6 Recovery-stress balance and injury risk in team sports

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Introduction

Sport participation involves a considerable risk of injury for both recreational and elite athletes (Fuller et al., 2012). Even in a small country like the Netherlands with approximately 17 million inhabitants, every year 1.4 million people receive medical attention because of an athletic injury (Schmikli et al., 2009). Of these injuries, 59% occur in organised sport settings. Especially team sports have a relatively high injury risk. Soccer, field hockey, and volleyball together are responsible for 41% of all injuries (Schmikli et al., 2009). These injuries can be divided into traumatic and overuse injuries. Traumatic injuries are characterised by a sudden event, while overuse injuries develop over time and result from repeated micro trauma.

The consequences of these injuries are not only physical (e.g., tissue damage) (Dvorak & Junge, 2000), but also psychosocial (e.g., anxiety for re-injury) (Larson et al., 1996). In professional football, it has been found that due to these consequences, players are unable to compete for about 12% of the time per season (Ekstrand et al., 2011). As a result, coaches cannot play in optimal team formation. This unavailability of players hinders performance and can lead to serious financial losses, which are caused by reduced commercial income and medical care (Woods et al., 2002). Therefore, there is a need for injury prevention that targets evidence-based risk factors. This is especially relevant in team sports, because of the high injury incidence.

Risk factors

Risk factors are commonly divided into extrinsic and intrinsic risk factors. Extrinsic risk factors include factors such as weather, field conditions, rules, and equipment (Meeuwisse et al., 2007). Intrinsic risk factors, on the other side, are internal to the athlete and include factors like age, coordination


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of movements, flexibility, and risk-taking behaviour (Van der Sluis et al., 2017). Together, extrinsic and intrinsic risk factors may predispose an athlete to injury. However, risk factors alone are usually not sufficient to cause an injury. It depends on the inciting event during which the injury occurs (Meeuwisse et al., 2007). Screening of these factors before the start of the season could indicate the individual risk profile (Dallinga et al., 2012). However, some risk factors are unstable and vary from day to day or from week to week. For example, training load and the following recovery are highly variable. In addition, psychological and social factors add weight to this delicate balance. Pressure from parents or coaches, conflicts with fellow players, or stress due to relationship problems at home, at school, or in the workplace can place an additional load on the players. These psychosocial factors also show high variability (Brink et al., 2010). In order to identify starting points for the development of prevention strategies, this chapter provides an overview of theoretical models and future research while taking recovery into consideration.

Theoretical models on training load, stress, recovery, and injuries

In order to understand the role of stress and recovery in relation to injuries, several theoretical models have been developed. These models focus on training load or psychosocial stress and recovery, or the combination of these. Depending on the underlying mechanism, these models try to explain overuse injuries or traumatic injuries.

The model of Cook and Purdam (2009) focuses on the role of training load (type, frequency, volume, intensity) and the association with tendon structure and overuse. This continuum model of tendon pathology assumes that the amount of load is critical and determines if the structure of the tendon improves or worsens. An adequate amount of load results in an increased net collagen synthesis, causing positive adaptations of structural and mechanical properties of the tendon tissue (Cook & Purdam, 2009; Kjaer et al., 2006; Magnusson et al., 2010). Overload, on the other hand, can be defined as a mismatch between tendon load and the tendon’s load-bearing capacity. This mismatch can lead to changes in the tendon structure, resulting in reactive tendinopathy, tendon disrepair, and, finally, degenerative tendon abnormalities (Kjaer et al., 2006; Magnusson et al., 2010). Long-lasting overload can thus result in overuse injuries.

Andersen and Williams (1988) explained the underlying mechanism between psychosocial stress and the occurrence of traumatic injuries. They stated that when athletes experience stressful situations, psychosocial stress contributes to their stress response. Players may have greater or lesser capacity to deal with these stress factors. For example, having plenty of social support results in a bigger buffer to channel these stress factors. If players are unable to cope with stress, it leads to increases in muscle tension, reduced coordination, narrowing of the visual field, and an increase in distractibility. These changes make team
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Sport players more susceptible to traumatic injury since they may not see tackles in time or are unable to restore balance due to coordination deficits.

Finally, the model of Kenttä and Hassmén (1998) describes the athletic balance, which consists of both physical and psychosocial stress and recovery components. A disturbed balance between these factors contributes to the development of a general or local overload (overuse injuries). It is assumed that individuals have different capacities and thus respond in various ways to stress and recovery. This balance is especially delicate in younger players that deal with sudden increases in training load as part of youth academies (Figure 6.1). This takes place in a phase of physical and psychosocial maturation (Van der Sluis et al., 2014). Combining sport with school or work causes additional psychological stress. Finally, pressure from teammates, friends, and parents provides social stress. These physical and psychosocial stressors require adequate recovery.

