be general or sports-specific, and for the latter, objective or subjective.[30]

Measuring the external load typically involves quantifying the training or competition load of an athlete, such as hours of training, distance run, watts produced, number of games played or pitches thrown; however, other external factors, such as life events, daily hassles or travel may be equally important. The internal load is measured by assessing the internal physiological and psychological response to the external load,[23, 27] and specific examples include measures such as heart rate (physiological/objective), rating of perceived exertion, or inventories for psychosocial stressors (psychological/subjective).

Whereas measuring external load is important in understanding the work completed and capabilities and capacities of the athlete, measuring internal load is critical in determining the appropriate stimulus for optimal biological adaptation.[2, 4] As individuals will respond differently to any given stimulus, the load required for optimal adaptation differs from one athlete to another. For example, the ability to maintain a certain running speed or cycling power output for a certain duration may be achieved with a *high or low* perception of effort or heart rate, depending on numerous inter- and intra-individual factors, such as fitness and fatigue.[26]

A recent systematic review on internal load monitoring concluded that subjective measures were more sensitive and consistent than objective measures in determining acute and chronic changes in athlete wellbeing in response to load.[30] The following subscales may be particularly useful: non-sport stress, fatigue, physical recovery, general health/wellbeing, being in shape, vigour/motivation and physical symptoms/injury.[15-17, 31, 32] These variables offer the coach and other support staff essential data on the athlete's readiness to train or compete, and may thus inform individual adjustments to prescribed training.[30]

Finally, it has been demonstrated that athletes may perform longer and/or more intense training,[33] or perceive loads as significantly harder[25, 34, 35] than what was intended by the coach or prescribed in the training program. This may pose a considerable problem in the long term, as it may lead to maladaptation. This underscores the importance of monitoring external and internal loads in the individual athlete, rather than as a team average, as it may reveal dissociations between external and internal loads, and helps ensure that the applied load matches that prescribed by the coach.[26]

Table 1. Examples of measurement tools to monitor external and internal load

Load type	Examples of measurements
External load	Training or competition time (seconds, minutes, hours, or days)[36]
	Training or competition frequency (e.g., sessions or competitions per day, week, month)[37]
	Type of training or competition[38]
	Time-motion analysis (e.g., global positioning system (GPS) analysis)[39]
	Power output, speed, acceleration [40]

Neuromuscular function (e.g., jump test, isokinetic dynamometry, plyometric push up)[41]

Movement repetition counts (e.g., pitches, throws, bowls, serves, jumps)[42, 43]

Distance (e.g., kilometres run, cycled or swam)[44]

Acute:chronic load ratio[45]

Internal load Perception of effort (e.g., rating of perceived exertion, RPE)[46]

Session rating of perceived effort (e.g., session duration (min) x RPE)[28]

Psychological inventories

(e.g., profile of mood states (POMS),[47] recovery-stress questionnaire for athletes (REST-Q-Sport),[48] daily analysis of life demands for athletes (DALDA),[49] total recovery scale (TQR),[17] life events survey for collegiate athletes (LESCA),[50] multi-component training distress scale (MTDS),[51] the hassle and uplift scale,[52] brief COPE (Carver, 1997),[53] the Swedish universities scales of personality (SSP),[54] state trait anxiety inventory (STAI),[55] sport anxiety scale (SAS),[56], athletic coping skills inventory-28 (ACSI-28),[57], body consciousness scale,[58] perceived motivational climate in sport questionnaire (PMCSQ),[59] and commitment to exercise scale (CtES)[60]

Sleep (e.g., sleep quality, sleep duration)[61]

Biochemical/hormonal/immunological assessments[18, 26]

Psychomotor speed[62]

Heart rate (HR)[63]

HR to RPE Ratio[64]

HR recovery (HRR)[65]

HR variability (HRV)[66]

Training impulse (TRIMP)[67]

Blood lactate concentrations[68]

Blood lactate to RPE Ratio[69]

Monitoring of symptoms and injuries

Injury surveillance is an established part of top-level sport.[70-75] Traditional injury surveillance systems rely on a clearly identifiable onset and use the duration of time-loss from sport to measure severity.[76-79] While acute injury onset is most often easily identifiable, those related to overuse are by definition the cumulative result of repeated loading (rather than instantaneous energy transfer), leading to tissue maladaptation.[80, 81]

Hence, they have no clear onset, but occur gradually over time, with a progressive manifestation of clinical symptoms or functional limitations. They are therefore only reported as an injury when they meet the operational injury definition used in a particular study (e.g., whether symptom debut, reduced performance, or time-loss from sports).

New recommendations have been introduced that not only prescribe prospective monitoring of injuries with continuous or serial measurements, but also call for valid and sensitive scoring instruments, the use of prevalence and not incidence to report injury risk, and classification of injury severity according to functional level, rather than the duration of time loss from sports.[82] Based on these recommendations, novel methodology (often coupled with new technology such as mobile apps) sensitive to both injury and antecedent symptoms (e.g., pain, soreness) and functional limitations has been developed. Studies utilising these tools demonstrate that the prevalence of injuries related to overuse (due to training and competition maladaptation) represent as much of a problem as acute injuries in many sports.[83-85]

Load and risk of injury in athletes

All the members of the consensus group were asked to independently search and review the literature relating load to injury in sport and to contribute to a draft document of the results before meeting in person for three days to try to reach consensus. This meeting provided a further opportunity for the consensus group to review the literature and to draft a preliminary version of the consensus statement. We agreed on a post-hoc literature search, conducted by the first author of this consensus document after the meeting to attempt to capture all relevant scientific information from the different sporting codes. We searched the electronic databases of PubMed (i.e., including MEDLINE) and SPORTDiscus to identify studies for review, using combinations of the terms listed in Box 1. Full details on the search strategy are available from the authors. We limited the search to the English language and studies published prior to June 2016. Box 2 details the study inclusion criteria.

Box 1. Search categories and terms

Injury	injur*, overuse, soreness, pain, strain*, sprain*, muscle*, musculoskeletal*, bone*, tendon*, tendin*
Load	load*, workload*, train*, compet*, recovery, volume*, intensit*, duration*, stress*, congestion, saturation, distance, mileage, exposure*, hours, days, weeks, jump*, throw*, pitch*, psychosocial*, travel
Sport	sport*, athlete*, “alpine skiing”, archer*, athletics, aquatics, badminton, baseball, basketball, biathlon, boxing, canoeing, cricket, “cross-country skiing”, curling, cycling, diving, diver*, equestrian, fencing, fencer*, football*, “freestyle skiing”, golf*, gymnast*, handball, hockey, “ice hockey”, judo, kayak*, “nordic combined”, orienteer*, pentathlon, rowing, rower*, rugby, running, runner*, sailing, shooting, skating, skater*, skeleton, “ski jumping”, “ski jumper*”, snowboard*, soccer, swimm*, taekwondo, tennis, trampoline, triathl*, volleyball, “water polo”, weightlift*, wrestl*

Box 2. Study inclusion criteria

- Studies involving athletes of all levels (recreational to elite) and all major Olympic and professional sporting codes
- Studies where injuries were documented by either clinical diagnosis or self-report
- Studies where injuries were related to competition, training, competition calendar congestion, psychological or travel load
- Studies where single (load) or multiple risk factors (load and other risk factors) for injury were studied using univariate or multivariate analyses
- Studies using one of the following research designs: systematic review (with or without a meta-analysis), randomised controlled trials, prospective cohort studies, retrospective cohort studies, cross-sectional studies, and case-control studies

Final decisions to include publications were based on consensus, and the methodology and results of the publications (n=104) included in this review are summarised in appendix B (online).

Absolute load and injury risk

The majority of studies on the relationship between load and injury risk in sport have utilised various measurements of *absolute* load, that is, an athlete’s external or internal load, irrespective of the rate of load application or load history (appendices A and B). High absolute training and/or competition load was identified as a risk factor for injury in athletics/running,[86-107] baseball,[42, 108-110] cricket,[111-116] football (soccer),[117, 118] orienteering,[119] rugby league,[120-125] rugby union,[126, 127] swimming,[106, 128] triathlon,[129-134] volleyball,[135] and water polo.[136] On the other hand, high absolute load was reported as *not* increasing injury risk in different studies that included

athletics/running, Australian football, rugby league, rugby union, and triathlon.[137-151] In some instances, high absolute load appeared to offer protection from injury in elite[116, 134, 152, 153] and non-elite athletes.[98, 132, 154-156]

Poorly managed training or competition loads can increase injury risk through a variety of mechanisms operating either at a tissue level or at a whole-athlete level. At a tissue level, training and competition load may lead to excessive microdamage and injury if the magnitude (intensity, frequency, duration) of loading is beyond the tissue's current loadbearing capacity (sometimes referred to as its "envelope of function"),[157] or if the recovery between loading cycles is insufficient.[158] This mechanism forms the basis of pathoetiological models of a range of overuse injury types, including bone stress injuries,[159, 160] tendinopathy,[158] and patellofemoral pain.[157] It has also been suggested that cumulative tissue fatigue due to repetitive loading may increase athletes' susceptibility for injuries typically thought to be entirely acute in nature, such as anterior cruciate ligament ruptures,[161] however, this hypothesis needs further corroboration.

At an athlete level, inappropriate loading can increase injury risk by impairing factors such as decision-making ability, coordination and neuromuscular control. Fatigue from training and competition leads to reduced muscular force development and contraction velocity. In turn, this can increase the forces imposed on passive tissues,[162-164] adversely alter kinetics, kinematics and neural feedback,[165-170] reduce joint stability,[171-174] and thus contribute to increased risk of acute and overuse injuries.

The studies associating low absolute loads with increased risk of injury[98, 116, 132, 134, 152-156] may imply inability to cope with impending higher loads. Training and competition engenders a number of adaptations within various bodily systems and organs, which are specific to the stimuli applied. Depending on the type of stimulus, defined by the mode of exercise and the intensity, duration and frequency of loading, neuromuscular, cardiovascular, skeletal and metabolic adaptations occur.[2-5], The various biological adaptations induced by (appropriate) training increase athletes' capacity to accept and withstand load, and may thus provide athletic resilience to athletes, resulting in protection from injuries.

Relative load, rapid changes in load and injury risk

While the studies on absolute load document a relationship between high and low loads and injuries, they fail to take into account the rate of load application (i.e., the load history or fitness) of the athlete. Recent studies indicate that high absolute loads may not be the problem per se, but rather excessive and rapid increases in the load that an athlete is exposed to relative to what he/she is prepared for, with evidence emerging from Australian football,[150, 152, 175-177] basketball,[178] cricket,[116, 179] football,[180-182] rugby league,[122, 183-185] and rugby union.[127] Specifically, large week-to-week changes in load (rapid increases in intensity, duration, or frequency) have been shown to place the athlete at a significantly increased risk of injury.[45, 127, 152, 175, 177]

Based on earlier work by Banister & Calvert,[67] Gabbett and colleagues[45, 186] recently introduced the concept of the acute:chronic load ratio to model the relationship between changes in load and injury risk (Figure 4). This ratio describes the acute training load (e.g., the training load of the last week) to the chronic load (e.g., the four-week rolling average of load). If chronic load has been progressively and systematically increased to high levels (i.e., the athlete has developed fitness) and the acute load is low (i.e., the athlete is experiencing minimal fatigue), then the athlete is considered well prepared. Conversely, if acute load exceeds the chronic workload (i.e., acute loads have been rapidly increased, resulting in fatigue, or training over the last four weeks has been inadequate to develop fitness), then the athlete is considered underprepared and likely at an increased risk of injury. Hence, this model takes into account both the positive and negative effects of training and competition loads. The model has currently been validated through data from three different sports (Australian football, cricket and rugby league),[187] demonstrating that injury likelihood is low (less than 10%) when the acute:chronic load ratio is within the range of 0.8 to 1.3. However, when the acute:chronic load ratio exceeds 1.5 (i.e., the load in the most recent week is 1.5 times greater than the average of the last four weeks), the likelihood of injury more than doubles (Figure 4).[183, 187]

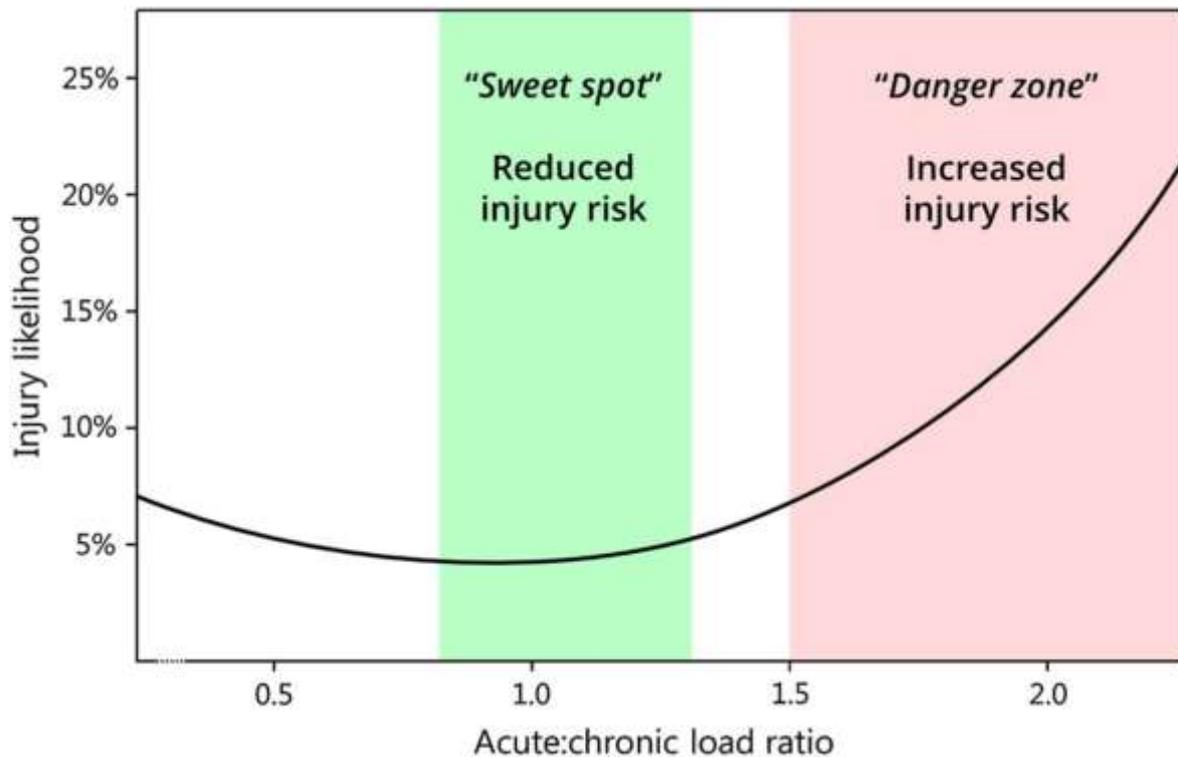


Figure 4. Acute:chronic load ratio (redrawn from Gabbett, 2016[45])

Interestingly, there are reports of a latent period of increased injury risk following rapid increases in load. For example, Hulin and colleagues[179, 183] found that an acute:chronic load ratio higher than 1.5 had little to no effect on injury likelihood in the *current week*, but that the likelihood of injury in *the week following* a rapid increase in load was two to four times higher. Furthermore, Orchard and colleagues[113] found a delayed injury risk lasting up to a month following a rapid load increase in cricket fast bowlers.

Overall, these data suggest that team-sport athletes respond significantly better to relatively small increases (and decreases), rather than larger fluctuations in loading. Provided that the athlete reaches these loads in a gradual and controlled fashion, high loads and physically hard training appear to offer a protective effect against injuries, due to the mediating effect on adaptation and development of physical qualities. Pending confirmation through research, it is generally believed that the same principles are applicable in athletes participating in individual endurance[188] and technical sports.

Competition calendar congestion and injury risk

Through intensified participation, competition typically places greater demands on the athlete than does training (when exposure is adjusted for). Depending on the magnitude of the increase in intensity, it can be argued that competition itself should be regarded as a

rapid increase in load (i.e., high acute load through competition), relative to what the athlete is prepared for (lower chronic load through training). This could be one contributing factor to the significantly elevated injury rates typically found in competition compared to training across sports, with competition identified as an injury risk factor in the literature.[189]

Calendar congestion, referring to the accumulation of matches/events over a shorter period of time than usual, may represent an exacerbated rapid increase in the acute load imposed on the athlete. Of the 12 studies exploring this relationship, eight (four in elite football, two in elite and junior cricket, one in junior tennis, and one in elite rugby league) found that competition congestion leads to increased injury rates,[37, 111, 112, 190-194] whereas four (two in elite football, one in elite cricket, one in elite rugby league) found no significant associations.[115, 184, 195, 196] In cricket, Dennis and colleagues found that elite fast bowlers having <2 or ≥ 5 days of recovery days between bowling sessions,[111] as well as junior fast bowlers with an average of <3.5 rest days[112] were at significantly increased risk of injury. In comparison, Orchard and colleagues[115] found a non-significant trend that elite bowlers who exceed 100 overs in 17 days are at an increased risk of injury.

Jayanthi and colleagues[190] investigated the medical withdrawal rates in United States Tennis Association junior national tennis tournaments, and found that the number of medical withdrawals increased significantly if players played five or more, compared with four or less matches in a tournament. Comparative data from elite tennis are currently non-existent. In elite rugby league, two studies have explored the relationship between match congestion and injury risk. Murray and colleagues[192] found that match congestion can lead to either high or low injury rates, depending on the playing position and its inherent game demands. In contrast, Hulin and colleagues[184] found no difference in injury risk between short and long recovery periods.

In football, six studies have investigated the impact of either short[37, 191, 193, 195] or prolonged[191, 194, 196] periods of match congestion on subsequent injury rates, with match congestion typically defined as playing two matches per week, compared to one, albeit using different cut-offs for days of in-between recovery. Whereas no difference was found in injury rates in match cycles with ≤ 3 days compared to ≥ 4 days in-between recovery,[191, 195] significantly higher injury rates were observed in match cycles with ≤ 3

days[193, 194] or ≤ 4 days[37, 191, 193] compared to ≥ 6 days of between-match recovery. Other reports on prolonged congestion periods (weeks) and injury rates have provided conflicting results; Bengtsson and colleagues[191] observed higher muscle injury rates during matches in congested periods, while Carling and colleagues[196] found no association.

Although there are some conflicting results and limited data, the majority of the available data on competition frequency seems to demonstrate that a congested competition calendar is associated with an increased risk of competition injury. In football, a pattern is emerging where two, compared to one match per week, significantly increases the risk of match injury. Overall, training injuries seem uninfluenced, or even reduced,[194] during periods of match congestion. It is possible that this can be attributed to deliberate down-regulation of the training load, as orienting the training towards recovery during periods of competition congestion is a customary practice in elite sport.

Psychological load and injury risk

A number of psychological variables may influence injury risk. These include psychological stressors, such as negative life-event stress[22, 32, 197-203], daily hassles,[32, 204-207] and sports-related stress (e.g. feeling of insufficient breaks and rest, stiff and tense muscles, feeling vulnerable to injuries),[117, 133, 207] but also personality variables such as trait anxiety[22, 32, 199, 205, 208, 209] state anxiety,[203], stress susceptibility,[205], type A behaviours,[210] trait irritability,[205] and mistrust,[22] as well as maladaptive coping strategies.[22, 149, 205, 211]

The proposed mechanism by which psychological stress responses increase injury risk is through attentional and somatic changes such as increased distractibility and peripheral narrowing, as well as muscle tension, fatigue, and reduced timing/coordination.[32, 197, 198, 200, 207] The evidence for the potential of daily hassles to predict injuries may be particularly important, as it suggests a potential rapid change to the injury risk to which an athlete is exposed.[32, 206] Furthermore, the burden placed on athletes undergoing major negative life events or chronic daily hassles may also increase their vulnerability to consider other minor stressors and events as stressful.[32]

Travel load and injury risk

The modern-day elite athlete typically competes in a number of international competitions and tournaments. This necessitates international travel not only for competition purposes, but also to attend training camps. Long-distance air travel across several time zones exposes passengers to travel fatigue and jet lag, which is suggested to negatively influence performance[212-214] and susceptibility to illness.[215, 216] However, no link has yet been established for injuries. Fuller et al.[217] and Schwellnus et al.[218] found no evidence to suggest that extensive air travel and crossing multiple time zones led to an increase risk of injury in elite rugby union players. Similarly, Fowler et al.[219] observed no significant effect of regular national travel on recovery or injury rate in professional Australian soccer players.

