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

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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 (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 multisport 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,

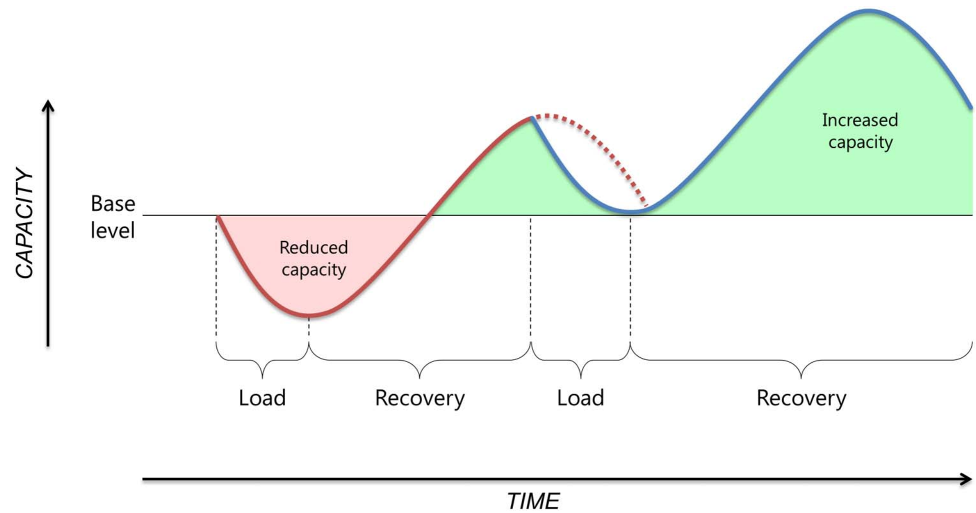

Figure 1 Biological adaptation through cycles of loading and recovery (adapted from Meeusen[6]).

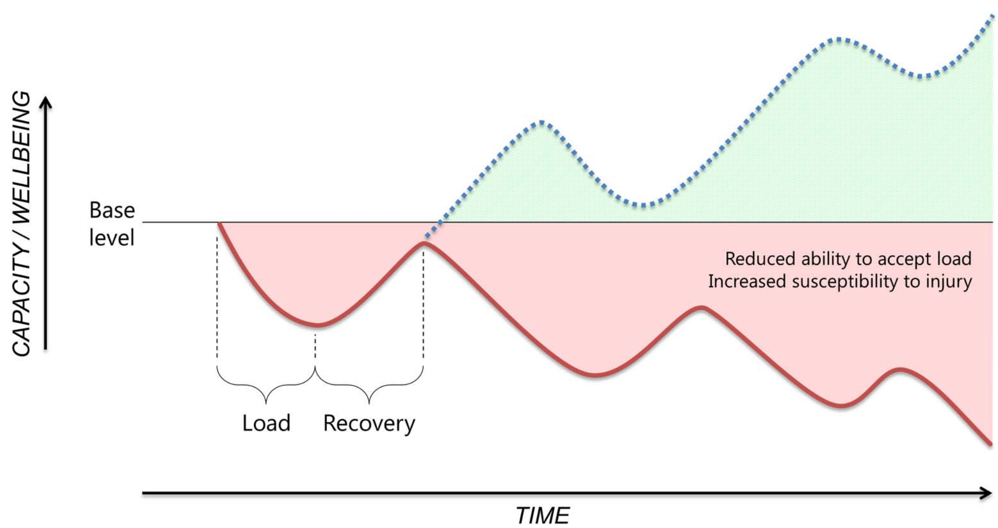

Figure 2 Biological maladaptation through cycles of excessive loading and/or inadequate recovery (adapted from Meeusen[6]).

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

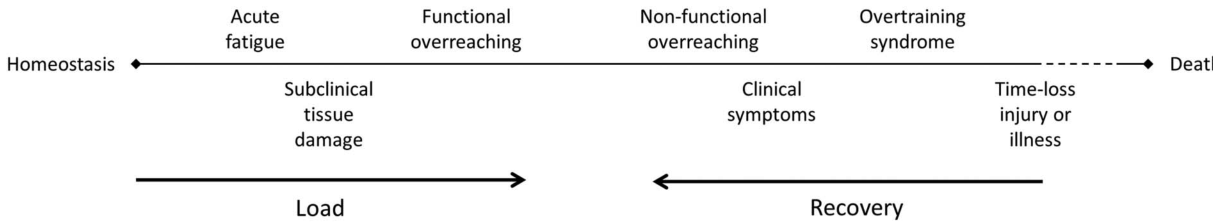

Figure 3 Well-being continuum (adapted from Fry *et al*[16]).

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

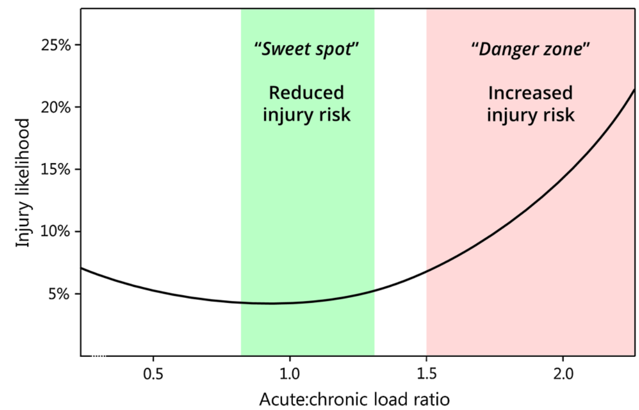

Figure 4 Acute:chronic load ratio (redrawn from Gabbett[45]).

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]

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.

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