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

Torbjørn Soligard,[1] Martin Schwellnus,[2] Juan-Manuel Alonso,[3] Roald Bahr,[3,4,5] Ben Clarsen,[4,5] H Paul Dijkstra,[3] Tim Gabbett,[6,7] Michael Gleeson,[8] Martin Hägglund,[9] Mark R Hutchinson,[10] Christa Janse van Rensburg,[2] Karim M Khan,[11] Romain Meeusen,[12] John W Orchard,[13] Babette M Pluim,[14,15] Martin Raftery,[16] Richard Budgett,[1] Lars Engebretsen[1,4,17]

▸ Additional material is published online only. To view please visit the journal online (http://dx.doi.org/10.1136/bjsports-2016-096581).

For numbered affiliations see end of article.

Correspondence to
Dr Torbjørn Soligard, Medical and Scientific Department, International Olympic Committee, Château de Vidy, Lausanne 1007, Switzerland; torbjorn.soligard@olympic.org

Accepted 5 July 2016

To cite: Soligard T, Schwellnus M, Alonso J-M, *et al*. *Br J Sports Med* 2016;**50**:1030–1041.

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 (defined broadly to include 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 (1) prescription of training and competition load, as well as for (2) monitoring of training, competition and psychological load, athlete well-being 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-sport events packed into the calendar year.

Inherent to the growth of sport and more strenuous competition programmes, 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 use 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.

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 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]

We consider the relationship between load and health as a well-being 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 well-being along a continuum that progresses from homeostasis through the stages of acute fatigue, functional and non-functional over-reaching, 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 (eg, 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.

A key concept to appreciate for those responsible for managing load is 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 (eg, age, sex, sport,

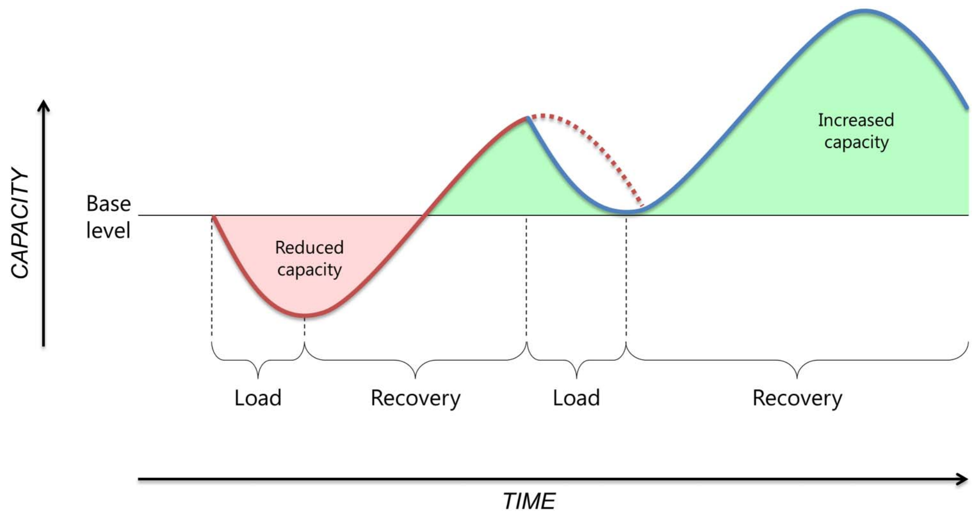

Figure 1 Biological adaptation through cycles of loading and recovery (adapted from Meeusen[6]).