Methodological considerations

There are a number of reasons for the significant heterogeneity among the included papers on the relationship between load and injury risk in this consensus paper. The studies were conducted in different sports, on samples of different skill-levels, ages and sizes, and have employed a wide variety of research designs and methodologies, including different definitions and measurement methods of load and injury. It is perhaps not surprising, for example, that a cross-sectional registration of high weekly distance of swimming yields different results on the prevalence of shoulder supraspinatus tendinopathy in 80 male and female elite swimmers with a mean age of 16 years[128] than does prospective recording of high session ratings of perceived exertion (session-RPE) on injury incidence in 220 male rugby league players with a mean age of 21 years.[121]

The findings show that one of the most frequently used measures of load is the session-RPE,[117, 120-124, 127, 146, 150, 152, 153, 175, 178, 179] or similar cross-products of training duration and subjectively reported intensity.[104, 105, 149] These tools are particularly common in team sports, and have the advantage of combining external (duration) and internal (rating of perceived exertion) load, which may aid in revealing fatigue.[26, 30] However, these tools also have limitations in that they do not differentiate between short high-intensity sessions and long low-intensity sessions. For example, a 30-minute session with a RPE of 8 and a 120-minute session with a RPE of 2 will both yield a session-RPE of 240; however, the two sessions likely have very different effects on injury risk and pattern.

Load is also commonly recorded and reported as the exposure to training per unit of time [90, 106, 131, 131, 132, 134, 139, 140, 144, 145, 148, 151, 156] or the distance (mileage) of running, cycling or swimming.[86-100, 102, 103, 107, 128-130, 134, 137, 139-143, 155] However, these are highly inaccurate measures of load, as they fail to account for the intensity, movement repetitions, or impact load performed. Recently, it has become increasingly popular to use GPS/micro-technology units to quantify running load, particularly in team sports.[147, 150-152, 176, 177, 181-184, 188] In certain individual sports such as cycling, the use of load sensors allow for composite measures incorporating both training volume and intensity. In early baseball and cricket research, throw counts emerged as a simple and potentially effective technique to monitor load, with reports that exceeding thresholds of pitches (e.g., pitching more than 100 innings per year)[110] or throws (e.g., completing more than 75 throws per week)[114] significantly increased the risk of injury. However, measures relying solely on external load do not take into account the intensity of the training or internal response of the athlete, and may therefore have problems with both sensitivity and specificity in the identification of athletes in maladaptive states.

The variation in results may also be explained by differences in research design and data analysis. The studies on calendar congestion are specifically limited by 1) small sample sizes (following players from only one team),[37, 184, 192-196] which may restrict external validity and increase risk of statistical (random) error, 2) disregarding individual exposure and thereby player rotation strategies,[191, 194-196] which potentially can dilute the actual injury risk of a player exposed to the full load, or 3) employing retrospective cross-sectional designs.[190]

Most of the studies employ either prospective/retrospective cohort or cross-sectional designs. While these studies may demonstrate an association (correlation) between the independent (load) and dependent (injury) variables, the main challenge is to rule out interaction with potential confounding factors. The best study design to examine and identify risk factors that predict injury or illness is large-scale (multi-centre) prospective cohort studies. Nonetheless, unlike experimental studies such as randomised controlled trials, cohort and cross-sectional studies rely on adequate data collection and subsequent multivariate analysis to control for the effect of and interaction with other variables – and thereby strengthen the causal relationship. In contrast, use of univariate analyses, or failing

to record data on extraneous variables that influence the dependent variable, may produce spurious results and lead to incorrect conclusions.

Timpka and colleagues[149] recently demonstrated the importance of controlling for the potentially complex interactions between risk factors, when they integrated psychological with physiological and epidemiological data from elite track and field athletes, and found that the maladaptive coping behaviour self-blame replaced training load as a risk factor for overuse injury. The authors suggested that overuse injuries in athletics may not be predicted by the training load per se,[104] but rather, by high load applied in situations when the athlete is in need of rest. Their findings are important, as they emphasise both the need to control for all risk factors, and that adaptations that occur may lead to large variations in an individual's ability to accept and respond to load, which can alter risk and affect aetiology in a dynamic, recursive fashion.[13]

Practical guidelines for load management

The aim of load management is to optimally configure training, competition and other load to maximise adaptation and performance with minimal risk of injury. Load management therefore comprises the appropriate prescription, monitoring and adjustment of external and internal loads, for which a number of key practical guidelines can be provided.

Prescribing training and competition load

Evidence is emerging that poor load management with ensuing maladaptation is a major risk factor for sports injury. The limitation of data to a few select sports and athlete populations, combined with the distinct natures of different sports, make it difficult to provide sport-specific guidelines for load management. However, certain general points can be made:

- High loads can have either positive or negative influences on injury risk in athletes, with the rate of load application and intrinsic risk factor profile being critical factors. Athletes respond significantly better to relatively small increases (and decreases), rather than larger fluctuations in loading. While it is likely that different sports will have different load-injury profiles, current evidence from Australian football, cricket and rugby league suggests that athletes should limit weekly increases of their training load to less than 10%, or maintain an acute:chronic load

ratio within a range of 0.8 to 1.3, to stay in positive adaptation and thus reduce the risk of injuries.

- In football, playing two matches (i.e., ≤ 4 days recovery between matches), compared to one match per week increases the risk of injury. In these circumstances, football teams should consider using squad rotation to prevent large increases in match loads for individual players.
- Load should always be prescribed on an individual and flexible basis, as there is large intra- and inter-individual variation in the timeframe of response and adaptation to load.
- Special attention should be given to load management in developing athletes, who are at increased risk when introduced to new loads, changes in loads or congested competition calendars.[180, 220-222]
- Variation in an athlete's psychological stressors should also guide the prescription of training and/or competition loads.
- Coaches and support staff must schedule adequate recovery, particularly after intensive training periods, competitions and travel, including nutrition and hydration, sleep and rest, active rest, relaxation strategies and emotional support.
- Sports governing bodies must consider the health of the athletes, and hence, the competition load when planning their event calendars. This requires increased coordination between single- and multi-sport event organisers, and the development of a comprehensive calendar of all international sports events.

Monitoring load

Scientific monitoring of the athlete's loads is key to successful load management, athlete adaptation and injury mitigation in sport.

- Coaches and support staff are recommended to employ objective methods to monitor the athlete's load and detect meaningful change.
- Load should always be monitored individually.
- No single marker has been validated to identify when an athlete has entered a maladaptive state; hence, it is recommended to use a combination of external and internal load measures that are relevant and specific to the nature of each sport.
- Subjective load measures are particularly useful, and coaches and support staff may employ them with confidence. Subscales that evaluate non-sport stress, fatigue,

physical recovery, general health/wellbeing and being in shape are responsive to both acute and chronic training.[30]

- Load is not an isolated variable, but must be monitored using a comprehensive approach taking into account interaction with and relative contributions from other intrinsic and extrinsic factors, such as injury history, physiological, psychological (e.g., non-sport loads), biochemical, immunological, environmental and genetic factors, as well as age and sex.
- Special consideration should be given to the monitoring of both acute and chronic loads, and the acute:chronic load ratio of the individual athlete.
- Monitoring should be done frequently (e.g., daily or weekly measures self-administered by the athlete) to enable acute adjustments to training and competition loads as required; however, with consideration given to minimising the burden on athletes.

Psychological load management

Psychological load (stressors) such as negative life-event stress and daily hassles can significantly increase the risk of injury in athletes. Clinical practical recommendations centre on reducing state-level stressors and educating athletes, coaches and support staff in proactive stress management, and comprise:[32]

- Developing resilience strategies to help athletes understand the relationship between personal traits, negative life events, thoughts, emotions, and physiological states, which, in turn, may help them minimise the impact of negative life events and the subsequent risk of injury.
- Educating athletes in stress-management techniques, confidence building, and goal setting, optimally under supervision of a sport psychologist, to help minimise the effects of stress and reduce the likelihood of injury.
- Reducing training and/or competition load and intensity to mitigate injury risk for athletes who appear unfocused as a consequence of negative life events or ongoing daily hassles.
- Implementing periodical stress assessments (e.g., hassle and uplift scale,[52] or LESCA[50]) to inform adjustment of athletes' training and/or competition loads. An athlete who reports high levels of daily hassle or stress could likely benefit from

reducing the training load during a specified time period to prevent potential fatigue, injuries, or burnout.[32]

Monitoring of injury

The use of sensitive measures to monitor an athlete's health can lead to early detection of symptoms and signs of injury, early diagnosis and appropriate intervention. Athletes' innate tendency to continue to train and compete despite the existence of physical complaints or functional limitations, particularly at the elite level, highlight the pressing need to use appropriate injury monitoring tools.

- On-going, scientific injury (and illness) surveillance systems should be established in all sports.
- Monitoring tools must be sensitive not only to acute and overuse injuries, but to early clinical symptoms, such as pain and functional limitations.
- Injury monitoring should ideally be on-going, but must at least occur for a period of time (e.g., at least four weeks) after rapid increases in loads.

Research directions for load management in sport

In general, there is a paucity of research data on the relationship between load (training, competition, competition calendar congestion, psychological, travel, or other) and injury risk, with limited evidence from a few select sports.

The potential of future research lies in informing the development of training and competition programs tailored to the needs of the individual, following interaction with and variation in other risk factors. We identified that research should be directed towards:

- Promoting further large-scale prospective cohort studies investigating the dose-response relationship between load and injury. Particular focus should be placed on the potential interactions with and relative contributions from other physiological, psychological, environmental and genetic risk factors, to further elucidate the global capacity of individuals to adapt to different loads at any given time.
- Increasing the understanding on how psychological and psychosocial factors interact with physiological and mechanical factors to increase injury vulnerability.

- Exploring whether it is possible, taking into account inter- and intra-individual variation, to identify optimal training and competition loads (or upper limits) for elite and developing athletes in different sports, including training intensity, duration and frequency, competition frequency (calendar congestion and cut-offs for number of recovery days) and season duration.
- Conducting further studies on the impact of the acute:chronic load ratio (i.e., rapid increases/decreases in load compared to relatively stable loading) on injury risk in multiple sports, including individual endurance and technical sports.
- Investigating the potential latent period (time frame of onset and end) of increased injury risk following (rapid) changes in load.
- Elucidating special needs, competition matching, and load-induced adaptations in young talented athletes.
- Studying the effects of short and prolonged competition congestion in sports, using individual, rather than team load data.
- Examining the effects of periodisation on injury risk in sport.
- Validating the efficacy and sensitivity of established and emerging external and internal load monitoring measures to identify maladaptation and increased injury risk in athletes.
- Elucidating the influence of load and recovery on the development of fatigue, subclinical tissue damage, clinical symptoms, and injury.
- Further examining the relationship (including mechanisms) between travel fatigue and jet lag, and injury risk.
- Exploring the possibility of utilising experimental research designs, such as randomised controlled trials to evaluate the effect of load monitoring interventions (e.g., confining the acute:chronic load ratio between 0.8 to 1.3) compared with a control group (e.g., usual loading routines) on injury rates in sport
- Reviewing sport-governing bodies' initiatives to mitigate load-induced health problems, and assessing the effectiveness of current policies and practices.

Summary

Data on the relationship between load and risk of injury are limited to a few select sports and athlete populations. High loads can have either positive or negative influences on injury risk in athletes, with the rate of load application in combination with the athlete's internal risk factor profile likely being critical factors. Athletes respond significantly better to relatively small increases (and decreases), rather than larger fluctuations in loading. There is evidence from some sports that if load is applied in a moderate and progressive manner, and rapid increases in load – relative to what the athlete is prepared for – are avoided, high loads and physically hard training may offer a protective effect against injuries. Load must always be prescribed on an individual and flexible basis, as there is large intra- and inter-individual variation in the timeframe of response and adaptation to load. Regular athlete monitoring is fundamental to ensure appropriate and therapeutic levels of external and internal loads and thus to maximise performance and minimise the risk of injury. Sports governing bodies must consider the health of the athletes, and hence, the overall competition load when planning event calendars. More research is needed on the impact of competition calendar congestion and rapid changes in load on injury risk in multiple sports, as well as on the interaction with other physiological, psychological, environmental and genetic risk factors.

Reference List

- 1 Hill J. Sport In History: An Introduction. London: Palgrave Macmillan; 2010.
- 2 Booth FW, Thomason DB. Molecular and cellular adaptation of muscle in response to exercise: perspectives of various models. *Physiol Rev* 1991;71:541-85.
- 3 Hawley JA, Hargreaves M, Joyner MJ, et al. Integrative biology of exercise. *Cell* 2014;159:738-49.
- 4 Viru A, Viru M. Nature of training effects. In: Garrett WE, Jr., Kirkendall DT, eds. Exercise and Sport Science. 1st ed. Philadelphia: Lippincott Williams and Wilkins 2000:67-96.
- 5 Brooks GA, Fahey TD, Baldwin KM. Exercise Physiology: Human Bioenergetics and its Applications. 4th ed. New York: McGraw-Hill; 2004.

- 6 Meeusen R. Overtraining syndrome. In: Mujika I, Hausswirth C, eds. Recovery for performance in sport. Champaign, IL: Human Kinetics 2013:9-20.
- 7 McCall A, Carling C, Nedelec M, et al. Risk factors, testing and preventative strategies for non-contact injuries in professional football: current perceptions and practices of 44 teams from various premier leagues. *Br J Sports Med* 2014;48:1352-57.
- 8 McCall A, Davison M, Andersen TE, et al. Injury prevention strategies at the FIFA 2014 World Cup: perceptions and practices of the physicians from the 32 participating national teams. *Br J Sports Med* 2015;49:603-08.
- 9 McCall A, Dupont G, Ekstrand J. Injury prevention strategies, coach compliance and player adherence of 33 of the UEFA Elite Club Injury Study teams: a survey of teams' head medical officers. *Br J Sports Med* 2016;50:725-30.
- 10 Baker S, O'Neill B, Karpf R. The Injury Fact Book. 2nd ed. New York, NY: Oxford University Press; 1992.
- 11 Kibler WB, Chandler TJ, Stracener ES. Musculoskeletal adaptations and injuries due to overtraining. *Exerc Sport Sci Rev* 1992;20:99-126.
- 12 Meeuwisse WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med* 1994;4:166-70.
- 13 Meeuwisse WH, Tyreman H, Hagel B, et al. A dynamic model of etiology in sport injury: the recursive nature of risk and causation. *Clin J Sport Med* 2007;17:215-19.
- 14 Drew MK, Finch CF. The Relationship Between Training Load and Injury, Illness and Soreness: A Systematic and Literature Review. *Sports Med* 2016.
- 15 Kuipers H, Keizer HA. Overtraining in elite athletes. Review and directions for the future. *Sports Med* 1988;6:79-92.
- 16 Fry RW, Morton AR, Keast D. Overtraining in athletes. An update. *Sports Med* 1991;12:32-65.
- 17 Kenttä G, Hassmén P. Overtraining and recovery. A conceptual model. *Sports Med* 1998;26:1-16.
- 18 Meeusen R, Duclos M, Foster C, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc* 2013;45:186-205.
- 19 Schwellnus M, Soligard T, Alonso JM, et al. International Olympic Committee consensus statement on training and competition load and the risk of illness: How much is too much? (CORRECT REFERENCE TO BE ADDED BY BJSM). *Br J Sports Med* 2016. In press. doi:
- 20 Budgett R. Overtraining syndrome. *Br J Sports Med* 1990;24:231-36.

- 21 Lehmann M, Foster C, Keul J. Overtraining in endurance athletes: a brief review. *Med Sci Sports Exerc* 1993;25:854-62.
- 22 Johnson U, Ivarsson A. Psychological predictors of sport injuries among junior soccer players. *Scand J Med Sci Sports* 2011;21:129-36.
- 23 Borresen J, Lambert MI. The quantification of training load, the training response and the effect on performance. *Sports Med* 2009;39:779-95.
- 24 Oxford Dictionaries. "Load". Oxford University Press. Date accessed: 24.5.2016. Available from: <http://www.oxforddictionaries.com/definition/english/load>.
- 25 Wallace LK, Slattery KM, Coutts AJ. The ecological validity and application of the session-RPE method for quantifying training loads in swimming. *J Strength Cond Res* 2009;23:33-38.
- 26 Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med* 2014;44 Suppl 2:S139-S147.
- 27 Impellizzeri FM, Rampinini E, Marcora SM. Physiological assessment of aerobic training in soccer. *J Sports Sci* 2005;23:583-92.
- 28 Foster C. Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exerc* 1998;30:1164-68.
- 29 Pyne DB, Martin DT. Fatigue-insights from individual and team sports. In: Marino FE, editor. Regulation of fatigue in exercise. New York: Nova Science 2011:177-185.
- 30 Saw AE, Main LC, Gastin PB. Monitoring the athlete training response: subjective self-reported measures trump commonly used objective measures: a systematic review. *Br J Sports Med* 2015.
- 31 Hooper SL, Mackinnon LT. Monitoring overtraining in athletes. Recommendations. *Sports Med* 1995;20:321-27.
- 32 Ivarsson A, Johnson U, Podlog L. Psychological predictors of injury occurrence: a prospective investigation of professional Swedish soccer players. *J Sport Rehabil* 2013;22:19-26.
- 33 Foster C, Heimann KM, Esten PL, et al. Differences in perceptions of training by coaches and athletes. *SA J Sports Med* 2001;8:3-7.
- 34 Murphy AP, Duffield R, Kellett A, et al. Comparison of athlete-coach perceptions of internal and external load markers for elite junior tennis training. *Int J Sports Physiol Perform* 2014;9:751-56.
- 35 Brink MS, Frencken WG, Jordet G, et al. Coaches' and players' perceptions of training dose: not a perfect match. *Int J Sports Physiol Perform* 2014;9:497-502.
- 36 Gabbett TJ. Incidence of injury in semi-professional rugby league players. *Br J Sports Med* 2003;37:36-43.

- 37 Dupont G, Nedelec M, McCall A, et al. Effect of 2 soccer matches in a week on physical performance and injury rate. *Am J Sports Med* 2010;38:1752-58.
- 38 Bengtsson H, Ekstrand J, Walden M, et al. Match injury rates in professional soccer vary with match result, match venue, and type of competition. *Am J Sports Med* 2013;41:1505-10.
- 39 Aughey RJ. Applications of GPS technologies to field sports. *Int J Sports Physiol Perform* 2011;6:295-310.
- 40 Jobson SA, Passfield L, Atkinson G, et al. The analysis and utilization of cycling training data. *Sports Med* 2009;39:833-44.
- 41 Twist C, Highton J. Monitoring fatigue and recovery in rugby league players. *Int J Sports Physiol Perform* 2013;8:467-74.
- 42 Lyman S, Fleisig GS, Andrews JR, et al. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am J Sports Med* 2002;30:463-68.
- 43 Bahr MA, Bahr R. Jump frequency may contribute to risk of jumper's knee: a study of interindividual and sex differences in a total of 11,943 jumps video recorded during training and matches in young elite volleyball players. *Br J Sports Med* 2014;48:1322-26.
- 44 Macera CA. Lower extremity injuries in runners. Advances in prediction. *Sports Med* 1992;13:50-57.
- 45 Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? *Br J Sports Med* 2016;50:273-80.
- 46 Robinson DM, Robinson SM, Hume PA, et al. Training intensity of elite male distance runners. *Med Sci Sports Exerc* 1991;23:1078-82.
- 47 Morgan WP, Brown DR, Raglin JS, et al. Psychological monitoring of overtraining and staleness. *Br J Sports Med* 1987;21:107-14.
- 48 Kellmann M, Kallus KW. The recovery-stress-questionnaire for athletes. Frankfurt: Swets and Zeitlinger; 2000.
- 49 Rushall BS. A tool for measuring stress tolerance in elite athletes. *Journal of Applied Sport Psychology* 1990;2:51-66.
- 50 Petrie TA. Psychosocial antecedents of athletic injury: the effects of life stress and social support on female collegiate gymnasts. *Behav Med* 1992;18:127-38.
- 51 Main L, Grove JR. A multi-component assessment model for monitoring training distress among athletes. *European Journal of Sport Science* 2009;9:195-202.
- 52 DeLongis A, Folkman S, Lazarus RS. The impact of daily stress on health and mood: psychological and social resources as mediators. *J Pers Soc Psychol* 1988;54:486-95.

- 53 Carver CS. You want to measure coping but your protocol's too long: consider the brief COPE. *Int J Behav Med* 1997;4:92-100.
- 54 Gustavsson JP, Bergman H, Edman G, et al. Swedish universities Scales of Personality (SSP): construction, internal consistency and normative data. *Acta Psychiatr Scand* 2000;102:217-25.
- 55 Spielberger CD, Gorsuch RL, Lushene R, Vagg PR, Jacobs GA. Manual for the state-trait anxiety inventory. Palo Alto, CA: Consulting Psychologists; 1983.
- 56 Smith RE, Smoll FL, Schutz RW. Measurement and correlates of sport-specific cognitive and somatic trait anxiety: the sport anxiety scale. *Anxiety Research* 1990;2:263-80.
- 57 Smith RE, Schutz RW, Smoll FL, et al. Development and validation of a multidimensional measure of sport-specific psychological skills: the athletic coping skills inventory-28. *J Sport Exerc Psychol* 1995;17:379-98.
- 58 Miller LC, Murphy R, Buss RH. Consciousness of body: Private and public. *J Pers Soc Psychol* 1981;41:397-406.
- 59 Seifriz JJ, Duda JL, Chi L. The relationship of perceived motivational climate and beliefs about success in basketball. *J Sport Exerc Psychol* 1992;14:375-91.
- 60 Davis C, Brewer H, Ratusny D. Behavioral frequency and psychological commitment: necessary concepts in the study of excessive exercising. *J Behav Med* 1993;16:611-28.
- 61 Halson SL. Sleep in elite athletes and nutritional interventions to enhance sleep. *Sports Med* 2014;44 Suppl 1:S13-S23.
- 62 Nederhof E, Lemmink KA, Visscher C, et al. Psychomotor speed: possibly a new marker for overtraining syndrome. *Sports Med* 2006;36:817-28.
- 63 Hopkins WG. Quantification of training in competitive sports. Methods and applications. *Sports Med* 1991;12:161-83.
- 64 Martin DT, Andersen MB. Heart rate-perceived exertion relationship during training and taper. *J Sports Med Phys Fitness* 2000;40:201-08.
- 65 Daanen HA, Lamberts RP, Kallen VL, et al. A systematic review on heart-rate recovery to monitor changes in training status in athletes. *Int J Sports Physiol Perform* 2012;7:251-60.
- 66 Plews DJ, Laursen PB, Stanley J, et al. Training adaptation and heart rate variability in elite endurance athletes: opening the door to effective monitoring. *Sports Med* 2013;43:773-81.
- 67 Banister EW, Calvert TW. Planning for future performance: implications for long term training. *Can J Appl Sport Sci* 1980;5:170-76.
- 68 Beneke R, Leithauser RM, Ochentel O. Blood lactate diagnostics in exercise testing and training. *Int J Sports Physiol Perform* 2011;6:8-24.

- 69 Snyder AC, Jeukendrup AE, Hesselink MK, et al. A physiological/psychological indicator of over-reaching during intensive training. *Int J Sports Med* 1993;14:29-32.
- 70 Engebretsen L, Soligard T, Steffen K, et al. Sports injuries and illnesses during the London Summer Olympic Games 2012. *Br J Sports Med* 2013;47:407-14.
- 71 Junge A, Dvorak J. Injury surveillance in the World Football Tournaments 1998-2012. *Br J Sports Med* 2013;47:782-88.
- 72 Willick SE, Webborn N, Emery C, et al. The epidemiology of injuries at the London 2012 Paralympic Games. *Br J Sports Med* 2013;47:426-32.
- 73 Alonso JM, Jacobsson J, Timpka T, et al. Preparticipation injury complaint is a risk factor for injury: a prospective study of the Moscow 2013 IAAF Championships. *Br J Sports Med* 2015;49:1118-24.
- 74 Mountjoy M, Junge A, Benjamin S, et al. Competing with injuries: injuries prior to and during the 15th FINA World Championships 2013 (aquatics). *Br J Sports Med* 2015;49:37-43.
- 75 Soligard T, Steffen K, Palmer-Green D, et al. Sports injuries and illnesses in the Sochi 2014 Olympic Winter Games. *Br J Sports Med* 2015;49:441-47.
- 76 Hägglund M, Waldén M, Bahr R, et al. Methods for epidemiological study of injuries to professional football players: developing the UEFA model. *Br J Sports Med* 2005;39:340-46.
- 77 Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med* 2006;40:193-201.
- 78 Fuller CW, Molloy MG, Bagate C, et al. Consensus statement on injury definitions and data collection procedures for studies of injuries in rugby union. *Br J Sports Med* 2007;41:328-31.
- 79 Junge A, Engebretsen L, Alonso JM, et al. Injury surveillance in multi-sport events: the International Olympic Committee approach. *Br J Sports Med* 2008;42:413-21.
- 80 Cook J, Finch CF. The long-term impact of overuse injuries on life-long participation in sport and health status. In: Farelli AD, editor. *Sport participation: health benefits, injuries and psychological effects*. Hauppauge, NY: Nova Science Publishers 2011:85-104.
- 81 Bahr R, Alfredson H, Järvinen M, Järvinen T, Khan K, Kjær M et al. Types and causes of injuries. In: Bahr R, editor. *The IOC manual of sports injuries: an illustrated guide to the management of injuries in physical activity*. Hoboken: Wiley-Blackwell 2012:1-25.
- 82 Bahr R. No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. *Br J Sports Med* 2009;43:966-72.
- 83 Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma

- Research Centre (OSTRC) overuse injury questionnaire. *Br J Sports Med* 2013;47:495-502.
- 84 Clarsen B, Ronsen O, Myklebust G, et al. The Oslo Sports Trauma Research Center questionnaire on health problems: a new approach to prospective monitoring of illness and injury in elite athletes. *Br J Sports Med* 2014;48:754-60.
- 85 Clarsen B, Bahr R, Heymans MW, et al. The prevalence and impact of overuse injuries in five Norwegian sports: Application of a new surveillance method. *Scand J Med Sci Sports* 2015;25:323-30.
- 86 Koplán JP, Powell KE, Sikes RK, et al. An epidemiologic study of the benefits and risks of running. *JAMA* 1982;248:3118-21.
- 87 Jacobs SJ, Berson BL. Injuries to runners: a study of entrants to a 10,000 meter race. *Am J Sports Med* 1986;14:151-55.
- 88 Lysholm J, Wiklander J. Injuries in runners. *Am J Sports Med* 1987;15:168-71.
- 89 Marti B, Vader JP, Minder CE, et al. On the epidemiology of running injuries. The 1984 Bern Grand-Prix study. *Am J Sports Med* 1988;16:285-94.
- 90 Bovens AM, Janssen GM, Vermeer HG, et al. Occurrence of running injuries in adults following a supervised training program. *Int J Sports Med* 1989;10 Suppl 3:S186-S190.
- 91 Macera CA, Pate RR, Powell KE, et al. Predicting lower-extremity injuries among habitual runners. *Arch Intern Med* 1989;149:2565-68.
- 92 Marti B, Knobloch M, Tschopp A, et al. Is excessive running predictive of degenerative hip disease? Controlled study of former elite athletes. *BMJ* 1989;299:91-93.
- 93 Walter SD, Hart LE, McIntosh JM, et al. The Ontario cohort study of running-related injuries. *Arch Intern Med* 1989;149:2561-64.
- 94 Haglund-Åkerlind Y, Eriksson E. Range of motion, muscle torque and training habits in runners with and without Achilles tendon problems. *Knee Surg Sports Traumatol Arthrosc* 1993;1:195-99.
- 95 Koplán JP, Rothenberg RB, Jones EL. The natural history of exercise: a 10-yr follow-up of a cohort of runners. *Med Sci Sports Exerc* 1995;27:1180-84.
- 96 Messier SP, Edwards DG, Martin DF, et al. Etiology of iliotibial band friction syndrome in distance runners. *Med Sci Sports Exerc* 1995;27:951-60.
- 97 McCrory JL, Martin DF, Lowery RB, et al. Etiologic factors associated with Achilles tendinitis in runners. *Med Sci Sports Exerc* 1999;31:1374-81.
- 98 Satterthwaite P, Norton R, Larmer P, et al. Risk factors for injuries and other health problems sustained in a marathon. *Br J Sports Med* 1999;33:22-26.

- 99 Hootman JM, Macera CA, Ainsworth BE, et al. Predictors of lower extremity injury among recreationally active adults. *Clin J Sport Med* 2002;12:99-106.
- 100 McKean KA, Manson NA, Stanish WD. Musculoskeletal injury in the masters runners. *Clin J Sport Med* 2006;16:149-54.
- 101 Schueller-Weidekamm C, Schueller G, Uffmann M, et al. Incidence of chronic knee lesions in long-distance runners based on training level: findings at MRI. *Eur J Radiol* 2006;58:286-93.
- 102 Knobloch K, Yoon U, Vogt PM. Acute and overuse injuries correlated to hours of training in master running athletes. *Foot Ankle Int* 2008;29:671-76.
- 103 van Middelkoop M, Kolkman J, Van Ochten J, et al. Risk factors for lower extremity injuries among male marathon runners. *Scand J Med Sci Sports* 2008;18:691-97.
- 104 Jacobsson J, Timpka T, Kowalski J, et al. Injury patterns in Swedish elite athletics: annual incidence, injury types and risk factors. *Br J Sports Med* 2013;47:941-52.
- 105 Huxley DJ, O'Connor D, Healey PA. An examination of the training profiles and injuries in elite youth track and field athletes. *Eur J Sport Sci* 2014;14:185-92.
- 106 Ristolainen L, Kettunen JA, Waller B, et al. Training-related risk factors in the etiology of overuse injuries in endurance sports. *J Sports Med Phys Fitness* 2014;54:78-87.
- 107 van der Worp MP, de WA, van CR, et al. The 5- or 10-km Marikenloop run: a prospective study of the etiology of running-related injuries in women. *J Orthop Sports Phys Ther* 2016;46:462-70.
- 108 Lyman S, Fleisig GS, Waterbor JW, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc* 2001;33:1803-10.
- 109 Olsen SJ, Fleisig GS, Dun S, et al. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am J Sports Med* 2006;34:905-12.
- 110 Fleisig GS, Andrews JR, Cutter GR, et al. Risk of serious injury for young baseball pitchers: a 10-year prospective study. *Am J Sports Med* 2011;39:253-57.
- 111 Dennis R, Farhart P, Goumas C, et al. Bowling workload and the risk of injury in elite cricket fast bowlers. *J Sci Med Sport* 2003;6:359-67.
- 112 Dennis RJ, Finch CF, Farhart PJ. Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *Br J Sports Med* 2005;39:843-46.
- 113 Orchard JW, James T, Portus M, et al. Fast bowlers in cricket demonstrate up to 3- to 4-week delay between high workloads and increased risk of injury. *Am J Sports Med* 2009;37:1186-92.
- 114 Saw R, Dennis RJ, Bentley D, et al. Throwing workload and injury risk in elite cricketers. *Br J Sports Med* 2011;45:805-08.

- 115 Orchard JW, Blanch P, Paoloni J, et al. Fast bowling match workloads over 5-26 days and risk of injury in the following month. *J Sci Med Sport* 2015;18:26-30.
- 116 Orchard JW, Blanch P, Paoloni J, et al. Cricket fast bowling workload patterns as risk factors for tendon, muscle, bone and joint injuries. *Br J Sports Med* 2015;49:1064-68.
- 117 Brink MS, Visscher C, Arends S, et al. Monitoring stress and recovery: new insights for the prevention of injuries and illnesses in elite youth soccer players. *Br J Sports Med* 2010;44:809-15.
- 118 Owen AL, Forsyth JJ, Wong dP, et al. Heart rate-based training intensity and its impact on injury incidence among elite-level professional soccer players. *J Strength Cond Res* 2015;29:1705-12.
- 119 von Rosen P, Heijne AI, Frohm A. Injuries and associated risk factors among adolescent elite orienteers: a 26-week prospective registration study. *J Athl Train* 2016;51:321-28.
- 120 Gabbett TJ. Influence of training and match intensity on injuries in rugby league. *J Sports Sci* 2004;22:409-17.
- 121 Gabbett TJ. Reductions in pre-season training loads reduce training injury rates in rugby league players. *Br J Sports Med* 2004;38:743-49.
- 122 Gabbett TJ, Domrow N. Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *J Sports Sci* 2007;25:1507-19.
- 123 Gabbett TJ. The development and application of an injury prediction model for noncontact, soft-tissue injuries in elite collision sport athletes. *J Strength Cond Res* 2010;24:2593-603.
- 124 Gabbett TJ, Jenkins DG. Relationship between training load and injury in professional rugby league players. *J Sci Med Sport* 2011;14:204-09.
- 125 Gabbett TJ, Ullah S. Relationship between running loads and soft-tissue injury in elite team sport athletes. *J Strength Cond Res* 2012;26:953-60.
- 126 Lee AJ, Garraway WM, Arneil DW. Influence of preseason training, fitness, and existing injury on subsequent rugby injury. *Br J Sports Med* 2001;35:412-17.
- 127 Cross MJ, Williams S, Trewartha G, et al. The influence of in-season training loads on injury risk in professional rugby union. *Int J Sports Physiol Perform* 2016;11:350-55.
- 128 Sein ML, Walton J, Linklater J, et al. Shoulder pain in elite swimmers: primarily due to swim-volume-induced supraspinatus tendinopathy. *Br J Sports Med* 2010;44:105-13.
- 129 Vleck VE, Garbutt G. Injury and training characteristics of male elite, development squad, and club triathletes. *Int J Sports Med* 1998;19:38-42.

- 130 Burns J, Keenan AM, Redmond AC. Factors associated with triathlon-related overuse injuries. *J Orthop Sports Phys Ther* 2003;33:177-84.
- 131 Egermann M, Brocai D, Lill CA, et al. Analysis of injuries in long-distance triathletes. *Int J Sports Med* 2003;24:271-76.
- 132 Shaw T, Howat P, Trainor M, et al. Training patterns and sports injuries in triathletes. *J Sci Med Sport* 2004;7:446-50.
- 133 Main LC, Landers GJ, Grove JR, et al. Training patterns and negative health outcomes in triathlon: longitudinal observations across a full competitive season. *J Sports Med Phys Fitness* 2010;50:475-85.
- 134 Vleck VE, Bentley DJ, Millet GP, et al. Triathlon event distance specialization: training and injury effects. *J Strength Cond Res* 2010;24:30-36.
- 135 Visnes H, Bahr R. Training volume and body composition as risk factors for developing jumper's knee among young elite volleyball players. *Scand J Med Sci Sports* 2013;23:607-13.
- 136 Wheeler K, Kefford T, Mosler A, et al. The volume of goal shooting during training can predict shoulder soreness in elite female water polo players. *J Sci Med Sport* 2013;16:255-58.
- 137 Collins K, Wagner M, Peterson K, et al. Overuse injuries in triathletes. A study of the 1986 Seafair Triathlon. *Am J Sports Med* 1989;17:675-80.
- 138 D'Souza D. Track and field athletics injuries--a one-year survey. *Br J Sports Med* 1994;28:197-202.
- 139 Korkia PK, Tunstall-Pedoe DS, Maffulli N. An epidemiological investigation of training and injury patterns in British triathletes. *Br J Sports Med* 1994;28:191-96.
- 140 Bennell KL, Crossley K. Musculoskeletal injuries in track and field: incidence, distribution and risk factors. *Aust J Sci Med Sport* 1996;28:69-75.
- 141 Duffey MJ, Martin DF, Cannon DW, et al. Etiologic factors associated with anterior knee pain in distance runners. *Med Sci Sports Exerc* 2000;32:1825-32.
- 142 Rauh MJ, Koepsell TD, Rivara FP, et al. Epidemiology of musculoskeletal injuries among high school cross-country runners. *Am J Epidemiol* 2006;163:151-59.
- 143 Kelsey JL, Bachrach LK, Procter-Gray E, et al. Risk factors for stress fracture among young female cross-country runners. *Med Sci Sports Exerc* 2007;39:1457-63.
- 144 Brooks JH, Fuller CW, Kemp SP, et al. An assessment of training volume in professional rugby union and its impact on the incidence, severity, and nature of match and training injuries. *J Sports Sci* 2008;26:863-73.
- 145 Viljoen W, Saunders CJ, Hechter GH, et al. Training volume and injury incidence in a professional rugby union team. *SA J Sports Med* 2009;21:97-101.

- 146 Killen NM, Gabbett TJ, Jenkins DG. Training loads and incidence of injury during the preseason in professional rugby league players. *J Strength Cond Res* 2010;24:2079-84.
- 147 Nielsen RO, Buist I, Parner ET, et al. Predictors of running-related injuries among 930 novice runners: a 1-year prospective follow-up study. *Orthop J Sports Med* 2013;1:2325967113487316.
- 148 Zwungenberger S, Valladares RD, Walther A, et al. An epidemiological investigation of training and injury patterns in triathletes. *J Sports Sci* 2014;32:583-90.
- 149 Timpka T, Jacobsson J, Dahlstrom O, et al. The psychological factor 'self-blame' predicts overuse injury among top-level Swedish track and field athletes: a 12-month cohort study. *Br J Sports Med* 2015;49:1472-77.
- 150 Duhig S, Shield AJ, Opar D, et al. The effect of high-speed running on hamstring strain injury risk. *Br J Sports Med* 2016; Published Online First: 10 June 2016. doi:10.1136/bjsports-2015-095679.
- 151 Murray NB, Gabbett TJ, Townshend AD. Relationship between pre-season training load and in-season load and injury in elite Australian Football players. *Int J Sports Physiol Perform* 2016. In press. doi: n/a
- 152 Piggott B, Newton MJ, McGuigan MR. The relationship between training load and incidence of injury and illness over a pre-season at an Australian Football League club. *J Aust Strength Cond* 2009;17:4-17.
- 153 Veugelers KR, Young WB, Fahrner B, et al. Different methods of training load quantification and their relationship to injury and illness in elite Australian football. *J Sci Med Sport* 2016;19:24-28.
- 154 Taunton JE, Ryan MB, Clement DB, et al. A prospective study of running injuries: the Vancouver Sun Run "In Training" clinics. *Br J Sports Med* 2003;37:239-44.
- 155 Rasmussen CH, Nielsen RO, Juul MS, et al. Weekly running volume and risk of running-related injuries among marathon runners. *Int J Sports Phys Ther* 2013;8:111-20.
- 156 Clausen MB, Zebis MK, Moller M, et al. High injury incidence in adolescent female soccer. *Am J Sports Med* 2014;42:2487-94.
- 157 Dye SF. The pathophysiology of patellofemoral pain: a tissue homeostasis perspective. *Clin Orthop Relat Res* 2005;100-10.
- 158 Magnusson SP, Langberg H, Kjaer M. The pathogenesis of tendinopathy: balancing the response to loading. *Nat Rev Rheumatol* 2010;6:262-68.
- 159 Bennell KL, Malcolm SA, Wark JD, et al. Models for the pathogenesis of stress fractures in athletes. *Br J Sports Med* 1996;30:200-04.
- 160 Warden SJ, Davis IS, Fredericson M. Management and prevention of bone stress injuries in long-distance runners. *J Orthop Sports Phys Ther* 2014;44:749-65.