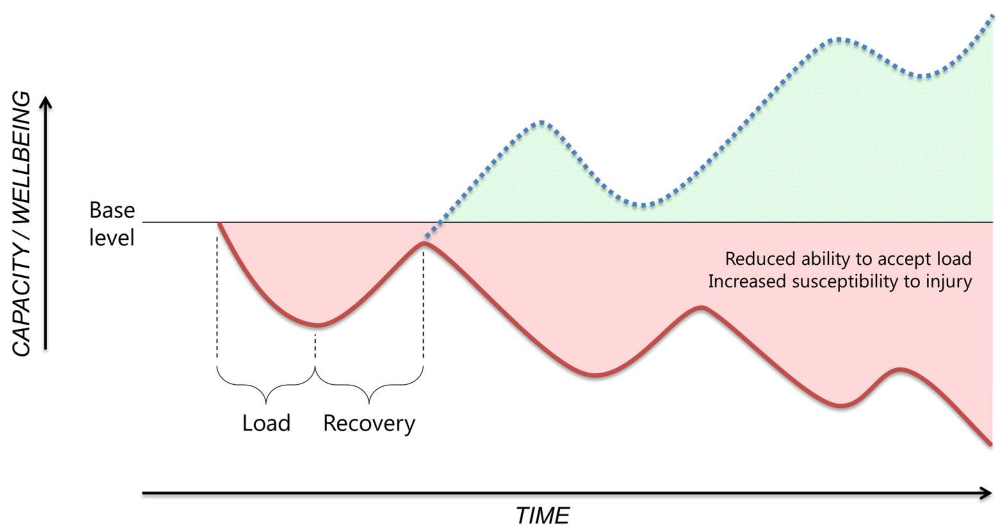

Figure 2 Biological maladaptation through cycles of excessive loading and/or inadequate recovery (adapted from Meeusen[6]).

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 programme. Ultimately, the time frame of recovery and adaptation—and hence susceptibility to injury—varies within and among athletes.

The International Olympic Committee convened a consensus meeting from 24 to 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 online supplementary appendix A.

Load: more than just workload alone

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 on 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 (ie, 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

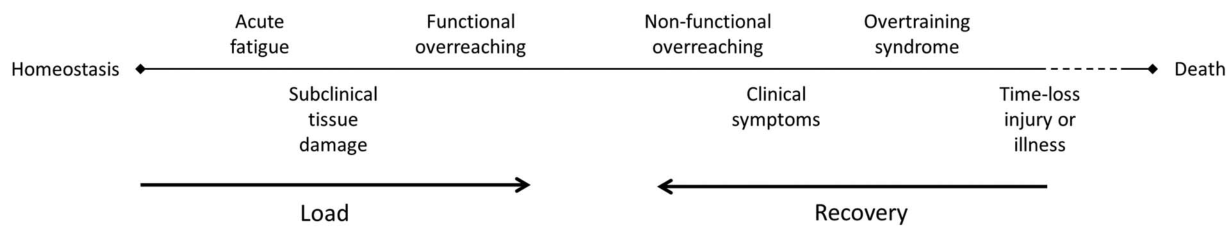

Figure 3 Well-being continuum (adapted from Fry *et al*[16]).

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 in the following section.

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 well-being, 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 programmes and competition calendars, and, importantly, ensuring therapeutic levels of load to minimise the risk of non-functional over-reaching (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 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

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 (eg, sessions or competitions per day, week, month)[37]
	Type of training or competition[38]
	Time-motion analysis (eg, global positioning system analysis)[39]
	Power output, speed, acceleration[40]
	Neuromuscular function (eg, jump test, isokinetic dynamometry and plyometric push-up)[41]
	Movement repetition counts (eg, pitches, throws, bowls, serves and jumps)[42 43]
	Distance (eg, kilometres run, cycled or swam)[44]
	Acute:chronic load ratio[45]
Internal load	Perception of effort (eg, rating of perceived exertion and RPE)[46]
	Session rating of perceived effort (eg, session duration (min)×RPE)[28]
	Psychological inventories (eg, 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] multicomponent training distress scale (MTDS),[51] the hassle and uplift scale,[52] brief COPE,[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 (eg, sleep quality and sleep duration)[61]
	Biochemical/hormonal/immunological assessments[18 26]
	Psychomotor speed[62]
	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]

HR, heart rate; RPE, ratings of perceived exertion.

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 well-being in response to load.[30] The following subscales may be particularly useful: non-sport stress, fatigue, physical recovery, general health/well-being, 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 programme. This may pose a considerable problem in the long term, as it may lead to maladaptation. This emphasises 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]

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 (eg, 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 injury and antecedent symptoms (eg, pain and soreness) and functional limitations has been developed. Studies using these tools demonstrate that the prevalence of injuries related to overuse (due to training and competition maladaptation) represents 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 3 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 (ie, including MEDLINE) and SPORTDiscus to identify studies for review, using combinations of the terms listed in table 2. 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 1 details the study inclusion criteria.