- 161 Lipps DB, Wojtys EM, Ashton-Miller JA. Anterior cruciate ligament fatigue failures in knees subjected to repeated simulated pivot landings. *Am J Sports Med* 2013;41:1058-66.
- 162 Asmussen E. Muscle fatigue. *Med Sci Sports* 1979;11:313-21.
- 163 Fitts RH. Muscle fatigue: the cellular aspects. *Am J Sports Med* 1996;24:S9-13.
- 164 Gandevia SC. Spinal and supraspinal factors in human muscle fatigue. *Physiol Rev* 2001;81:1725-89.
- 165 Skinner HB, Wyatt MP, Hodgdon JA, et al. Effect of fatigue on joint position sense of the knee. *J Orthop Res* 1986;4:112-18.
- 166 Thomas AC, McLean SG, Palmieri-Smith RM. Quadriceps and hamstrings fatigue alters hip and knee mechanics. *J Appl Biomech* 2010;26:159-70.
- 167 Cortes N, Greska E, Kollock R, et al. Changes in lower extremity biomechanics due to a short-term fatigue protocol. *J Athl Train* 2013;48:306-13.
- 168 Cortes N, Greska E, Ambegaonkar JP, et al. Knee kinematics is altered post-fatigue while performing a crossover task. *Knee Surg Sports Traumatol Arthrosc* 2014;22:2202-08.
- 169 Hooper DR, Szivak TK, Comstock BA, et al. Effects of fatigue from resistance training on barbell back squat biomechanics. *J Strength Cond Res* 2014;28:1127-34.
- 170 Liederbach M, Kremenic IJ, Orishimo KF, et al. Comparison of landing biomechanics between male and female dancers and athletes, part 2: Influence of fatigue and implications for anterior cruciate ligament injury. *Am J Sports Med* 2014;42:1089-95.
- 171 Baratta R, Solomonow M, Zhou BH, et al. Muscular coactivation. The role of the antagonist musculature in maintaining knee stability. *Am J Sports Med* 1988;16:113-22.
- 172 Wojtys EM, Wylie BB, Huston LJ. The effects of muscle fatigue on neuromuscular function and anterior tibial translation in healthy knees. *Am J Sports Med* 1996;24:615-21.
- 173 Nyland JA, Shapiro R, Caborn DN, et al. The effect of quadriceps femoris, hamstring, and placebo eccentric fatigue on knee and ankle dynamics during crossover cutting. *J Orthop Sports Phys Ther* 1997;25:171-84.
- 174 Rozzi SL, Lephart SM, Fu FH. Effects of muscular fatigue on knee joint laxity and neuromuscular characteristics of male and female athletes. *J Athl Train* 1999;34:106-14.
- 175 Rogalski B, Dawson B, Heasman J, et al. Training and game loads and injury risk in elite Australian footballers. *J Sci Med Sport* 2013;16:499-503.

- 176 Colby MJ, Dawson B, Heasman J, et al. Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *J Strength Cond Res* 2014;28:2244-52.
- 177 Murray NB, Gabbett TJ, Townsend NE, et al. Individual and combined effects of acute and chronic running loads on injury risk in elite Australian footballers. *Scand J Med Sci Sports* 2016. In press. doi: n/a
- 178 Anderson L, Triplett-McBride T, Foster C, et al. Impact of training patterns on incidence of illness and injury during a women's collegiate basketball season. *J Strength Cond Res* 2003;17:734-38.
- 179 Hulin BT, Gabbett TJ, Blanch P, et al. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med* 2014;48:708-12.
- 180 Lovell G, Galloway H, Hopkins W, et al. Osteitis pubis and assessment of bone marrow edema at the pubic symphysis with MRI in an elite junior male soccer squad. *Clin J Sport Med* 2006;16:117-22.
- 181 Bowen L, Gross AS, Gimpel M, et al. Accumulated workloads and the acute:chronic workload ratio relate to injury risk in elite youth football players. *Br J Sports Med* 2016. In press. doi: bjsports-2015-095820
- 182 Ehrmann FE, Duncan CS, Sindhusake D, et al. GPS and injury prevention in professional soccer. *J Strength Cond Res* 2016;30:360-67.
- 183 Hulin BT, Gabbett TJ, Lawson DW, et al. The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. *Br J Sports Med* 2016;50:231-36.
- 184 Hulin BT, Gabbett TJ, Caputi P, et al. Low chronic workload and the acute:chronic workload ratio are more predictive of injury than between-match recovery time: a two-season prospective cohort study in elite rugby league players. *Br J Sports Med* 2016; Published Online First: 5 February 2016. doi:10.1136/bjsports-2015-095364.
- 185 Windt J, Gabbett TJ, Ferris D, et al. A training load—injury paradox: Is greater pre-season participation associated with lower in-season injury risk in elite rugby league players? *Br J Sports Med* 2016; Published Online First: 13 April 2016. doi:10.1136/bjsports-2016-095973.
- 186 Gabbett TJ, Hulin BT, Blanch P, et al. High training workloads alone do not cause sports injuries: how you get there is the real issue. *Br J Sports Med* 2016;50:444-45.
- 187 Blanch P, Gabbett TJ. Has the athlete trained enough to return to play safely? The acute:chronic workload ratio permits clinicians to quantify a player's risk of subsequent injury. *Br J Sports Med* 2016;50:471-75.
- 188 Nielsen RO, Parner ET, Nohr EA, et al. Excessive progression in weekly running distance and risk of running-related injuries: an association which varies according to type of injury. *J Orthop Sports Phys Ther* 2014;44:739-47.

- 189 Murphy DF, Connolly DA, Beynon BD. Risk factors for lower extremity injury: a review of the literature. *Br J Sports Med* 2003;37:13-29.
- 190 Jayanthi NA, O'Boyle J, Durazo-Arvizu RA. Risk factors for medical withdrawals in United States tennis association junior national tennis tournaments: a descriptive epidemiologic study. *Sports Health* 2009;1:231-35.
- 191 Bengtsson H, Ekstrand J, Hagglund M. Muscle injury rates in professional football increase with fixture congestion: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med* 2013;47:743-47.
- 192 Murray NB, Gabbett TJ, Chamari K. Effect of different between-match recovery times on the activity profiles and injury rates of national rugby league players. *J Strength Cond Res* 2014;28:3476-83.
- 193 Carling C, McCall A, Le GF, et al. The impact of short periods of match congestion on injury risk and patterns in an elite football club. *Br J Sports Med* 2016;50:764-68.
- 194 Dellal A, Lago-Penas C, Rey E, et al. The effects of a congested fixture period on physical performance, technical activity and injury rate during matches in a professional soccer team. *Br J Sports Med* 2015;49:390-94.
- 195 Carling C, Orhant E, Legall F. Match injuries in professional soccer: inter-seasonal variation and effects of competition type, match congestion and positional role. *Int J Sports Med* 2010;31:271-76.
- 196 Carling C, Le GF, Dupont G. Are physical performance and injury risk in a professional soccer team in match-play affected over a prolonged period of fixture congestion? *Int J Sports Med* 2012;33:36-42.
- 197 Williams JM, Tonymon P, Andersen MB. Effects of life-event stress on anxiety and peripheral narrowing. *Behav Med* 1990;16:174-81.
- 198 Williams JM, Tonymon P, Andersen MB. The effects of stressors and coping resources on anxiety and peripheral narrowing. *J Appl Sport Psych* 1991;3:126-41.
- 199 Williams JM, Andersen MB. Psychosocial antecedents of sport injury: Review and critique of the stress and injury model. *J Appl Sport Psych* 1998;10:5-25.
- 200 Rogers TJ, Landers DM. Mediating effects of peripheral vision in the life event stress/athletic injury relationship. *J Sport Exerc Psychol* 2005;27:271-88.
- 201 Williams JM, Andersen MB. Psychosocial antecedents of sport injury and interventions for risk reduction. In: Tenenbaum G, Eklund RC, eds. Handbook of sport psychology. 3rd edition ed. New York: John Wiley & Sons 2007:379-403.
- 202 Steffen K, Pensgaard AM, Bahr R. Self-reported psychological characteristics as risk factors for injuries in female youth football. *Scand J Med Sci Sports* 2009;19:442-51.
- 203 Sibold J, Zizzi S. Psychosocial variables and time to injury onset: a hurdle regression analysis model. *J Athl Train* 2012;47:537-40.

- 204 Fawcner HJ, McMurray NE, Summers JJ. Athletic injury and minor life events: a prospective study. *J Sci Med Sport* 1999;2:117-24.
- 205 Ivarsson A, Johnson U. Psychological factors as predictors of injuries among senior soccer players. A prospective study. *J Sports Sci Med* 2010;9:347-52.
- 206 Ivarsson A, Johnson U, Lindwall M, et al. Psychosocial stress as a predictor of injury in elite junior soccer: a latent growth curve analysis. *J Sci Med Sport* 2014;17:366-70.
- 207 Laux P, Krumm B, Diers M, et al. Recovery-stress balance and injury risk in professional football players: a prospective study. *J Sports Sci* 2015;33:2140-48.
- 208 Petrie TA. Coping skills, competitive trait anxiety and playing status: moderation effects on the life stress–injury relationship. *J Sport Exerc Psychol* 1993;15:261-74.
- 209 Lavalley L, Flint F. The relationship of stress, competitive anxiety, mood state, and social support to athletic injury. *J Athl Train* 1996;31:296-99.
- 210 Nigorikawa T, Oishi K, Yasukawa M, et al. Type a behavior pattern and sports injuries. *Jap J Phys Fit Sports Med* 2003;52:359-67.
- 211 Hanson SJ, McCullagh P, Tonymon P. The relationship of personality characteristics, life stress and coping resources to athletic injury. *J Sport Exerc Psychol* 1992;14:262-72.
- 212 Leatherwood WE, Dragoo JL. Effect of airline travel on performance: a review of the literature. *Br J Sports Med* 2013;47:561-67.
- 213 Reilly T, Waterhouse J, Edwards B. Jet lag and air travel: implications for performance. *Clin Sports Med* 2005;24:367-80, xii.
- 214 Reilly T, Atkinson G, Edwards B, et al. Coping with jet-lag: a position statement for the european college of sport science. *European Journal of Sport Science* 2007;7:1-7.
- 215 Schwellnus MP, Derman WE, Jordaan E, et al. Elite athletes travelling to international destinations >5 time zone differences from their home country have a 2-3-fold increased risk of illness. *Br J Sports Med* 2012;46:816-21.
- 216 Fowler PM, Duffield R, Lu D, et al. Effects of long-haul transmeridian travel on subjective jet-lag and self-reported sleep and upper respiratory symptoms in professional rugby league players. *Int J Sports Physiol Perform* 2016; Published Online First: 18 January 2016. doi:10.1123/ijsp.2015-0542.
- 217 Fuller CW, Taylor AE, Raftery M. Does long-distance air travel associated with the Sevens World Series increase players' risk of injury? *Br J Sports Med* 2015;49:458-64.
- 218 Schwellnus MP, Thomson A, Derman W, et al. More than 50% of players sustained a time-loss injury (>1 day of lost training or playing time) during the 2012 Super

- Rugby Union Tournament: a prospective cohort study of 17,340 player-hours. *Br J Sports Med* 2014;48:1306-15.
- 219 Fowler P, Duffield R, Waterson A, et al. Effects of regular away travel on training loads, recovery, and injury rates in professional Australian soccer players. *Int J Sports Physiol Perform* 2015;10:546-52.
- 220 DiFiori JP, Benjamin HJ, Brenner JS, et al. Overuse injuries and burnout in youth sports: a position statement from the American Medical Society for Sports Medicine. *Br J Sports Med* 2014;48:287-88.
- 221 Bergeron MF, Mountjoy M, Armstrong N, et al. International Olympic Committee consensus statement on youth athletic development. *Br J Sports Med* 2015;49:843-51.
- 222 Fortington LV, Berry J, Buttifant D, et al. Shorter time to first injury in first year professional football players: A cross-club comparison in the Australian Football League. *J Sci Med Sport* 2016;19:18-23.

Appendix A: Terminology and definitions

Term	Definition
Injury	Any physical complaint that results from competition or training, regardless of its consequence on sports participation or performance (adapted from Fuller et al., 2006[1]).
Illness	A new or recurring symptomatic sickness or disease, or the presence of sub-clinical immunological precursors of symptomatic illness, that was incurred during competition or training, and either receiving medical attention or was self-reported by athletes, regardless of the consequences with respect to absence from competition or training (adapted from Engebretsen et al., 2013[2]).
Load	The sport and non-sport burden (single or multiple physiological, psychological or mechanical stressors) as a stimulus that is applied to a human biological system (including subcellular elements, a single cell, tissues, one or multiple organ systems, or the individual).
External load	Any external stimulus applied to the athlete that is measured independently of their internal characteristics.[3]
Internal load	Load measurable by assessing internal response factors within the biological system, which may be physiological, psychological, or other.[3]
Competition load	The cumulative amount of stress placed on an individual from a single or multiple competitions over a period of time, including stress imposed directly by exertion in a single sport or competition and indirectly by factors such as the frequency or saturation of events, the duration of the season or the number of days of the competition, and travel associated with competition.
Training load	The cumulative amount of stress placed on an individual from a single or multiple training sessions (structured or unstructured) over a period of time.
Non-sports load	The cumulative amount of stress placed on an individual from non-sport activities, including any physiological and psychological stimuli / stressors outside of sport.
Absolute load	Load applied to the biological system from training, competition and non-sport activities, irrespective of rate of load application, history of loading or fitness level.
Relative load	Load applied to the biological system from training, competition and non-sport

activities, taking into account the rate of load application, history of loading or fitness level.

Acute load	Absolute load that is applied over a shorter period of time (e.g. days). It is recognised that this period may vary, but for the purposes of this consensus a standard of 1 week or less to define acute load has been adopted, as this is the most commonly used practical measure of acute load as defined in the literature.[4]
Chronic load	Absolute load that is applied over a longer period of time (e.g. weeks or months). It is recognised that this period may vary, but for the purposes of this consensus a standard of 4 weeks or longer to define chronic load has been adopted, as this is the most commonly used practical measure of chronic load as defined in the literature.[4]
Acute:chronic load ratio	A ratio comparing the load that the athlete has performed at, or been exposed to, relative to the load that he or she has been prepared for (reflecting “athlete readiness”).[5] This parameter may be used to assess relative risk of injury; i.e., if an athlete is at a relatively fit (low-risk) or fatigued (high-risk) state. For example, if the acute (e.g., weekly) training load is low (i.e., the athlete is experiencing minimal ‘fatigue’) and the rolling average chronic training load (e.g., over 4 weeks) is high (i.e., the athlete has developed ‘fitness’), then the acute:chronic load ratio will be around 1 or less, indicating that the athlete is in a well-prepared state. If the acute load is high (i.e., training loads have been rapidly increased from one week to another) and the rolling average chronic training load (e.g., over 4 weeks) is low, then the ratio of the acute:chronic load will exceed 1 and the athlete is likely to experience increased fatigue.[5]
Load management	The appropriate prescription, monitoring, and adjustment of external and internal loads.
Load mismanagement	Inappropriate prescription, monitoring, or adjustment of external and internal loads, leading to maladaptation in the athlete.
Excessive loading	Single or repeated load cycles (incl. physiological, psychological, travel load and other) with inadequate recovery or rest that manifests as maladaptation, injury, or illness.
Repetitive load	Repeated, sequential application of a load to a biological system, characterised by a lack of variation in type, intensity, duration, or frequency. The load may or may not allow for adequate recovery between single load applications.

Adaptation	A positive change in the biological system in response to external loading and adequate subsequent recovery.
Maladaptation	A negative change in the biological system in response to external loading and/or inadequate recovery.
Recovery	The full return of the biological system to homeostasis without maladaptation.
Fatigue	Tiredness resulting from mental or physical exertion or illness, in sport often manifested as failure to maintain the required or expected force (or power output) (adapted from the Oxford Dictionary[6] and Edwards, 1983[7]).
Functional overreaching (overreaching)	A deliberate accumulation of load during a training cycle aimed at enhancing performance. The accumulated training load can result in a short-term decrement in performance capacity; however, when appropriate periods of recovery are provided, physiological responses will compensate the training-related stress and lead to enhanced performance compared to baseline levels, often labelled ‘super-compensation’ (adapted from Meeusen et al., 2013[8]).
Non-functional overreaching	Intentional increased loading or training that results in physiological or physical maladaptation. It is a state of extreme overreaching, which will lead to a stagnation or decrease in performance that will not resume for several weeks or months. Eventually, after sufficient rest, the athlete will be able to fully recover.[8]
Overtraining syndrome	Prolonged maladaptation of the athlete, with negative changes in markers of performance and several biological, neurochemical and hormonal regulation mechanisms, occurring in some athlete after periods of excessive loading and non-functional overreaching; however, with a multifactorial aetiology (adapted from Meeusen et al., 2013[8]).
Load monotony	The repetition of the same load over an extended time period (usually days to weeks), measurable as <i>the mean acute load / standard deviation of the acute load</i> . [9]
Load strain	A measure of the intensity of load monotony and is defined as <i>the weekly load multiplied by load monotony</i> . [9]
Capacity	The actual or potential ability of an athlete to accept load. This is affected by various factors including fitness status before load, loading rate, psychological factors and various other internal and external factors. [10]
Reserve capacity	The measure of available capacity over and above the capacity needed to meet routine or current load demands. [11]

Readiness	The relative preparedness of an athlete to accept a load.
Training	The physical and mental preparation athletes undergo in an effort to optimise performance.
Training volume	The product of duration and frequency of training.
Training intensity	The level of effort an individual exerts during exercise relative to his or her maximum effort, measurable using objective (e.g., heart rate/oxygen consumption) or subjective tools (e.g., rating of perceived exertion).
Periodisation	A framework for planned and systematic variation of training parameters with the goal of optimising training adaptations specific to a particular sport, often targeting a specific timeframe or date.[12]
Calendar saturation	A measure of the concentration of competitive events (individual or team) over a defined period of time (usually week or months).
Calendar congestion	An overly saturated calendar schedule with reduced time periods between events allowing less time for recovery.
Psychological load	The cumulative amount of stress placed on an individual from psychological stimuli / stressors.
Travel load	The cumulative amount of stress placed on an individual related to total travel time, distance, frequency, and across time zones.

Unreferenced definitions were developed by the consensus group

Reference List

- 1 Fuller CW, Ekstrand J, Junge A, et al. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Br J Sports Med* 2006;40:193-201.
- 2 Engebretsen L, Soligard T, Steffen K, et al. Sports injuries and illnesses during the London Summer Olympic Games 2012. *Br J Sports Med* 2013;47:407-14.
- 3 Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med* 2014;44 Suppl 2:S139-S147.

- 4 Hulin BT, Gabbett TJ, Blanch P, et al. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med* 2014;48:708-12.
- 5 Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? *Br J Sports Med* 2016;50:273-80.
- 6 Oxford Dictionaries. "Fatigue". Oxford University Press. Date accessed: 9.6.2016. Available from: <http://www.oxforddictionaries.com/definition/english/fatigue>.
- 7 Edwards RHT. Biochemical basis of fatigue in exercise performance: catastrophe theory in muscular fatigue. In: Knuttgen HG, Vogel JA, Poortmans JR, eds. *Biochemistry of exercise*. Champaign, IL: Human Kinetics 1983.
- 8 Meeusen R, Duclos M, Foster C, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc* 2013;45:186-205.
- 9 Foster C. Monitoring training in athletes with reference to overtraining syndrome. *Med Sci Sports Exerc* 1998;30:1164-68.
- 10 Goldstein RE. Exercise capacity. In: Walker HK, Hall WD, Hurst JW, eds. *Clinical methods: the history, physical, and laboratory examinations*. 3rd edition ed. Boston: Butterworths 1990.
- 11 Tate C, Franklin N. Reserve capacity. In: Rippe JM, editor. *Encyclopedia of lifestyle medicine & health*. Thousand Oaks, CA: Sage Publications 2012.
- 12 Gamble P. Periodization of training for team sports athletes. *Strength & Conditioning Journal* 2006;28:56-66.

Appendix B: Studies examining the relationship between load in sport and risk of injury

Reference	Study design	Sport	Population (n, level, sex, age)	Injury definition	Study duration	Measurements / monitoring	Load monitoring		Load studied					Multiple injury risk factors included	Analysis		Main findings
							External	Internal	Absolute load	Relative load	Competition calendar congestion	Psychological load	Travel load		Univariate	Multivariate	
Bowen et al., 2016[1]	Prospective cohort	Football	32, elite, male, 17.3 ± 0.9 years (mean ± SD)	Time-loss	2 seasons	Injuries recorded by medical team, load (total distance, high-speed distance, accelerations and total load) captured through GPS/accelerometer	Y			Y				Y	Y		<ul style="list-style-type: none"> Non-contact injury risk was significantly increased when a high acute high-speed distance was combined with low chronic high-speed distance (RR= 2.55), but not high chronic high-speed distance (RR=0.47) Contact injury risk was greatest when acute:chronic total distance and accelerations ratios were very high (1.76 and 1.77, respectively)(RR=4.98)
Carling et al., 2016[2]	Prospective cohort	Football	1 team, elite, male, n/a	Time-loss	6 seasons	Injuries recorded by medical team, exposure hours, competition congestion (days of recovery between matches), player positional role	Y				Y			Y	Y		<ul style="list-style-type: none"> The risk of injury was higher in the final 15 min of the final matches in a two-match congestion cycle (RR: 3.1) and overall (RR: 2.0) and in the first-half (RR: 2.6) of the final game in a three-match congestion cycle Rates of non-contact injury due to a 'change in direction' (RR: 7.8) and ankle sprains (RR: 10.4) were higher in the third match of a congested cycle
Cross et al., 2016[3]	Prospective cohort	Rugby union	173, elite, male, n/a	Time-loss	1 season	Injuries recorded by medical team, training load (session-RPE; weekly, week-to-week, cumulative 1-4 weeks, training monotony & strain, and acute:chronic load ratio)	Y	Y	Y	Y				Y		Y	<ul style="list-style-type: none"> Players had an increased risk of injury if they had high one-week cumulative loads (1245 AU, OR: 1.68), or large week-to-week changes in load (1069 AU, OR: 1.58) In addition, a 'U-shaped' relationship was observed for four-week cumulative loads, with an apparent increase in risk associated with higher loads (>8651 AU, OR: 1.39)
Duhig et al., 2016[4]	Prospective cohort	Australian football	51, elite, male, 22.2 ± 3.4 years (mean ± SD)	Hamstring strain injury (acute pain in the posterior thigh that caused immediate cessation of exercise)	2 seasons	Injuries recorded by medical team, load (running distances (captured through GPS) and session-RPE)	Y	Y	Y	Y				Y	Y		<ul style="list-style-type: none"> Trivial differences were observed between injured and uninjured groups for standardized session-RPE, total distance travelled and distances covered whilst accelerating and decelerating However, higher than 'typical' (i.e., Z = 0) summed four weekly high-speed running session means were associated with a greater likelihood of hamstring strain injury (OR = 1.96, 95% CI = 1.54 - 2.51, p<0.001) Furthermore, modelling of high speed running data indicated that reducing mean distances in the week prior to injury may decrease the probability of hamstring strain injury
Ehrmann et al., 2016[5]	Prospective cohort	Football	19, elite, male, 25.7 ± 5.1 years (mean ± SD)	Time-loss (non-contact soft tissue injuries)	1 season	Injuries recorded by medical team, load (total distance, high-intensity running distance, very-high intensity running distance, new body load, and meters per minute) captured through GPS-units	Y			Y				Y	Y		<ul style="list-style-type: none"> Players performed significantly higher meters per minute in the weeks preceding an injury compared with their seasonal averages (+9.6 and +7.4% for 1- and 4-week blocks, respectively) (p , 0.01), indicating an increase in training and gameplay intensity leading up to injuries
Hulin et al., 2016[6]	Prospective cohort	Rugby League	28, elite, male, 24.8 ± 3.4 years (mean ± SD)	Time-loss	2 seasons	Injuries recorded by medical team, match and training load (absolute total distance run captured by GPS/micro-technology-units, between-match recovery days)	Y			Y	Y			Y		Y	<ul style="list-style-type: none"> No difference was found between the match-injury risk of short and long between-match recovery periods (7.5±2.5% vs 6.8±2.5%) Players who had shorter recovery and acute:chronic workload ratios ≥1.6, were 3.4–5.8 times likely to sustain a match injury than players with lower acute:chronic workload ratios (RR range 3.41–5.80; CI 1.17 to 19.2) Acute:chronic workload ratios between 1.2 and 1.6 during short between-match recovery times demonstrated a greater risk of match injury than ratios between 1.0 and 1.2 (RR=2.88; CI 0.97 to 8.55).

Hulin et al., 2016[7]	Prospective cohort	Rugby league	53, elite, male, 23.4 ± 3.5 years (mean ± SD)	Time-loss	2 seasons	Injuries recorded by medical team, load (distance (m) covered in field training and matches captured by GPS/micro-technology-units)	Y			Y				Y	Y		<ul style="list-style-type: none"> Compared with all other ratios, a very-high acute:chronic workload ratio (≥ 2.11) demonstrated the greatest risk of injury in the current week (16.7% injury risk) and subsequent week (11.8% injury risk)
Murray et al., 2016[8]	Prospective cohort	Australian football	46, elite, male, 23.1 ± 3.7 years (mean ± SD)	Time-loss	1 season	Injuries recorded by medical team, load (completed sessions, exposure hours, running loads captured by GPS/micro-technology units)	Y		Y					Y		Y	<ul style="list-style-type: none"> No significant difference in injury risk was found between the low training load group (26.8/1,000 hours) and the high training load group (14.2/1,000 hours) ($\chi^2=3.48$, $df=2$, $RR=1.9$, $p=0.17$)
Murray et al., 2016[9]	Prospective cohort	Australian football	59, elite, male, 23 ± 4 years (mean ± SD)	Non-contact time-loss	2 seasons	Injuries recorded by medical team, running load captured by GPS/micro-technology units	Y		Y					Y	Y		<ul style="list-style-type: none"> An acute:chronic workload ratio of >2.0 for total distance during the in-season was associated with a 5 to 8-fold greater injury risk in the current (relative risk (RR)=8.65, $p=0.001$) and subsequent week (RR=5.49, $p=0.016$) Players with a high-speed distance acute:chronic workload ratio of >2.0 were 5 to 11 times more likely to sustain an injury in the current (RR=11.62, $p=0.006$) and subsequent week (RR=5.10, $p=0.014$)
van der Worp et al., 2016[10]	Prospective cohort	Running	417, female, recreational, 38.6 ± 11.5 (mean ± SD)	Time-loss (running-related pain of the lower back and/or the lower extremity)	12 weeks	Self-reported injuries, questionnaires sent every 4 weeks (from 8 weeks before to 4 weeks after the event), recording personal and anthropometric information, past musculoskeletal injuries, past/current running routines, running-shoe characteristics, and participation in other sports. Two orthopaedic tests (navicular drop test and extension of the first metatarsophalangeal joint) were performed in the 8 weeks period before the event	Y		Y					Y		Y	<ul style="list-style-type: none"> A weekly training distance of more than 30 km (HR: 3.28; 95% CI: 1.23- 8.75) and a previous running injury longer than 12 months ago (HR: 1.88; 95% CI: 1.03- 3.45) were associated with the occurrence of running-related injuries
Veugelers et al., 2016[11]	Prospective cohort	Australian football	45, male, elite, 23.4 ± 3.8 years (mean ± SD)	Non-contact time-loss/modified training	15 weeks	Injuries recorded by medical team/fitness staff, training load (session-RPE; one- and two-weekly cumulative; low and high training load groups)	Y	Y	Y					y		Y	<ul style="list-style-type: none"> A significant pattern existed across all training load measures which suggested lower odds of injury and illness in high training load groups ($p < 0.05$, $OR = 0.199-0.202$)
von Rosen et al., 2016[12]	Prospective cohort	Orienteering	64 (♂: 31, ♀:33), elite, 17 ± 1 years (mean ± SD)	Physical complaint	26 weeks	Weekly web-based questionnaire capturing self-reported data on injuries, training volume, running volume, and running intensity. Injuries diagnosed during telephone interviews.	Y	Y	Y					Y		Y	<ul style="list-style-type: none"> Time to the first reported injury was associated with training volume ($\beta = 0.184$, $p=0.001$), competition time ($\beta = -0.701$, $p=0.009$), running on asphalt roads ($\beta = -0.348$, $p=0.008$), and running on forest surfaces and trails ($\beta = -0.331$, $P=0.007$)
Windt et al., 2016[13]	Prospective cohort	Rugby league	30, elite, male, 25 ± 3 years (mean ± SD)	Match time-loss	1 season	Injuries recorded by medical team, load (completed sessions, exposure hours, running loads captured by GPS-units)	Y		Y					Y		Y	<ul style="list-style-type: none"> Controlling for training load in a given week, completing 10 additional preseason sessions was associated with a 17% reduction in the odds of injury in the subsequent week ($OR=0.83$, 95% $CI=0.70$ to 0.99) Increased preseason participation was associated with a lower percentage of games missed due to injury ($r=-0.40$, $p<0.05$), with 10 preseason sessions predicting a 5% reduction in the percentage of games missed Neither acute:chronic workload ratios nor chronic workloads in isolation were significantly associated with injury

Dellal et al., 2015[14]	Prospective cohort	Football	16, elite, male, 24.3 ± 3.2 years (mean ± SD)	Time-loss	3 x 18 days of 6 matches	Injuries recorded by medical team, competition congestion (days of recovery between matches), exposure hours, computerised motion-analysis of running distance and intensity, ball passes and control	Y				Y			Y	Y		<ul style="list-style-type: none"> No difference in overall incidence of injury between congested periods and non-congested periods However, during congested periods, the match injury rate was higher, the training injury rate lower and the mean lay-off duration for injuries was shorter
Fowler et al., 2015[15]	Prospective cohort	Football	18, male, elite, 26.4 (24.7–28.1) years	Time-loss	1 season	Injuries recorded by medical team, exposure hours, travel time and kilometres, training load (session-RPE), wellness questionnaire	Y	Y				Y	Y		Y		<ul style="list-style-type: none"> No significant differences existed between match location or competition phase for injury incidence, rate, severity, type, or the activity at the time of injury
Fuller et al., 2015[16]	Prospective cohort	Rugby union	563, male, elite, 22.7/24.0 ± 3.0 years (mean ± SD)	Time-loss	5 years	Injuries recorded by medical team, travel time and time zones, match exposure hours, anthropometry	Y					Y	Y	Y			<ul style="list-style-type: none"> There was no evidence to suggest that players were exposed to a greater risk of injury following extensive air travel and crossing multiple time zones
Laux et al., 2015[17]	Prospective cohort	Football	22, elite, male, 25.8 ± 5 years (mean ± SD)	Time-loss	16 months	Injuries recorded by medical team, subjective stress and recovery variables (REST-Q-Sport)		Y			Y		Y		Y		<ul style="list-style-type: none"> The stress-related scales “fatigue” (OR 1.70), “disturbed breaks” (OR 1.84) and “injury” (OR 1.77) and the recovery-related scale “sleep quality” (OR 0.53) significantly predicted subsequent injuries
Orchard et al., 2015[18]	Prospective cohort	Cricket	235, elite, male, n/a	Time-loss	15 seasons	Injuries recorded by medical team, match load (number of balls bowled by fast bowlers)	Y		Y	Y			Y		Y		<ul style="list-style-type: none"> High acute workload, low recent workload, high previous season workload and moderate career workload are risk factors for tendon injuries in cricket fast bowlers Low career workload and high recent workload are risk factors for stress fractures in cricket fast bowlers
Orchard et al., 2015[19]	Prospective cohort	Cricket	235, elite, male, n/a	Time-loss	15 seasons	Injuries recorded by medical team, load (fixture congestion)	Y		Y		Y		Y		Y		<ul style="list-style-type: none"> Fast bowlers who bowled more than 50 match overs in a 5 day period had a significant increase in injury over the next month compared to bowlers who bowled 50 overs or less (RR 1.54; 95% CI 1.04–2.29) For periods ranging from 12 to 26 days, there was no statistically-significant increase in injury over the next month from exceeding thresholds of certain amounts of overs, although bowlers who bowled more than 100 overs in 17 days had a non-significant increase in injury over the next month (RR 1.78; 95% CI 0.90–3.50)
Owen et al., 2015[20]	Prospective cohort	Football	23, male, elite, 25.6 ± 4.6 years (mean ± SD)	Time-loss	2 seasons	Injuries recorded by medical team, training load (time spent in high and very high intensity zones of 85-90% and ≥90% of maximal heart rate, exposure hours)	Y		Y				Y		Y		<ul style="list-style-type: none"> Players achieving more time in the very high intensity zone during training increased the odds of sustaining a match injury (OR=1.87, 95% CI 1.12-3.12, p=0.02), but not training injury
Timpka et al., 2015[21]	Prospective cohort	Athletics	266 (♂: 118, ♀:148), elite, youth and adult athletes	Modified training	12 months	Injuries were self-reported, training load (number of training hours per week, weekly training intensity, training load rank index (the reported training intensity multiplied with minutes of training performed during the week), psychological variables (Body Consciousness Scale, Brief COPE, Perceived Motivational Climate in Sport Questionnaire, Commitment to Exercise Scale)	Y	Y	Y					Y		Y	<ul style="list-style-type: none"> The coping behaviour self-blame replaced training load in an integrated explanatory model of overuse injury risk in athletes What seemed to be more strongly related to the likelihood of overuse injury was not the athletics load per se, but, rather, the load applied in situations when the athlete’s body was in need of rest

Clausen et al., 2014[22]	Prospective cohort	Football	498, female, amateur to elite, 15-18 years of age	Physical complaint	5 months	Self-reported injuries and exposure hours, playing level	Y		Y					Y	Y	<ul style="list-style-type: none"> Higher average exposure in injury-free weeks was associated with a lower injury risk (p<0.001) Players with low exposure (≤1 hour per week) were 3 to 10 times more likely to sustain a time-loss injury compared with other players (p<0.01)
Colby et al., 2014[23]	Prospective cohort	Australian football	46, male, elite, 25.1 ± 3.4 years (mean ± SD)	Medical attention	1 season	Injuries recorded by medical team, game and training load (various measures of running load captured by GPS/accelerometer units)	Y			Y				Y	Y	<ul style="list-style-type: none"> Higher cumulative loads predicted increases in injury risk
Hulin et al., 2014[24]	Prospective cohort	Cricket	28, elite, male, 26 ± 5 years (mean ± SD)	Time-loss	5 seasons	Injuries recorded by medical team, training load (balls bowled per week and session-RPE; one-week data (acute load) compared with 4-week rolling average data (chronic load))	Y	Y		Y				Y	Y	<ul style="list-style-type: none"> An acute:chronic load ratio >1.5 was associated with an increased risk of injury in the week after exposure, for internal (RR =2.2) and external load (RR=2.1) Fast bowlers with internal and external acute:chronic load ratios greater than 2 had a relative risk of injury of 4.5 and 3.3, respectively
Huxley et al., 2014[25]	Retrospective cohort	Athletics	103 (♂: 34, ♀: 66, 3 unidentified), 17.7 ± 2.4 years (mean ± SD)	Time-loss (>3 weeks out)	5 years	Self-reported injuries and training load (frequency, intensity, hours and modality)	Y	Y	Y					Y	Y	<ul style="list-style-type: none"> Injured athletes trained at a higher intensity at 13-14 years (p<0.01), completed more high-intensity training sessions at 13-14 years (p<0.01) and 15-16 years (p<0.05) and had a higher yearly training load at 13-14 years (p<0.01)
Ivarsson et al., 2014[26]	Prospective cohort	Football	101 (♂: 67, ♀: 34), elite, 16.7 ± 0.9 years (mean ± SD)	Time-loss (>3 days)	10 weeks	Injuries recorded by athletic trainer, psychological load (weekly measurement of levels of daily hassles and daily uplifts) captured through The Hassles and Uplifts Scale			Y			Y		Y	Y	<ul style="list-style-type: none"> The results show that injury occurrence was significantly associated with both the initial level of daily hassle and the change in daily hassle High initial daily hassle levels and a smaller decrease in daily hassles were associated with injury occurrence Moreover, injury occurrence was significantly associated with a greater decrease in daily uplift
Murray et al., 2014[27]	Prospective cohort	Rugby league	43, elite, male, 24 ± 1 years (mean ± SD)	Time-loss (match)	1 season	Injuries recorded by medical team, competition congestion (days of recovery between matches), match load (activity profiles captured by GPS/micro-technology-units)	Y				Y			Y	Y	<ul style="list-style-type: none"> Injury rates for the “adjustables” positional group were the highest after short between-match recovery cycles, whereas the injury rates of hit-up forwards and outside backs positional groups were the highest after long between-match recovery cycles
Nielsen et al., 2014[28]	Prospective cohort	Running	874 (♂: 469, ♀: 464), recreational, 37.2 ± 10.3 years (mean ± SD)	Time-loss (>1 week)	1 year	Self-reported injuries with following clinical examination, running loads captured through GPS-units	Y			Y				Y	Y	<ul style="list-style-type: none"> No statistically significant differences in injury rates were found There was a trend of an increased rate of distance-related injuries (patellofemoral pain, iliotibial band syndrome, medial tibial stress syndrome, gluteus medius injury, greater trochanteric bursitis, injury to the tensor fascia latae, and patellar tendinopathy) in runners who progressed their weekly running distance by more than 30% compared with those progressing less than 10% (hazard ratio = 1.59 [95% CI: 0.96 to 2.66], p = 0.07)
Ristolainen et al., 2014[29]	Retrospective cohort	Cross-country skiing, swimming, long-distance running	446 (♂: 200, ♀: 246), elite, 21.8 ± 4.9 (mean ± SD)	Physical complaint (non-acute causation)	1 year	Self-reported overuse injuries, training load/variables (such as starting age of training, years of active training, hours trained yearly, competition hours and weekly resting days) and anthropometric variables	Y		Y					Y	Y	<ul style="list-style-type: none"> Athletes with less than 2 rest days per week during the training season had 5.2-fold risk (95% CI: 1.89-14.06, p=0.001) for an overuse injury Athletes who trained more than 700 hours during a year had 2.1-fold risk (95% CI: 1.21-3.61, p=0.008) for an overuse injury compared to the others
Schwellnus et al., 2014[30]	Prospective cohort	Rugby union	152, male, elite, 25.0 ± 3.4 years (mean ± SD)	Time-loss	16 weeks	Injuries and related data (on risk factors and mechanisms) recorded by medical team, exposure hours	Y						Y	Y	Y	<ul style="list-style-type: none"> There was no difference in the incidence rate of injuries between playing at home compared with away (locations ≥6 h time difference)

Zwingerberger et al., 2014[31]	Prospective cohort	Triathlon	Retrospective: 212 (♂: 169, ♀: 43), 40.3 years (mean) Prospective: 49, (♂: 40, ♀: 9), 39 years (mean)	n/a	Retrospective: 1 year / Prospective: 1 year	Self-reported injuries, load (weekly training hours, yearly training hours, years of triathlon activity), anthropometric data	Y		Y				Y	Y		<ul style="list-style-type: none"> There was no significant difference in the rate of injury between athletes with ≥ 10 training hours per week (28.7%) and athletes with less than 10 training hours per week (19.5%, $p = 0.116$).
Bengtsson et al., 2013[32]	Prospective cohort	Football	27 teams, elite, male, n/a	Time-loss	11 seasons	Injuries recorded by medical team, exposure hours, competition congestion (days of recovery between matches)	Y				Y		Y		Y	<ul style="list-style-type: none"> Total injury rates (RR 1.09) and muscle injury rates (RR 1.32) were increased in matches with short recovery compared with matches with long recovery before the match High match load was associated with increased muscle injury rate in matches in the same period, and with increased ligament injury rate in training in the subsequent period
Ivarsson et al., 2013[33]	Prospective cohort	Football	56 (♂: 38, ♀: 18), elite, 25.1 \pm 5.5 years (mean \pm SD)	Time-loss	1 season	Injuries recorded by medical staff, psychological variables (The Hassle and Uplift Scale, Life Events Survey for Collegiate Athletes, Brief COPE, Swedish Universities Scales of Personality)		Y				Y	Y		Y	<ul style="list-style-type: none"> Negative-life-event stress and daily hassle, in addition to trait anxiety, were significant predictors of injury among professional soccer players, accounting for 24% of the variance
Jacobsson et al., 2013[34]	Prospective cohort	Athletics	292 (♂: 131, ♀: 161), elite, 24 years (range 18–37), youth: 17 years	Modified training	1 year	Self-reported injuries, training load (number of training hours per week, weekly training intensity, training load rank index (the reported training intensity multiplied with minutes of training performed during the week)), captured through baseline and weekly questionnaires	Y		Y				Y	Y	Y	<ul style="list-style-type: none"> Athletes in the third (HR 1.79; 95% CI 1.54 to 2.78) and fourth training load rank index quartiles (HR 1.79; 95% CI 1.16 to 2.74) had almost a twofold increased risk of injury compared with their peers in the first quartile
Nielsen et al., 2013[35]	Prospective cohort	Running	930 (♂: 468, ♀: 462), recreational, 37.2 \pm 10.2 years (mean \pm SD)	Time-loss (>1 week)	1 year	Self-reported injuries with following clinical examination, running loads captured through GPS-units. Sex, age, body mass index (BMI), behavior (Type A Self-Rating Inventory), running experience, other sports activity, previous running-related injuries, and other injuries not related to running assessed prior to or at baseline	Y		Y				Y		Y	<ul style="list-style-type: none"> No significant or clinically relevant relationships were found for running experience ($p=0.30$) or other sports activities ($p=0.30$)
Rasmussen et al., 2013[36]	Retrospective cohort	Running	662 (♂: 468, ♀: 462), recreational, 41.4 \pm 10.4 years (mean \pm SD)	Time-loss (>2 weeks)	1 year	Self-reported injuries and load (average weekly volume of running) captured through a questionnaire	Y		Y				Y		Y	<ul style="list-style-type: none"> When adjusting for previous injury and previous marathons, the relative risk (RR) of suffering an injury rose by 2.02 (95% CI: 1.26–3.24), $p < 0.01$ among runners with an average weekly training volume below 30 km/week compared with runners with an average weekly training volume of 30–60 km/week No significant differences were found between runners exceeding 60 km/week and runners running 30–60 km/week (RR=1.13 [0.5–2.8], $p=0.80$).
Rogalski et al., 2013[37]	Prospective cohort	Australian football	46, elite, male, 22.2 \pm 2.9 years (mean \pm SD)	Time-loss/modified training	1 season	Injuries recorded by medical team, training and game load (session-RPE; rolling weekly sums and week-to-week changes in load)	Y	Y		Y			Y	Y		<ul style="list-style-type: none"> Larger 1 weekly (>1750 AU, OR= 2.44–3.38), 2 weekly (>4000 AU, OR= 4.74) and previous to current week changes in load (>1250 AU, OR= 2.58) were significantly related ($p < 0.05$) to a higher injury risk throughout the in-season phase