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 online supplementary appendix B.

Absolute load and injury risk

The majority of studies on the relationship between load and injury risk in sport have used various measurements of absolute load, that is, an athlete's external or internal load, irrespective of the rate of load application or load history (see online supplementary 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]

Table 2 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 1 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.

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 and 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 (figure 2).[158] This mechanism forms the basis of pathoaetiological 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 an increased risk of injury[98 116 132 134 152–156] may imply inability to cope with impending higher loads. Training and competition engender 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 (ie, 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 and 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 (eg, the training load of the last week) to the chronic load (eg, the 4-week rolling average of load). If chronic load has been progressively and systematically increased to high levels (ie, the athlete has developed fitness) and the acute load is low (ie, the athlete is experiencing minimal fatigue), then the athlete is considered well prepared. Conversely, if acute load exceeds the chronic load (ie, acute loads have been rapidly increased, resulting in fatigue, or training over the last 4 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 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 (<10%) when the acute:chronic load ratio is within the range of 0.8–1.3. However, when the acute:chronic load ratio exceeds 1.5 (ie, the load in the most recent week is 1.5 times greater than the average of the last 4 weeks), the likelihood of injury more than doubles (figure 4).[183 187]

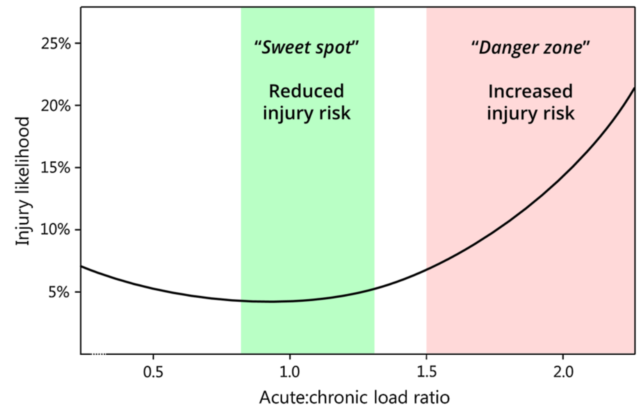

Figure 4 Acute:chronic load ratio (redrawn from Gabbett[45]).

Interestingly, there are reports of a latent period of increased injury risk following rapid increases in load. For example, Hulin *et al*[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 *et al*[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 the 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 (ie, 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 and one in elite rugby league) found no significant associations.[115 184 195 196] In cricket, Dennis *et al*[111] found that elite fast bowlers having <2 or ≥5 days of recovery days between bowling sessions, 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 *et al*[115] found a non-significant trend that elite bowlers who exceed 100 overs in 17 days are at an increased risk of injury.

Jayanthi *et al*[190] investigated the medical withdrawal rates in US 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 *et al*[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 *et al*[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 *et al*[191] observed higher muscle injury rates during matches in congested periods, whereas Carling *et al*[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 downregulation 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 (eg, feeling of insufficient breaks and rest, stiff and tense muscles, and 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-min session with an RPE of 8 and a 120-min session with an RPE of 2 will 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[90 106 131 132 134 139 140 144 145 148 151 156] 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 global positioning system/microtechnology 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 allows for composite measures incorporating 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 (eg, pitching >100 innings per year)[110] or throws (eg, completing >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 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 the 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 (multicentre) 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, the 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 *et al*[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 a 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 <10%, or maintain an acute:chronic load ratio within a range of 0.8–1.3, to stay in positive adaptation and thus reduce the risk of injuries.
- In football, playing two matches (ie, ≤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 inter- and intra-individual variation in the time frame 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-sport and multisport 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 scientific 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/well-being and being in shape are responsive to 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 (eg, non-sport loads), biochemical, immunological, environmental and genetic factors, as well as age and sex.
- Special consideration should be given to the monitoring of acute and chronic loads, and the acute:chronic load ratio of the individual athlete.
- Monitoring should be performed frequently (eg, 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 (eg, hassle and uplift scale,[52] or life events survey for collegiate athletes[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 symptoms or functional limitations, particularly at the elite level, highlights 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 (eg, at least 4 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 programmes 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 the number of recovery days) and season duration.
- Conducting further studies on the impact of the acute: chronic load ratio (ie, 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 using experimental research designs, such as randomised controlled trials, to evaluate the effect of load monitoring interventions (eg, confining the acute:chronic load ratio between 0.8 and 1.3) compared with a control group (eg, 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. As with all research, there is a need to look to innovative policies and tools[223] to promote knowledge translation.