Visnes et al., 2013[38]	Prospective cohort	Volleyball	141 (♂: 69, ♀: 72), elite, 16.8 ± 0.8 years (mean ± SD)	Symptoms of jumper's knee lasting for at least 12 weeks	4 seasons	Injuries recorded by medical team, match and training load (number of hours of volleyball and other training, number of sets played in matches), body composition	Y		Y					Y		Y	<ul style="list-style-type: none"> Volleyball training had an odds ratio of injury (OR: 1.72 (1.18–2.53) for every extra hour trained Match exposure was the strongest sports-related predictor for developing jumper's knee with an OR of 3.88 (1.80–8.40) for every extra set played per week
Wheeler et al., 2013[39]	Prospective cohort	Water polo	7, female, elite, 23 years (18-29)	Physical complaint (shoulder soreness)	2 training camps	Self-reported shoulder soreness, shooting load (number of shots, time between shots) captured by video cameras	Y		Y					Y		Y	<ul style="list-style-type: none"> It was shown that 74% (p=0.013) of shoulder soreness was explained by the volume of goal shooting during training, with greater soreness associated with less rest time between shots (p=0.032)
Carling et al., 2012[40]	Prospective cohort	Football	1 team, elite, male, n/a	Time-loss	26 days	Match injuries recorded by medical team, exposure hours, competition congestion (days of recovery between matches), computerised motion-analysis of running distance and intensity	Y			Y				Y	Y		<ul style="list-style-type: none"> The incidence of match injury during the congested fixture period was similar to rates reported outside this period, but the mean lay-off duration of injuries was substantially shorter during the former (p < 0.05)
Gabbett & Ullah, 2012[41]	Prospective cohort	Rugby league	34, elite, male, 23.6 ± 3.8 years (mean ± SD)	Tissue	1 season	Injuries recorded by medical team, training load (high- and low-intensity running and movement activities captured by GPS/micro-technology-units), exposure hours	Y		Y					Y		Y	<ul style="list-style-type: none"> The risk of injury was 2.7 (95% CI 1.2–6.5) times higher when very high-velocity running (i.e., sprinting) exceeded 9 m per session The risk of sustaining a soft-tissue injury was significantly lower in players who covered greater distances at very low, low, and moderate intensities
Sibold & Zizzi, 2012[42]	Prospective cohort	American football, football, volleyball, tennis, cross-country running	177 (♂: 116, ♀: 61), collegiate athletes, 19.5 ± 1.4 years (mean ± SD)	Time-loss	n/a	Injuries recorded by athletic trainers, psychological variables (Life Events Survey for College Athletes, Sport Anxiety Scale), orthopaedic screening		Y				Y		Y		Y	<ul style="list-style-type: none"> Higher levels of negative life-event stress (z=5.02, p<0.001), as well as worry (z=2.98, p<0.003) predicted a lower injury risk, whereas concentration disruption (z=-3.95, p<0.001) predicted higher injury risk
Fleisig et al., 2011[43]	Retrospective cohort	Baseball	481, youth pitchers, male, 12.0 ± 1.7 years (mean ± SD)	Elbow surgery, shoulder surgery, or retirement due to throwing injury	10 seasons	Self-reported injuries, pitching load (amount of pitching, curveballs thrown) captured through annual questionnaire	Y		Y					Y	Y		<ul style="list-style-type: none"> Participants who pitched more than 100 innings in a year were 3.5 times more likely to be injured (95% CI: 1.16 to 10.44)
Gabbett & Jenkins, 2011[44]	Prospective cohort	Rugby league	79, elite, male, 23.3 ± 3.8 years (mean ± SD)	Physical complaint	4 seasons	Injuries recorded by medical team, training load (session-RPE), exposure hours	Y	Y	Y					Y	Y		<ul style="list-style-type: none"> Training load was significantly related (P < 0.05) to overall injury (r = 0.82), non-contact field injury (r = 0.82), and contact field injury (r = 0.80) rates, suggesting that the harder professional rugby league players train, the more injuries they are likely to sustain
Johnson & Ivarsson, 2011[45]	Prospective cohort	Football	108 (♂: 85, ♀: 23), high-school, 17-19 years	n/a	1 season	Injuries recorded by athletic trainers, psychological variables (Life Events Survey For Collegiate Athletes, State Trait Anxiety Inventory, Sport Anxiety Scale, Athletic Coping Skills Inventory-28, Swedish Universities Scales of Personality)		Y				Y		Y		Y	<ul style="list-style-type: none"> Negative life event stress significantly predicted the occurrence of injury In total, four significant predictors could together explain 23% of injury occurrence: life event stress, somatic trait anxiety, mistrust and ineffective coping

Saw et al., 2011[46]	Prospective cohort	Cricket	28, elite, male, 24.4 ± 3.9 years (mean ± SD)	Physical complaint (shoulder or elbow pain associated with throwing)	1 season	Injuries recorded by medical team, throwing load (number of throw-downs, fielding drill throws, warm-up throws, match throws) captured through video recordings or recorded by researchers/reported by players	Y		Y					Y	Y		<ul style="list-style-type: none"> Injured players threw approximately 40 more throws/week (p=0.004) and 12.5 more throws per throwing day (p=0.061) than uninjured players Players were at a significantly increased risk of injury if they completed more than 75 throws/week (RR: 1.73, 95% CI: 1.03 to 2.92), and there was a trend towards an increased risk if they completed more than 40 throws per throwing day (RR: 1.41, 95% CI: 0.88 to 2.26) Injured players also completed more throws and had more throwing days (and consequently less rest days) in the week before injury, as compared with the rest of their season preceding that point
Brink et al., 2010[47]	Prospective cohort	Football	53, elite, male, 15-18 years	Physical complaint	2 seasons	Injuries recorded by medical team, match and training load (session-RPE, exposure hours; training monotony/strain); REST-Q-Sport	Y	Y	Y			Y		Y		Y	<ul style="list-style-type: none"> Physical load (duration, load monotony, strain) was positively associated with traumatic injury (range OR 1.01 to 2.59) The association between psychosocial load and injury risk was unclear, with only 1 ("fitness/injury") out of 19 subscales being significantly higher for players with injury
Carling et al., 2010[48]	Prospective cohort	Football	32, elite, male, n/a	Time-loss	4 seasons	Injuries recorded by medical team, exposure hours, competition congestion (days of recovery between matches), player positional role	Y				Y			Y	Y		<ul style="list-style-type: none"> A very short interval (≤ 3 days) between fixtures did not result in a greater injury rate (p = 0.40) or number of days lost to injury (p = 0.73) compared to a longer interval (≥ 4 days)
Dupont et al., 2010[49]	Prospective cohort	Football	1 team, elite, male, 25.6 ± 3.8 years (mean ± SD)	Time-loss	2 seasons	Injuries recorded by medical team, exposure hours, match-related physical performance (total distance, high-intensity distance, sprint distance, and number of sprints)	Y				Y			Y	Y		<ul style="list-style-type: none"> The injury rate was significantly higher when players played 2 matches per week versus 1 match per week (25.6 versus 4.1 injuries per 1000 hours of exposure; p<.001)
Gabbett, 2010[50]	Prospective cohort	Rugby league	91, elite, male, 23.7 ± 3.8 years (mean ± SD)	Time-loss	4 seasons	Injuries recorded by medical team, training load (session-RPE), exposure hours	Y	Y	Y					Y	Y		<ul style="list-style-type: none"> Players were 50–80% likely to sustain a preseason injury within the training load range of 3,000–5,000 units. These training load thresholds were considerably reduced (1,700–3,000 units) in the late-competition phase of the season Players that exceeded the training load threshold were 70 times more likely to test positive for noncontact, soft-tissue injury in an injury prediction model
Ivarsson & Johnson, 2010[51]	Prospective cohort	Football	48, amateur, male, 16-36 years	Time-loss	4 months	Injuries recorded by athletic trainers, psychological variables (Daily Hassles Scale, Life Events Survey for Collegiate Athletes, Football Worry Scale, Swedish universities Scales of Personality, Brief COPE)		Y				Y		Y		Y	<ul style="list-style-type: none"> No significant relationships between negative life event stress or levels of daily hassles and injury, although a tendency was identified for the latter Injury was significantly predicted by 4 personality trait predictors: somatic trait anxiety, psychic trait anxiety, stress susceptibility, and trait irritability
Killen et al., 2010[52]	Prospective cohort	Rugby league	36, elite, male,	Physical complaint	14 weeks (preseason)	Injuries recorded by medical team, training load (session-RPE; training monotony, training strain), psychological variables (players' perceptions relating to sleep, food, energy, mood, and stress), exposure hours	Y	Y	Y			Y		Y	Y		<ul style="list-style-type: none"> No significant relationship was found between the preseason weekly injury rate and the weekly load, nor was there a relationship between injury and psychological data

Main et al., 2010[53]	Prospective cohort	Triathlon	30 (♂: 20, 27.1 ± 9.1 years, ♀: 10, 27.4±6.6 years) (mean ± SD), well-trained	n/a	45 weeks	Weekly self-reported signs and symptoms of injuries (and minor aches and pains), upper-respiratory tract infections (e.g. headaches, nasal congestion, sneezing, sore throat, coughing etc.), load (number of training sessions per week, training duration, five point scale for perception of the session intensity, psychological variables (Perceived Stress Scale, Brunel Mood Disturbance Scale, Training Stress Scale, Athlete Burnout Questionnaire)	Y	Y	Y			Y		Y		Y	<ul style="list-style-type: none"> • Signs and symptoms of injury and illness (SAS) were significantly associated with increases in load ($p \leq 0.05$) • The greatest impact on SAS was produced by psychological stressors ($P \leq 0.001$)
Sein et al., 2010[54]	Cross-sectional	Swimming	80 (♂: 42, ♀: 38), elite, 15.9 ± 2.7 (mean ± SD)	Physical complaint (shoulder pain) / supraspinatus tendinopathy		Self-reported shoulder pain, clinically measured glenohumeral joint laxity, magnetic resonance imaging of the shoulder, training load (number of years, hours per week, weekly swimming distance, percentage of time in training spent in each stroke over the previous 3 months) captured through a questionnaire	Y		Y				Y		Y		<ul style="list-style-type: none"> • The number of hours swum/week ($r_s=0.39$, $p<0.005$) and weekly mileage ($r_s=0.34$, $p=0.01$) both correlated significantly with supraspinatus tendinopathy, while swimming stroke preference did not
Vleck et al., 2010[55]	Retrospective cohort	Triathlon	35, elite, male, n/a	Physical complaint	5 years	Self-reported (questionnaire) data on injury, training load (number, duration & type of training sessions), equipment type, demographic information, competitive experience (years), highest competitive level, personal best times, warm-up/cool-down & stretching practices	Y		Y				Y	Y			<ul style="list-style-type: none"> • Overall, running injury occurrence pos. correlated with total run training time ($r=0.34$, $p<0.05$), Achilles tendon injury occurrence pos. correlated with distance covered doing "run hill reps" ($r=0.92$, $p<0.01$) and slightly neg. correlated with time spent doing "long runs" ($r=0.15$, $p<0.05$), lower back injury occurrence pos. correlated with "speed bike" training time ($r=0.52$, $p<0.01$) • In Olympic distance triathletes, overuse injury was linked with percentage of training time spent performing "bike hill reps" ($r=0.44$, $p<0.05$) and frequency of both "hill rep" bike sessions ($r=0.39$, $p<0.05$) and "other" bike sessions ($r=0.35$, $p<0.05$) • In Ironman distance triathletes, overuse injury was pos. correlated with both the duration of each "speed run" session ($r=0.56$, $p<0.05$) and "speed bike" training time ($r=0.67$, $p<0.01$), and running overuse injuries was linked to competitive running experience ($r=0.59$, $p<0.05$)
Jayanthi et al., 2009[56]	Cross-sectional	Tennis	n/a, elite, boys and girls; age division 12, 14, 16, 18 years	Medical withdrawal	64 tournaments	Medical withdrawals recorded as injuries, load (number of matches) captured through official website	Y				Y		Y		Y		<ul style="list-style-type: none"> • The medical withdrawal rate was significantly higher in the fifth match or greater (26.3/1000) versus the first 4 matches (12.7/1000; $P < 0.0001$), even when analysing main draw and singles matches
Orchard et al., 2009[57]	Prospective cohort	Cricket	129, elite, male, n/a	Time-loss	10 seasons	Injuries recorded by medical team, load (number of overs)	Y		Y				Y	Y			<ul style="list-style-type: none"> • Bowlers who bowled more than 50 overs in a match had an injury incidence in the next 21 days of 3.37 injuries per 1000 overs bowled, a significantly increased risk compared with those bowlers who bowled less than 50 overs (RR: 1.77, 95% CI: 1.05-2.98) • Bowlers who bowled more than 30 overs in the second inning of a match had a significantly increased injury risk per over bowled in the next 28 days (RR: 2.42, 95% CI: 1.38-4.26)

Piggott et al., 2009[58]	Prospective cohort	Australian football	16, elite, male, 23.8 ± 5.1 years (mean ± SD)	Time-loss	15-week pre-season	Injuries (and illnesses) recorded by medical team, training load (session-RPE, mins > 80% max HR, total distance run, total distance run > 12 km/h (GPS-units), spikes (>10% change in load)), training load strain and monotony	Y	Y	Y	Y				Y	Y		<ul style="list-style-type: none"> • There was a significant relationship between total distance run and incidence of injury ($r = -0.52$, $p = 0.048$) • It was found that 40% of injuries could be explained by a preceding spike in training load
Steffen et al., 2009[59]	Prospective cohort	Football	1430, youth, female, 15.4 ± 0.8 years (mean ± SD)	Time-loss	1 season	Injuries recorded by physical therapists, psychological variables (Life Event Scale for Collegiate Athletes, Norwegian Sports Anxiety Scale, Brief Cope, Perception of Success Questionnaire, Perceived Motivational Climate in Sport Questionnaire) and data on sports participation, injury history and present lower limb symptoms and function captured through pre-season questionnaire		Y			Y			Y	Y	Y	<ul style="list-style-type: none"> • High life stress ($P=0.001$) and perception of a mastery climate ($P=0.03$) were significant risk factors for new injuries • In addition, there were significant differences in disfavoured for previously injured compared with non-injured players for ego orientation ($p=0.007$), perception of a performance climate ($p=0.003$) and experienced stressful life events ($P<0.001$)
Viljoen et al., 2009[60]	Prospective cohort	Rugby union	38, elite, male, 26 ± 2 years (mean ± SD)	Medical attention	3 seasons	Injuries recorded by medical team, training load (hours of off-season, pre-season, in-season and total training) recorded by strength and conditioning coach	Y		Y					Y	Y		<ul style="list-style-type: none"> • There was a non-significant association between reduction in training volume and reductions in the in-season match ($p=0.06$) and in-season total ($p=0.09$) injury rates over the 3 years • However, total pre-season injury rates and the number of recurrent injuries show an opposite non-significant trend
Brooks et al., 2008[61]	Prospective cohort	Rugby union	502, elite, male, n/a	Time-loss	2 seasons	Injuries recorded by medical team, training load (match and training exposure hours) recorded by team fitness coaches	Y		Y					Y	Y		<ul style="list-style-type: none"> • Higher training volumes (49.1 hours per week) did not increase the incidence of match or training injuries. However, higher training volumes did increase the severity of match injuries, particularly during the second half, and consequently resulted in a significant increase in the number of days' absence due to match injuries
Knobloch et al., 2008[62]	Retrospective cohort	Running	291 (♂: 248, ♀: 41), elite, 42 ± 9 years (mean ± SD)	Physical complaint	8 months	Self-reported injuries, load (years of running experience, number of training kilometres per week, kilometres per year, number of running contests within the last season, participation in other sports), and other variables (sex, age, BMI, preferred running discipline, competition level, running surfaces, use of eccentric training for the Achilles tendon, use of protective equipment, and time using each pair of shoes) captured through questionnaire	Y		Y					Y	Y		<ul style="list-style-type: none"> • Running more than 4 times a week (RR: 2.3, CI: 1.09 to 4.96, $p = 0.025$) or for more than 2600 km exposure (RR: 2, CI: 1.11 to 3.48, $p = 0.02$) had a higher risk for shin splint overuse injuries • Training more than 65 km/week increased the risk for back overuse injuries (RR: 2.3, CI: 1.13 to 4.65, $p = 0.019$) • Runners with more than 10 years of experience had a higher risk for overuse injuries of the back (RR: 3.3, CI: 1.16 to 4.57, $p = 0.015$) and Achilles tendinopathy (RR: 1.6, CI: 1.02 to 2.76, $p = 0.041$)
Van Middelkoop et al., 2008[63]	Prospective cohort	Running	694, recreational, male, 44 ± 9.6 years (mean ± SD)	Time-loss	1 month	Self-reported injuries, load (training distance, frequency and duration, running experience, type of training underground, training type (long-distance, interval) and shoes), and other variables (demographic factors, race event factors, lifestyle factors) captured through baseline and post-marathon questionnaires	Y		Y					Y	Y	Y	<ul style="list-style-type: none"> • More than six races in the previous 12 months [OR: 1.66; CI: 1.08–2.56] was associated with the occurrence of lower extremity injuries • Training distance >40 km a week was found to be a strong predictor of future calf injuries