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 inter- and intra-individual variation in the time frame 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.

Author affiliations
[1]Medical and Scientific Department, International Olympic Committee, Lausanne, Switzerland
[2]Section Sports Medicine, Faculty of Health Sciences, Institute for Sport, Exercise Medicine and Lifestyle Research, University of Pretoria, Hatfield,Pretoria, South Africa
[3]Sports Medicine Department, Aspetar, Qatar Orthopedic and Sports Medicine Hospital, Doha, Qatar
[4]Oslo Sports Trauma Research Center, Department of Sports Medicine, Norwegian School of Sport Sciences, Oslo, Norway
[5]Olympic Training Center (Olympiatoppen), Oslo, Norway
[6]School of Exercise Science, Australian Catholic University, Brisbane, Queensland, Australia
[7]School of Human Movement Studies, University of Queensland, Brisbane, Australia
[8]School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, UK
[9]Department of Medical and Health Sciences, Division of Physiotherapy, Linköping University, Linköping, Sweden
[10]Department of Orthopaedic Surgery and Sports Medicine, University of Illinois at Chicago, Chicago, Illinois, USA
[11]Department of Family Practice, Centre for Hip Health and Mobility, University of British Columbia, Vancouver, Canada
[12]Human Physiology Research Group, Vrije Universiteit Brussel, Brussels, Belgium
[13]School of Public Health, University of Sydney, Sydney, Australia
[14]Medical Department, Royal Dutch Lawn Tennis Association, Amersfoort, The Netherlands
[15]Amsterdam Collaboration on Health and Safety in Sports, IOC Research Centre for Prevention of Injury and Protection of Athlete Health, VUmc/AMC, Amsterdam, The Netherlands
[16]World Rugby, Dublin, Ireland
[17]Faculty of Medicine, University of Oslo, Oslo, Norway

Twitter Follow Torbjørn Soligard @TSoligard, Juan Manuel Alonso @DrJuanMAlonso, Ben Clarsen @benclarsen, Hendrik Dijkstra @DrPaulDijkstra, Roald Bahr @RoaldBahr, Tim Gabbett @TimGabbett, Martin Hägglund @MHgglund, Christa Janse van Rensburg @ChristaJVR, Karim M Khan @BJSM_BMJ, Romain Meeusen @RomainMeeusen, John W Orchard @DrJohnOrchard, Babette M Pluim @docpluim, Lars Engebretsen @larsengebretsen

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

Contributors 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.

Funding International Olympic Committee.

Competing interests TS works as Scientific Manager in the Medical and Scientific Department of the International Olympic Committee. KMK is the Editor-in-Chief of the *British Journal of Sports Medicine*. JWO is Chief Medical Officer for Cricket Australia and was the Chief Medical Officer of the International Cricket Council Cricket World Cup 2015. BMP is Chief Medical Officer of the Royal Dutch Lawn Tennis Association and member of the International Tennis Federation (ITF) Sport Science and Medicine Commission. She is Editor of the *British Journal of Sports Medicine*. LE is the Head of Scientific Activities in the Medical and Scientific Department of the International Olympic Committee, and Editor of the *British Journal of Sports Medicine* and *Journal of Bone and Joint Surgery*.

Provenance and peer review Not commissioned; externally peer reviewed.