Gabbett & Domrow, 2007[64]	Prospective cohort	Rugby league	183, elite, male, 21.4 years (mean)	Time-loss	2 seasons	Injuries recorded by medical team, training load (session-RPE), exposure hours, anthropometry, multi-stage fitness test, vertical jump test, agility test	Y	Y	Y	Y			Y	Y		<ul style="list-style-type: none"> • There was a 1.50 – 2.85 increase in the odds of injury for each arbitrary unit increase in training load • During the pre-season training phase there was a relationship between the 155-590 arbitrary unit training load range and injury incidence
Kelsey et al., 2007[65]	Prospective cohort	Running	127, competitive, female, 18–26 years	Stress fractures (confirmed by x-ray, bone scan, or MRI)	1.85 year per woman	Self-reported stress fractures confirmed by imaging, load (running experience, number of miles per week), bone densitometry, age at menarche and the number of menses per year	Y		Y				Y		Y	<ul style="list-style-type: none"> • There was no association between training load and risk of stress fracture
Lovell et al., 2006[66]	Retrospective cohort	Football	19, elite, male, 15-17 years	Osteitis pubis (physical complaint, clinical diagnose, MRI)	4 months	Retrospective recording of 2 months training load (questionnaire); prospective review of clinical diagnosis, investigations and records on presentation of athletes with groin pain; prospective serial MRI examinations of the pubis symphysis with grading of bone marrow oedema and other abnormalities	Y			Y			Y	Y		<ul style="list-style-type: none"> • There was a greatly decreased risk of developing groin pain (osteitis pubis) with more training prior to entry of the AIS soccer program (OR per 4 sessions of training, 0.003)
McKean et al., 2006[67]	Retrospective cohort	Running	2886, recreational, male & female, n/a	Time-loss	1 year	Self-reported injuries (diagnosed by health professional or themselves), load (number of runs and miles per week, years of running experience) and other variables (shoe characteristics, orthotic use) captured through questionnaire	Y		Y				Y		Y	<ul style="list-style-type: none"> • Running more times per week increased the risk of injury for both older and younger runners (OR: 1.32 – 2.24)
Olsen et al., 2006[68]	Case-control	Baseball	140, male, 14-20 years	Shoulder or elbow surgery / shoulder or elbow pain (controls)	1 year	Injuries recorded by orthopaedic surgeons. Self-reported injury history, load (numerous variables related to playing history), and other potential risk factors captured through questionnaire	Y		Y				Y		Y	<ul style="list-style-type: none"> • The injured group pitched significantly more months per year, games per year, innings per game, pitches per game, pitches per year, and warm-up pitches before a game • These pitchers were more frequently starting pitchers, pitched in more showcases, pitched with higher velocity, and pitched more often with arm pain and fatigue
Rauh et al., 2006[69]	Prospective cohort	Cross-country running	421 (♂: 235, ♀: 186), high-school, n/a	Time-loss	1 season	Injuries recorded by coaches, daily training load and exposure recorded by coaches (distance, intensity, surface, terrain), baseline questionnaire (prior running and injury experience), anthropometric measurements	Y		Y				Y		Y	<ul style="list-style-type: none"> • No significantly increased injury risks were found in relation to overall mileage or mileage by running pace
Schueller-Weidekamm et al., 2006[70]	Cross-sectional	Running	26 (♂: 7, ♀: 19), non-professional, 33 ± 5 years (mean ± SD)	Chronic knee lesions	n/a	Injuries recorded by radiologist and MRI specialist through MRI, load (training distance per week, running frequency, average duration of training per year, and training pace) captured through questionnaire	Y		Y				Y	Y		<ul style="list-style-type: none"> • Runners with a higher training level showed a statistically significant higher score for all chronic knee lesions than those with a lower training level (p < 0.05)
Dennis et al., 2005[71]	Prospective cohort	Cricket	44, junior, male, 14.7 ± 1.4 years (mean ± SD)	Physical complaint leading to time-loss/reduced performance (bowling overuse)	1 season	Injuries recorded by medical team, self-reported load (number of match and training deliveries bowled each day)	Y		Y		Y		Y	Y		<ul style="list-style-type: none"> • Injured bowlers had been bowling significantly more frequently than uninjured bowlers (p = 0.038) • Compared with bowlers with an average of >3.5 rest days between bowling, bowlers with an average of <3.5 rest days were at a significantly increased risk of injury (RR=3.1, 95% CI: 1.1 to 8.9)

Rogers & Landers, 2005[72]	Prospective cohort	Football	171 (♂: 98, ♀: 73), 16.1 ± 1.0 years (mean ± SD)	Time-loss	1 season	Injuries recorded by athletic trainer, psychological variables (Life Events Survey for Athletes, Perceived Stress Scale, State-Trait Anxiety Inventory, Perceived Social Support Friends/Family scales, Athletic Coping Skills Inventory), peripheral vision		Y				Y		Y	Y		<ul style="list-style-type: none"> Results showed that total life-event stress, negative life-event stress, and psychological coping skills significantly contributed to the prediction of the occurrence of athletic injury Additionally, psychological coping skills buffered the negative life-event stress/athletic injury relationship Peripheral narrowing during stress significantly mediated 8.1% of the negative life event stress/athletic injury relationship
Gabbett, 2004[73]	Prospective cohort	Rugby league	220, sub-elite, male, n/a	Physical complaint	3 seasons	Injuries recorded by head trainer, load (session-RPE), pre-season fitness tests, environmental conditions	Y	Y	Y					Y	Y	Y	<ul style="list-style-type: none"> High pre-season training loads were associated with higher training injury rates
Gabbett, 2004[74]	Prospective cohort	Rugby league	79, semi-professional, male, n/a	Physical complaint	1 season	Injuries recorded by head trainer, match and training load (session-RPE)	Y	Y	Y					Y	Y		<ul style="list-style-type: none"> A significant relationship ($p < 0.05$) was observed between training injury incidence and training intensity ($r = 0.83$), training duration ($r = 0.79$) and training load ($r = 0.86$) In addition, the incidence of match injuries were significantly correlated ($p < 0.05$) with match intensity ($r = 0.74$), match duration ($r = 0.86$) and match load ($r = 0.86$)
Shaw et al., 2004[75]	Cross-sectional	Triathlon	258 (♂: 190, ♀: 68), competitive & recreational, 16 - 63 years (mean=35 years)	Time-loss / medical attention / adverse social or economic effects / modified training	n/a	Self-reported injuries and load (total hours trained, number of hours trained weekly in the different disciplines) through questionnaire	Y		Y					Y		Y	<ul style="list-style-type: none"> Associations between hours of training and sustaining an injury were U-shaped, with those triathletes training at low levels and at high levels more likely to sustain an injury The likelihood of sustaining an injury was least when training for a total of 8 to 10 hours per week, specifically cycling for five to six hours and running for three to four hours weekly
Anderson et al., 2003[76]	Prospective cohort	Basketball	12, NCAA Division III, female, 18-22 years	Medical attention / time-loss	1 season	Weekly self-reported injuries, illnesses, and load (session-RPE, training monotony, training strain)	Y	Y		Y				Y	Y		<ul style="list-style-type: none"> An increase in injuries occurred during times of increased training loads, particularly during the first 2 weeks of formal practice, and immediately subsequent to the holidays The temporal relationship between training load and injury suggests a causative link ($p < 0.01$; $r = 0.675$)
Burns et al., 2003[77]	Prospective cohort	Triathlon	131 (♂: 91, ♀: 40), national level, 33.7 years (18-65)	Time-loss / medical attention / modified training / taking medicine	10 weeks (with 6-month retrospective survey)	Self-reported injuries, load (triathlon experience, training hours in swimming, cycling, and running), demographic data, warming-up and cooling-down protocol	Y		Y					Y		Y	<ul style="list-style-type: none"> Years of triathlon experience was associated with a significant increase in risk of injury ($\chi^2 = 7.387$, $p = 0.007$, odds ratio = 1.66) For competition season injury, there was an increase in risk in those triathletes who had higher preseason running mileage: for every extra hour per week of preseason running there was a 12% increased risk of competition season injury ($\chi^2 = 7.961$, $p = 0.005$, OR = 1.12)
Dennis et al., 2003[78]	Prospective cohort	Cricket	90, elite, male, 27 years (18 - 38)	Time-loss / performance-limiting / surgery	2 seasons	Injuries recorded by medical team, load (the frequency of bowling, the type of bowling performed (match or training) and the time frame within which the bowling was completed) captured by observation and fixture scorecards	Y		Y		Y			Y		Y	<ul style="list-style-type: none"> Compared to those bowlers with an average of 123-188 deliveries per week, bowlers with an average of fewer than 123 deliveries per week (RR= 1.4, 95% CI 1.0 to 2.0) or more than 188 deliveries per week (RR= 1.4, 95% CI 0.9 to 1.6) may be at an increased risk of injury Compared to bowlers with an average of 3-3.99 days between bowling sessions, bowlers with an average of less than 2 days (RR = 2.4, 95% CI 1.6 to 3.5) or 5 or more days between sessions (RR= 1.8, 95% CI 1.1 to 2.9) were at a significantly increased risk of injury
Egermann et al., 2003[79]	Retrospective cohort	Triathlon	656 (♂:588, ♀: 68), sub-elite, 35.8 ± 7.8 years (mean ± SD)	Time-loss	n/a	Self-reported injuries, load (number of years in competitive triathlon, weekly training hours in swimming, cycling, and running), demographic data	Y		Y					Y		Y	<ul style="list-style-type: none"> Athletes with more than 20 training hours per week had significantly more chronic back pain ($p = 0.002$) Athletes with a large number of weekly training hours suffered more muscle-tendon injuries ($p = 0.014$) (univariate only)

Taunton et al., 2003[80]	Prospective cohort	Running	844 (♂: 205, ♀: 635), recreational, n/a	Physical complaint	13 weeks	Self-reported (questionnaire administered 3 times over 13 weeks) injuries, load (days of running per week), demographic data, body mass index, predominant running surface, arch height, running shoe age, and concurrent cross training	Y		Y					Y		Y	• Running only one day a week was a significant risk factor in women, whereas in men, only a non-significant trend was found.
Hootman et al., 2002[81]	Prospective cohort	Running	3090 (♂: 2481, ♀: 609), recreational, 20-85 years	Medical attention	5 years	Self-reported injuries, load (number of miles per session, times per week, and pace per mile), demographic and anthropometric data captured through 12-month and five-year recall periods	Y		Y					Y		Y	• Running, walking or jogging mileage >20 miles per week, together with older age and previous lower extremity injury predicted lower extremity injury for both men and women.
Lyman et al., 2002[82]	Prospective cohort	Baseball	476 (♂: 475, ♀: 1), youth, 12 years (9-14)	Physical complaint (elbow or shoulder pain)	1 season	Self-reported injuries (questionnaires and interviews), load (types of pitches thrown, pitch counts, and pitching mechanics) captured through questionnaires, pitch count book, and video analysis, respectively	Y		Y					Y		Y	• There was a significant association between the number of pitches thrown in a game and during the season and the rate of elbow pain and shoulder pain
Lee et al., 2001[83]	Prospective cohort	Rugby union	803, professional / amateur, 23.9 ± 6.65 years (mean ± SD)	Time-loss	1 season	Injuries recorded by “observers”, self-reported load (number of weeks and sessions of attendance, average number of sessions per week, weekly hours of aerobic and power activities)	Y		Y					Y		Y	• There was a 3.9% relative increase (95% CI 1.9 to 5.9%) in the risk of injury over the season for each additional preseason training week attended
Lyman et al., 2001[84]	Prospective cohort	Baseball	298, youth, male, 10.8 ± 1.2 years (mean ± SD)	Physical complaint (elbow or shoulder pain)	2 seasons	Injuries, load (seasons pitched, pitching practice frequency, pitch count, pitch types used), baseball participation (e.g., years played, primary position played, baseball camp attendance), and demographic characteristics captured through interviews and pitch count books	Y		Y					Y		Y	• Throwing fewer than 300 or more than 600 pitches during the season was a risk factor for elbow pain • Throwing more than 75 pitches in a game, and throwing fewer than 300 pitches during the season were risk factors for shoulder pain
Duffey et al., 2000[85]	Retrospective cohort	Running	169, recreational, 35/36 ± 1 year (mean ± SD)	Time-loss / modified training / medical attention (anterior knee pain)	1 year	Injuries recorded by medical personnel, load (training regimen, running terrain, running experience) captured through questionnaire. In addition, anthropometric, muscular strength and endurance, rear-foot movement and kinetic data were collected.	Y		Y					Y		Y	• There was no difference in average weekly mileage or training pace between injured and uninjured runners
Fawcner et al., 1999[86]	Prospective cohort	Field hockey, volleyball, triathlon	98 (♂:29, ♀: 69), elite / recreational, 26.1 ± 4.2 years (mean ± SD)	Time-loss / medical attention	13 / 18 weeks	Injuries and load (daily hassles scale) self-reported / recorded by coaches		Y				Y		Y	Y		• Injured athletes were found to have a significant increase in minor life events (daily hassles) in the week prior to injury

McCrary et al., 1999[87]	Retrospective cohort	Running	89, recreational / competitive, n/a	Achilles tendinitis (inflammation and irritation of the Achilles tendon)	1 year	Injuries recorded by medical personnel, load (training pace, weekly mileage, years running,) captured through questionnaire. In addition, anthropometric, isokinetic, rear-foot movement and kinetic data were collected.	Y		Y					Y		Y	<ul style="list-style-type: none"> • Years running and training pace were significant risk factors for Achilles tendinitis
Satterthwaite et al., 1999[88]	Prospective cohort	Running	875, recreational, n/a	Medical attention / physical complaint	1 week	Injuries, load (running experience, training pattern), and demographic data captured through medical service, interviews and questionnaire	Y		Y					Y		Y	<ul style="list-style-type: none"> • Increased training was associated with increased risk of front thigh and hamstring problems, but decreased the risk of knee problems
Vleck & Garbutt, 1998[89]	Retrospective cohort	Triathlon	194, elite / competitive, n/a	Time-loss / modified training / taking medicine / medical attention	5 years	Self-reported injuries, load (training mileage, training time, and number of workouts in swimming, cycling and running over one week, years of competitive experience), anthropometric data and other risk factor data captured through questionnaire	Y		Y					Y	Y		<ul style="list-style-type: none"> • The number of running injuries sustained correlated with triathlon training distance, cycling distance ($p < 0.03$), swimming distance ($p < 0.01$), number of triathlon workouts ($p < 0.03$) and number of running sessions ($p < 0.03$) within one weeks race training • The number of overuse injuries sustained during cycling correlated with time spent running and cycling
Bennell & Crossley, 1996[90]	Retrospective cohort	Athletics	95 (♂: 49, ♀: 46), elite / competitive, 20.3 ± 2.0 (mean \pm SD)	Modified training >1 week	1 year	Injuries, load (average number of weekly training hours, training type, running distance), anthropometric, menstrual and biomechanical risk factors captured through interview	Y		Y					Y	Y		<ul style="list-style-type: none"> • There was no significant difference in average weekly training hours, running distance or training type when comparing injured and uninjured athletes
Koplan et al., 1995[91]	Retrospective cohort	Running	535 (♂: 326, ♀: 209), recreational,	Modified training / interference with school or work	10 years	Self-reported injuries and load (running mileage) captured through questionnaire	Y		Y					Y	Y		<ul style="list-style-type: none"> • The probability of experiencing an injury was associated with higher weekly mileage
Messier et al., 1995[92]	Retrospective cohort	Running	126, male & female, recreational / competitive, n/a,	Time-loss / modified training / medical attention (iliotibial band friction syndrome)	n/a	Injuries recorded by medical personnel, load (training regimen, running experience) captured through questionnaire, anthropometric, rear-foot motion, ground reaction force, knee muscular strength and endurance data were collected	Y		Y					Y		Y	<ul style="list-style-type: none"> • Weekly mileage, training pace, number of months using current training protocol, percentage of time spent swimming, and percentage of time spent running on a track were significant risk factors for injury
D'Souza, 1994[93]	Retrospective cohort	Athletics	147 (♂: 96, ♀: 51), university and junior athletes, 18 ± 2.5 years (mean \pm SD)	Time loss (>1 week)	1 year	Questionnaire (once) Injury frequency, severity and types; hours of training, number of training sessions attended, event specialisation, level of competition	Y		Y					Y	Y		<ul style="list-style-type: none"> • No significant relationship was found between the incidence of injuries and the hours spent in training
Korkia et al., 1994[94]	Prospective cohort	Triathlon	155 (♂: 124, ♀: 31), recreational, intermediate or elite, 34 ± 8.9 years (♂), 32 ± 7.3 (♀) years (mean \pm SD)	Time-loss	8 weeks	Self-reported injuries, training load (type of activity, intensity, mileage, duration, surface and rest days)	Y		Y					Y	Y		<ul style="list-style-type: none"> • The likelihood of an injury was positively associated with experience in triathlon, but not with the mean amount of weekly training or competition, intensity or frequency of training

Haglund-Åkerlind & Eriksson, 1993[95]	Retrospective cohort	Running	83, competitive, 26.9 ± 5.7 years (injured) 24.0 ± 6.5 years (uninjured) (mean ± SD)	Physical complaint (Achilles tendon problems)	n/a	Self-reported injuries, load (number of years in training; training sessions per week; distance covered per week; interval distance per week; hill, strength and jump training sessions per week; and number of competitive events per year), demographic & anthropometric data, data on running results, use of stretching, surface, and running shoes captured through questionnaire. Measurement of range of motion of the ankle and hip joints using a manual goniometer, assessment of malalignment and muscle atrophy and examination of the Achilles tendon were done in 20 runners.	Y		Y					Y	Y		<ul style="list-style-type: none"> The runners with Achilles tendon problems had trained for significantly more years and covered significantly longer distances per week than runners without Achilles tendon problems
Bovens et al., 1989[96]	Prospective cohort	Running	73 (♂: 58, ♀: 15), recreational, ♂: 35.2 ± 7.9 years, ♀: 33.5 ± 6.4 years (mean ± SD)	Physical complaint resulting in modified training	18—20 months	Self-reported injuries and load (distance, frequency, intensity of running) captured through a diary	Y		Y					Y	Y		<ul style="list-style-type: none"> There was a significant correlation between injuries and the distance covered during the training at the start of the training program
Collins et al., 1989[97]	Retrospective cohort	Triathlon	257 (♂: 197, ♀: 60), recreational / elite, 32 years (mean)	Time-loss / modified training / taking medicine / medical attention	1 year	Self-reported injuries, load (mileage per week and number of years in swimming, cycling, and running; hill training; number of previous triathlons; use of weights; participation in other sports), demographic data captured through questionnaire	Y		Y					Y	Y		<ul style="list-style-type: none"> Elite triathletes averaged more miles per week in each sport than the athletes as a whole and showed a higher incidence of injury (60%), although this was not a significant difference Higher weekly swimming, cycling, and running mileages did not lead to a higher incidence of injury
Macera et al., 1989[98]	Prospective cohort	Running	583 (♂: 485, ♀: 98), habitual runners, ♂: 41.6 ± 9.5 years, ♀: 36.1 ± 8.2 years (mean ± SD)	Modified training / medical attention / medication use (lower extremity)	Retrospective: 1 year / Prospective: 1 year	Self-reported injuries, load (average weekly distance, average days of running per week, participation in other physical activities), and demographic characteristics captured through baseline and monthly questionnaires	Y		Y					Y		Y	<ul style="list-style-type: none"> Running 64 km (40 miles) or more per week was the most important predictor of injury for men during the follow-up period (OR=2.9) Risk also was associated with having been a runner for less than 3 years (OR=2.2)
Marti et al., 1989[99]	Retrospective cohort	Running / bobsleigh	27 (running, mean age 42), 9 (bobsleigh, mean age 42), 23 controls (mean age 35)	Radiological evidence of degenerative hip disease	15 years	Load (weekly mileage), physiological and exercise characteristics of all subjects had been recorded in 1973, and in 1988 these measurements were repeated together with radiological examination of the hips	Y		Y					Y		Y	<ul style="list-style-type: none"> Mileage run (p=0024) (and age, p=0-017) in 1973 emerged as independent, significant, and positive predictors of radiological signs of degenerative hip disease in 1988 Among runners alone running pace in 1973 rather than mileage run was the stronger predictor of subsequent degenerative hip disease

Walter et al., 1989[100]	Prospective cohort	Running	1288 (♂: 985, ♀: 303), recreational / competitive, n/a	Modified training / medication use / medical attention	Retrospective: 1 year / Prospective: 1 year	Self-reported injuries, load (mileage, intensity, pace, years of running experience); running environment; use of stretching, warm-up, and cool-down exercises; activity in other sports or exercise; occupational activity level; characteristics of shoes; height and weight; racing history; smoking status captured through questionnaires.	Y		Y					Y		Y	<ul style="list-style-type: none"> The risk of injury was associated with increased running mileage, but not with other aspects of training, such as usual pace, usual running surface, hill running, or intense training
Marti et al., 1988[101]	Retrospective cohort	Running	4358, recreational, male, 35.0 ± 10.0 years (uninjured runners), 34.8 ± 10.1 years (injured runners) (mean ± SD)	Physical complaint	1 year	Self-reported injuries, load (number of kilometres run per week, years of running), data on running shoes, surface, use of orthotic devices, anthropometrics, medical consultations, work absences, and motivation captured through questionnaire	Y		Y					Y	Y		<ul style="list-style-type: none"> Occurrence of running injuries was independently associated with higher weekly mileage (p < 0.001) Higher mileage was also associated with more frequent medical consultations due entirely to running-related injuries
Lysholm & Wiklander, 1987[102]	Prospective cohort	Running	60 (♂: 44, ♀: 16), competitive / elite, n/a	Modified training >1 week	1 year	Self-reported injuries, load (mileage per month, number of workouts per month) captured through monthly questionnaires	Y		Y					Y	Y		<ul style="list-style-type: none"> In marathon runners there was a significant correlation between the injury rate during any 1 month and the distance covered during the preceding month (r = 0.59) No significant relation emerged between distance run and injury days during the same month
Jacobs & Berson, 1986[103]	Retrospective cohort	Running	451 (♂:355, ♀: 96), ♂: 33.9 (14-64) years, and ♀: 32.4 (8-57) years	Physical complaint	2 years	Self-reported injuries, load (miles run per week, days run per week, average pace of workouts, length of time running regularly, as well as interval, sprint, or hill running) and demographic information captured through questionnaire	Y		Y					Y	Y		<ul style="list-style-type: none"> Injured runners differed significantly from non-injured runners in that they were more likely to have (1) run more miles per week, (2) run more days per week, (3) run a faster pace, (4) run more races in the last year, (5) stretched before running, and (6) not participated regularly in other sports
Koplan et al., 1982[104]	Cross-sectional	Running	1423 (♂:693, ♀: 730), recreational, ♂: 33.4 years, ♀: 29.9 years (mean)	Modified training / medication use / medical attention		Self-reported injuries, load (weekly mileage, number of years running), demographic and lifestyle information captured through questionnaire	Y		Y					Y			<ul style="list-style-type: none"> The risk of injury increased with increasing weekly mileage This trend was similar for men and women, for all types of injuries, and for those injuries that led to a medical consultation Injuries were not independently associated with age, speed, BMI, or years of running