REFERENCES

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 edn. Philadelphia: Lippincott Williams and Wilkins, 2000:67–96.
5 Brooks GA, Fahey TD, Baldwin KM. *Exercise physiology: human bioenergetics and its applications*. 4th edn. 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;48:1352–7.
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;49:603–8.
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 edn. 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;46:861–83.
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 load in sport and risk of illness: how much is too much? *Br J Sports Med* 2016;50:1030–41.
20 Budgett R. Overtraining syndrome. *Br J Sports Med* 1990;24:231–6.
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. http://www.oxforddictionaries.com/definition/english/load (accessed 24 May 2016).
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;23:33–8.
26 Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med* 2014;44(Suppl 2):S139–47.
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;30:1164–8.
29 Pyne DB, Martin DT. Fatigue-insights from individual and team sports. In: Marino FE, ed. *Regulation of fatigue in exercise*. New York: Nova Science, 2011: 177–85.
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* 2016;50:281–91.
31 Hooper SL, Mackinnon LT. Monitoring overtraining in athletes. Recommendations. *Sports Med* 1995;20:321–7.
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;9:751–6.
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;38:1752–8.
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;30:463–8.
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;48:1322–6.
44 Macera CA. Lower extremity injuries in runners. Advances in prediction. *Sports Med* 1992;13:50–7.
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. *J Appl Sport Psychol* 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 multicomponent assessment model for monitoring training distress among athletes. *Eur J Sport Sci* 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, Luschene R, *et al*. *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 Res* 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):S13–23.
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;40:201–8.
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;5:170–6.
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;47:782–8.
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, Benjamen 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;49:441–7.
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;39:340–6.
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, ed. *Sport participation: health benefits, injuries and psychological effects*. Hauppauge, NY: Nova Science Publishers, 2011:85–104.
81 Bahr R, Alfredson H, Järvinen M, *et al*. Types and causes of injuries. In: Bahr R, ed. *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 Koplan 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;14:151–5.
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):S186–90.
91 Macera CA, Pate RR, Powell KE, *et al*. Predicting lower-extremity injuries among habitual runners. *Arch Intern Med* 1989;149:2565–8.
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;299:91–3.
93 Walter SD, Hart LE, McIntosh JM, *et al*. The Ontario cohort study of running-related injuries. *Arch Intern Med* 1989;149:2561–4.
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;1:195–9.
95 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;27:1180–4.
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;33:22–6.
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;29:671–6.
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;18:691–7.

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 Wijer A, van Cingel R, *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;39:253–7.
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;39:843–6.
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;45:805–8.
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;49:1064–8.
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 orienteerers: a 26-week prospective registration study. *J Athl Train* 2016;51:321–8.
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;38:743–9.
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;14:204–9.
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;11:350–5.
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;24:271–6.
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;24:30–6.
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;16:255–8.
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;28:191–6.
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;163:151–9.
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.
148 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.
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;49:1472–7.
150 Duhig S, Shield AJ, Opar D, *et al*. The effect of high-speed running on hamstring strain injury risk. *Br J Sports Med* 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.
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;19:24–8.
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;436:100–10.
158 Magnusson SP, Langberg H, Kjaer M. The pathogenesis of tendinopathy: balancing the response to loading. *Nat Rev Rheumatol* 2010;6:262–8.
159 Bennell KL, Malcolm SA, Wark JD, *et al*. Models for the pathogenesis of stress fractures in athletes. *Br J Sports Med* 1996;30:200–4.
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;22:2202–8.
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, Townshend AD, *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:10.1111/sms.12719
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;17:734–8.
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*. Published Online First: 22 July 2016 doi:10.1136/bjsports-2015-095820
182 Ehrmann FE, Duncan CS, Sindhusake D, *et al*. GPS and injury prevention in professional soccer. *J Strength Cond Res* 2016;30:360–7.
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;50:231–6.
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;50:1008–12.
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? Published Online First: 13 Apr 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;50:444–5.
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;50:471–5.
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, Beynnon 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;1:231–5.
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;47:743–7.
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;50:764–8.
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;49:390–4.
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;31:271–6.
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 edn. 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 Fawkner HJ, McMurrary 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;33:2140–8.
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 Lavallee L, Flint F. The relationship of stress, competitive anxiety, mood state, and social support to athletic injury. *J Athl Train* 1996;31:296–9.
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;47:561–7.
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. *Eur J Sport Sci* 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/ijspp.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;48:287–8.
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.
223 Soligard T, Schwellnus M, Alonso JM, *et al*. Infographic. International Olympic Committee consensus statement on load in sport and risk of injury: how much is too much? *Br J Sports Med* 2016;50:1042.