Reference List

- 1 Bowen L, Gross AS, Gimpel M, et al. Accumulated workloads and the acute:chronic workload ratio relate to injury risk in elite youth football players. *Br J Sports Med* 2016. In press. doi: bjsports-2015-095820

- 2 Carling C, McCall A, Le GF, et al. The impact of short periods of match congestion on injury risk and patterns in an elite football club. *Br J Sports Med* 2016;50:764-68.
- 3 Cross MJ, Williams S, Trewartha G, et al. The influence of in-season training loads on injury risk in professional rugby union. *Int J Sports Physiol Perform* 2016;11:350-55.
- 4 Duhig S, Shield AJ, Opar D, et al. The effect of high-speed running on hamstring strain injury risk. *Br J Sports Med* 2016; Published Online First: 10 June 2016. doi:10.1136/bjsports-2015-095679.
- 5 Ehrmann FE, Duncan CS, Sindhusake D, et al. GPS and injury prevention in professional soccer. *J Strength Cond Res* 2016;30:360-67.
- 6 Hulin BT, Gabbett TJ, Caputi P, et al. Low chronic workload and the acute:chronic workload ratio are more predictive of injury than between-match recovery time: a two-season prospective cohort study in elite rugby league players. *Br J Sports Med* 2016; Published Online First: 5 February 2016. doi:10.1136/bjsports-2015-095364.
- 7 Hulin BT, Gabbett TJ, Lawson DW, et al. The acute:chronic workload ratio predicts injury: high chronic workload may decrease injury risk in elite rugby league players. *Br J Sports Med* 2016;50:231-36.
- 8 Murray NB, Gabbett TJ, Townshend AD. Relationship between pre-season training load and in-season load and injury in elite Australian Football players. *Int J Sports Physiol Perform* 2016. In press. doi: n/a
- 9 Murray NB, Gabbett TJ, Townsend NE, et al. Individual and combined effects of acute and chronic running loads on injury risk in elite Australian footballers. *Scand J Med Sci Sports* 2016. In press. doi: n/a
- 10 van der Worp MP, de WA, van CR, et al. The 5- or 10-km Marikenloop run: a prospective study of the etiology of running-related injuries in women. *J Orthop Sports Phys Ther* 2016;46:462-70.
- 11 Veugelers KR, Young WB, Fahrner B, et al. Different methods of training load quantification and their relationship to injury and illness in elite Australian football. *J Sci Med Sport* 2016;19:24-28.
- 12 von Rosen P, Heijne AI, Frohm A. Injuries and associated risk factors among adolescent elite orienteers: a 26-week prospective registration study. *J Athl Train* 2016;51:321-28.

- 13 Windt J, Gabbett TJ, Ferris D, et al. A training load—injury paradox: Is greater pre-season participation associated with lower in-season injury risk in elite rugby league players? *Br J Sports Med* 2016; Published Online First: 13 April 2016. doi:10.1136/bjsports-2016-095973.
- 14 Dellal A, Lago-Penas C, Rey E, et al. The effects of a congested fixture period on physical performance, technical activity and injury rate during matches in a professional soccer team. *Br J Sports Med* 2015;49:390-94.
- 15 Fowler P, Duffield R, Waterson A, et al. Effects of regular away travel on training loads, recovery, and injury rates in professional Australian soccer players. *Int J Sports Physiol Perform* 2015;10:546-52.
- 16 Fuller CW, Taylor AE, Raftery M. Does long-distance air travel associated with the Sevens World Series increase players' risk of injury? *Br J Sports Med* 2015;49:458-64.
- 17 Laux P, Krumm B, Diers M, et al. Recovery-stress balance and injury risk in professional football players: a prospective study. *J Sports Sci* 2015;33:2140-48.
- 18 Orchard JW, Blanch P, Paoloni J, et al. Cricket fast bowling workload patterns as risk factors for tendon, muscle, bone and joint injuries. *Br J Sports Med* 2015;49:1064-68.
- 19 Orchard JW, Blanch P, Paoloni J, et al. Fast bowling match workloads over 5-26 days and risk of injury in the following month. *J Sci Med Sport* 2015;18:26-30.
- 20 Owen AL, Forsyth JJ, Wong dP, et al. Heart rate-based training intensity and its impact on injury incidence among elite-level professional soccer players. *J Strength Cond Res* 2015;29:1705-12.
- 21 Timpka T, Jacobsson J, Dahlstrom O, et al. The psychological factor 'self-blame' predicts overuse injury among top-level Swedish track and field athletes: a 12-month cohort study. *Br J Sports Med* 2015;49:1472-77.
- 22 Clausen MB, Zebis MK, Moller M, et al. High injury incidence in adolescent female soccer. *Am J Sports Med* 2014;42:2487-94.
- 23 Colby MJ, Dawson B, Heasman J, et al. Accelerometer and GPS-derived running loads and injury risk in elite Australian footballers. *J Strength Cond Res* 2014;28:2244-52.
- 24 Hulin BT, Gabbett TJ, Blanch P, et al. Spikes in acute workload are associated with increased injury risk in elite cricket fast bowlers. *Br J Sports Med* 2014;48:708-12.

- 25 Huxley DJ, O'Connor D, Healey PA. An examination of the training profiles and injuries in elite youth track and field athletes. *Eur J Sport Sci* 2014;14:185-92.
- 26 Ivarsson A, Johnson U, Lindwall M, et al. Psychosocial stress as a predictor of injury in elite junior soccer: a latent growth curve analysis. *J Sci Med Sport* 2014;17:366-70.
- 27 Murray NB, Gabbett TJ, Chamari K. Effect of different between-match recovery times on the activity profiles and injury rates of national rugby league players. *J Strength Cond Res* 2014;28:3476-83.
- 28 Nielsen RO, Parner ET, Nohr EA, et al. Excessive progression in weekly running distance and risk of running-related injuries: an association which varies according to type of injury. *J Orthop Sports Phys Ther* 2014;44:739-47.
- 29 Ristolainen L, Kettunen JA, Waller B, et al. Training-related risk factors in the etiology of overuse injuries in endurance sports. *J Sports Med Phys Fitness* 2014;54:78-87.
- 30 Schwellnus MP, Thomson A, Derman W, et al. More than 50% of players sustained a time-loss injury (>1 day of lost training or playing time) during the 2012 Super Rugby Union Tournament: a prospective cohort study of 17,340 player-hours. *Br J Sports Med* 2014;48:1306-15.
- 31 Zwingenberger S, Valladares RD, Walther A, et al. An epidemiological investigation of training and injury patterns in triathletes. *J Sports Sci* 2014;32:583-90.
- 32 Bengtsson H, Ekstrand J, Hagglund M. Muscle injury rates in professional football increase with fixture congestion: an 11-year follow-up of the UEFA Champions League injury study. *Br J Sports Med* 2013;47:743-47.
- 33 Ivarsson A, Johnson U, Podlog L. Psychological predictors of injury occurrence: a prospective investigation of professional Swedish soccer players. *J Sport Rehabil* 2013;22:19-26.
- 34 Jacobsson J, Timpka T, Kowalski J, et al. Injury patterns in Swedish elite athletics: annual incidence, injury types and risk factors. *Br J Sports Med* 2013;47:941-52.
- 35 Nielsen RO, Buist I, Parner ET, et al. Predictors of running-related injuries among 930 novice runners: a 1-year prospective follow-up study. *Orthop J Sports Med* 2013;1:2325967113487316.

- 36 Rasmussen CH, Nielsen RO, Juul MS, et al. Weekly running volume and risk of running-related injuries among marathon runners. *Int J Sports Phys Ther* 2013;8:111-20.
- 37 Rogalski B, Dawson B, Heasman J, et al. Training and game loads and injury risk in elite Australian footballers. *J Sci Med Sport* 2013;16:499-503.
- 38 Visnes H, Bahr R. Training volume and body composition as risk factors for developing jumper's knee among young elite volleyball players. *Scand J Med Sci Sports* 2013;23:607-13.
- 39 Wheeler K, Kefford T, Mosler A, et al. The volume of goal shooting during training can predict shoulder soreness in elite female water polo players. *J Sci Med Sport* 2013;16:255-58.
- 40 Carling C, Le GF, Dupont G. Are physical performance and injury risk in a professional soccer team in match-play affected over a prolonged period of fixture congestion? *Int J Sports Med* 2012;33:36-42.
- 41 Gabbett TJ, Ullah S. Relationship between running loads and soft-tissue injury in elite team sport athletes. *J Strength Cond Res* 2012;26:953-60.
- 42 Sibold J, Zizzi S. Psychosocial variables and time to injury onset: a hurdle regression analysis model. *J Athl Train* 2012;47:537-40.
- 43 Fleisig GS, Andrews JR, Cutter GR, et al. Risk of serious injury for young baseball pitchers: a 10-year prospective study. *Am J Sports Med* 2011;39:253-57.
- 44 Gabbett TJ, Jenkins DG. Relationship between training load and injury in professional rugby league players. *J Sci Med Sport* 2011;14:204-09.
- 45 Johnson U, Ivarsson A. Psychological predictors of sport injuries among junior soccer players. *Scand J Med Sci Sports* 2011;21:129-36.
- 46 Saw R, Dennis RJ, Bentley D, et al. Throwing workload and injury risk in elite cricketers. *Br J Sports Med* 2011;45:805-08.
- 47 Brink MS, Visscher C, Arends S, et al. Monitoring stress and recovery: new insights for the prevention of injuries and illnesses in elite youth soccer players. *Br J Sports Med* 2010;44:809-15.
- 48 Carling C, Orhant E, Legall F. Match injuries in professional soccer: inter-seasonal variation and effects of competition type, match congestion and positional role. *Int J Sports Med* 2010;31:271-76.
- 49 Dupont G, Nedelec M, McCall A, et al. Effect of 2 soccer matches in a week on physical performance and injury rate. *Am J Sports Med* 2010;38:1752-58.

- 50 Gabbett TJ. The development and application of an injury prediction model for noncontact, soft-tissue injuries in elite collision sport athletes. *J Strength Cond Res* 2010;24:2593-603.
- 51 Ivarsson A, Johnson U. Psychological factors as predictors of injuries among senior soccer players. A prospective study. *J Sports Sci Med* 2010;9:347-52.
- 52 Killen NM, Gabbett TJ, Jenkins DG. Training loads and incidence of injury during the preseason in professional rugby league players. *J Strength Cond Res* 2010;24:2079-84.
- 53 Main LC, Landers GJ, Grove JR, et al. Training patterns and negative health outcomes in triathlon: longitudinal observations across a full competitive season. *J Sports Med Phys Fitness* 2010;50:475-85.
- 54 Sein ML, Walton J, Linklater J, et al. Shoulder pain in elite swimmers: primarily due to swim-volume-induced supraspinatus tendinopathy. *Br J Sports Med* 2010;44:105-13.
- 55 Vleck VE, Bentley DJ, Millet GP, et al. Triathlon event distance specialization: training and injury effects. *J Strength Cond Res* 2010;24:30-36.
- 56 Jayanthi NA, O'Boyle J, Durazo-Arvizu RA. Risk factors for medical withdrawals in United States tennis association junior national tennis tournaments: a descriptive epidemiologic study. *Sports Health* 2009;1:231-35.
- 57 Orchard JW, James T, Portus M, et al. Fast bowlers in cricket demonstrate up to 3- to 4-week delay between high workloads and increased risk of injury. *Am J Sports Med* 2009;37:1186-92.
- 58 Piggott B, Newton MJ, McGuigan MR. The relationship between training load and incidence of injury and illness over a pre-season at an Australian Football League club. *J Aust Strength Cond* 2009;17:4-17.
- 59 Steffen K, Pensgaard AM, Bahr R. Self-reported psychological characteristics as risk factors for injuries in female youth football. *Scand J Med Sci Sports* 2009;19:442-51.
- 60 Viljoen W, Saunders CJ, Hechter GH, et al. Training volume and injury incidence in a professional rugby union team. *SA J Sports Med* 2009;21:97-101.
- 61 Brooks JH, Fuller CW, Kemp SP, et al. An assessment of training volume in professional rugby union and its impact on the incidence, severity, and nature of match and training injuries. *J Sports Sci* 2008;26:863-73.
- 62 Knobloch K, Yoon U, Vogt PM. Acute and overuse injuries correlated to hours of training in master running athletes. *Foot Ankle Int* 2008;29:671-76.

- 63 Van Middelkoop M, Kolkman J, Van Ochten J, et al. Risk factors for lower extremity injuries among male marathon runners. *Scand J Med Sci Sports* 2008;18:691-97.
- 64 Gabbett TJ, Domrow N. Relationships between training load, injury, and fitness in sub-elite collision sport athletes. *J Sports Sci* 2007;25:1507-19.
- 65 Kelsey JL, Bachrach LK, Procter-Gray E, et al. Risk factors for stress fracture among young female cross-country runners. *Med Sci Sports Exerc* 2007;39:1457-63.
- 66 Lovell G, Galloway H, Hopkins W, et al. Osteitis pubis and assessment of bone marrow edema at the pubic symphysis with MRI in an elite junior male soccer squad. *Clin J Sport Med* 2006;16:117-22.
- 67 McKean KA, Manson NA, Stanish WD. Musculoskeletal injury in the masters runners. *Clin J Sport Med* 2006;16:149-54.
- 68 Olsen SJ, Fleisig GS, Dun S, et al. Risk factors for shoulder and elbow injuries in adolescent baseball pitchers. *Am J Sports Med* 2006;34:905-12.
- 69 Rauh MJ, Koepsell TD, Rivara FP, et al. Epidemiology of musculoskeletal injuries among high school cross-country runners. *Am J Epidemiol* 2006;163:151-59.
- 70 Schueller-Weidekamm C, Schueller G, Uffmann M, et al. Incidence of chronic knee lesions in long-distance runners based on training level: findings at MRI. *Eur J Radiol* 2006;58:286-93.
- 71 Dennis RJ, Finch CF, Farhart PJ. Is bowling workload a risk factor for injury to Australian junior cricket fast bowlers? *Br J Sports Med* 2005;39:843-46.
- 72 Rogers TJ, Landers DM. Mediating effects of peripheral vision in the life event stress/athletic injury relationship. *J Sport Exerc Psychol* 2005;27:271-88.
- 73 Gabbett TJ. Reductions in pre-season training loads reduce training injury rates in rugby league players. *Br J Sports Med* 2004;38:743-49.
- 74 Gabbett TJ. Influence of training and match intensity on injuries in rugby league. *J Sports Sci* 2004;22:409-17.
- 75 Shaw T, Howat P, Trainor M, et al. Training patterns and sports injuries in triathletes. *J Sci Med Sport* 2004;7:446-50.
- 76 Anderson L, Triplett-McBride T, Foster C, et al. Impact of training patterns on incidence of illness and injury during a women's collegiate basketball season. *J Strength Cond Res* 2003;17:734-38.
- 77 Burns J, Keenan AM, Redmond AC. Factors associated with triathlon-related overuse injuries. *J Orthop Sports Phys Ther* 2003;33:177-84.

- 78 Dennis R, Farhart P, Goumas C, et al. Bowling workload and the risk of injury in elite cricket fast bowlers. *J Sci Med Sport* 2003;6:359-67.
- 79 Egermann M, Brocai D, Lill CA, et al. Analysis of injuries in long-distance triathletes. *Int J Sports Med* 2003;24:271-76.
- 80 Taunton JE, Ryan MB, Clement DB, et al. A prospective study of running injuries: the Vancouver Sun Run "In Training" clinics. *Br J Sports Med* 2003;37:239-44.
- 81 Hootman JM, Macera CA, Ainsworth BE, et al. Predictors of lower extremity injury among recreationally active adults. *Clin J Sport Med* 2002;12:99-106.
- 82 Lyman S, Fleisig GS, Andrews JR, et al. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am J Sports Med* 2002;30:463-68.
- 83 Lee AJ, Garraway WM, Arneil DW. Influence of preseason training, fitness, and existing injury on subsequent rugby injury. *Br J Sports Med* 2001;35:412-17.
- 84 Lyman S, Fleisig GS, Waterbor JW, et al. Longitudinal study of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc* 2001;33:1803-10.
- 85 Duffey MJ, Martin DF, Cannon DW, et al. Etiologic factors associated with anterior knee pain in distance runners. *Med Sci Sports Exerc* 2000;32:1825-32.
- 86 Fawkner HJ, McMurray NE, Summers JJ. Athletic injury and minor life events: a prospective study. *J Sci Med Sport* 1999;2:117-24.
- 87 McCrory JL, Martin DF, Lowery RB, et al. Etiologic factors associated with Achilles tendinitis in runners. *Med Sci Sports Exerc* 1999;31:1374-81.
- 88 Satterthwaite P, Norton R, Larmer P, et al. Risk factors for injuries and other health problems sustained in a marathon. *Br J Sports Med* 1999;33:22-26.
- 89 Vleck VE, Garbutt G. Injury and training characteristics of male elite, development squad, and club triathletes. *Int J Sports Med* 1998;19:38-42.
- 90 Bennell KL, Crossley K. Musculoskeletal injuries in track and field: incidence, distribution and risk factors. *Aust J Sci Med Sport* 1996;28:69-75.
- 91 Koplan JP, Rothenberg RB, Jones EL. The natural history of exercise: a 10-yr follow-up of a cohort of runners. *Med Sci Sports Exerc* 1995;27:1180-84.
- 92 Messier SP, Edwards DG, Martin DF, et al. Etiology of iliotibial band friction syndrome in distance runners. *Med Sci Sports Exerc* 1995;27:951-60.
- 93 D'Souza D. Track and field athletics injuries--a one-year survey. *Br J Sports Med* 1994;28:197-202.

- 94 Korkia PK, Tunstall-Pedoe DS, Maffulli N. An epidemiological investigation of training and injury patterns in British triathletes. *Br J Sports Med* 1994;28:191-96.
- 95 Haglund-Åkerlind Y, Eriksson E. Range of motion, muscle torque and training habits in runners with and without Achilles tendon problems. *Knee Surg Sports Traumatol Arthrosc* 1993;1:195-99.
- 96 Bovens AM, Janssen GM, Vermeer HG, et al. Occurrence of running injuries in adults following a supervised training program. *Int J Sports Med* 1989;10 Suppl 3:S186-S190.
- 97 Collins K, Wagner M, Peterson K, et al. Overuse injuries in triathletes. A study of the 1986 Seafair Triathlon. *Am J Sports Med* 1989;17:675-80.
- 98 Macera CA, Pate RR, Powell KE, et al. Predicting lower-extremity injuries among habitual runners. *Arch Intern Med* 1989;149:2565-68.
- 99 Marti B, Knobloch M, Tschopp A, et al. Is excessive running predictive of degenerative hip disease? Controlled study of former elite athletes. *BMJ* 1989;299:91-93.
- 100 Walter SD, Hart LE, McIntosh JM, et al. The Ontario cohort study of running-related injuries. *Arch Intern Med* 1989;149:2561-64.
- 101 Marti B, Vader JP, Minder CE, et al. On the epidemiology of running injuries. The 1984 Bern Grand-Prix study. *Am J Sports Med* 1988;16:285-94.
- 102 Lysholm J, Wiklander J. Injuries in runners. *Am J Sports Med* 1987;15:168-71.
- 103 Jacobs SJ, Berson BL. Injuries to runners: a study of entrants to a 10,000 meter race. *Am J Sports Med* 1986;14:151-55.
- 104 Koplan JP, Powell KE, Sikes RK, et al. An epidemiologic study of the benefits and risks of running. *JAMA* 1982;248:3118-21.