The load-injury relationship

The load-injury relationship has become a popular topic in sport science (Drew & Finch, 2016; Jaspers et al., 2017; Windt & Gabbett, 2017). When quantifying training load, a distinction between external load and internal load is made (Impellizzeri et al., 2005). The external load is then defined as the load that is prescribed by the coach, such as the distance covered or the time spent in certain speed zones or number of accelerations. The internal load,
on the other hand, takes individual characteristics such as fitness into account and is the actual physiological stress placed on the human body. Heart rate and session-rating of perceived exertion (sRPE) are the most commonly used tools in sports practice. As a result of recent technological developments in tracking sensors, advanced monitoring systems are now accessible for sport practice and allow for quantification of training load on a daily basis. Combined with valid injury registration, the association between training load and injury occurrence can be assessed. Over the years, a number of studies assessed whether different load indicators (volume in minutes, distance covered, time spent in high-intensity speed zones, sRPE, and heart rate) increase the injury risk (Figure 6.2) (Drew & Finch, 2016). Since more data are collected and stored, several time-varying covariates are introduced. In addition to using the cumulative load of one week, research suggests that cumulative load up to four weeks should be calculated in relation to injury occurrence (Drew & Finch, 2016). On top of that, authors introduced outcome measures that compare short-term load (one week) relative to long-term load (four weeks). This so-called acute:chronic ratio assumes that a relative high acute training load compared to the previous four weeks results in increased injury risk (Windt & Gabbett, 2017). Although a link between training load and injury with time-varying covariates is theoretically and practically appealing, evidence appears to be inconsistent. Reasons for this could be that often linearity is assumed and statistical limitations of a ratio calculation exist (Kalkhoven et al., 2021). Finally, it is important to realise that based on the injury mechanism (traumatic or overuse), different load indicators and time varying covariates can be relevant and likely require separate analysis (Brink et al., 2010).

Recovery-injury relationship

In contrast to the load-injury relationship, less is known on recovery and its link with injury occurrence. In general, recovery occurs after training or matches and can be indicated by concentrations of biochemical markers (e.g., creatine kinase, cortisol, and testosterone), field performance tests, or self-report measures (Nédélec et al., 2012). If the outcome of these tests is restored to normal values at baseline, then it is assumed that, for example, muscle tissue damage is repaired or mental fatigue is resolved (Kucera et al., 2005; Price et al., 2004; Schwebel et al., 2007). After full recovery, the player will be able to reach or exceed benchmark levels (Kucera et al., 2005; Price et al., 2004; Van Mechelen et al., 1996). If this is not the case, the player is not fully recovered (Doeven et al., 2019). To prevent injuries, it is very important for players to recover properly between the different bouts of exercise. Furthermore, in order to plan subsequent training sessions or prepare for upcoming matches, knowledge is needed about the exact time courses of recovery (Bishop et al., 2008; Nédélec et al., 2012). This appears particularly relevant during dense in-season weeks with a high number of matches. Indeed, injury risk increases with two matches per week compared to one match (Dupont et al., 2010). Consequently, if the
number of rest days between matches is reduced, the injury risk increases. Time courses of recovery after matches in team sports indeed indicate that more than two days are needed for full recovery (Nédélec et al., 2012). This supports the need for empirical studies and monitoring tools that are able to detect subtle changes in both load and recovery that can be linked to injuries.

One could argue that recovery can also be distinguished in external and internal recovery (Figure 6.3). External recovery would then be the number of activities that an individual actively executes to promote recovery. An example of this is the Total Quality of Recovery (TQR) action, as proposed by Kenttä and Hassmén (1998). This tool enables players to count points for recovery-related activities such as nutrition, hydration, sleep, relaxation, emotional

Figure 6.2 Visualization of changes in training load, psychosocial stress, or recovery using different time-varying co-variates. A distinction between traumatic and overuse injuries is highlighted and individual threshold determined based on a meaningful deviation (Z-score, dotted line) from an individuals' mean (continuous line). AU: Arbitrary Units, SWC: Smallest Worthwhile Change.
support, and active rest. The internal recovery takes individual characteristics into account and indicates the effect of these activities on the human body. For example, the TQR perceived can be seen as a tool to monitor the internal recovery. It should be noted that recovery-related activities often take place outside the organised training setting. As a consequence, it is extremely difficult for coaches to evaluate individual differences in recovery strategies. Indeed, studies confirmed a mismatch between the perception of both load (Brink et al., 2014, 2017) and recovery (Doeven et al., 2017) between coaches and players after matches. Coaches tend to overestimate recovery and the discrepancy is larger two days after matches compared to one day. This indicates that the longer players are out of sight of coaches, the more difficult it is to estimate their recovery. These activities could be very relevant for injury research. Unfortunately, no studies are available that link different recovery indicators to injury occurrence. Nor are there studies that use time-varying covariates and link these to traumatic injuries, overuse injuries, or both.

**Psychosocial stress, recovery, and injury risk**

Based on the theoretical models, it is assumed that not only physical parameters in terms of load and recovery, but also psychosocial stress and recovery
increase injury risk. Traditionally, assessment of stress (such as a negative major life event) is solely executed at the start of the season (Junge, 2000). Retrospective stressors over, for example, the last year are investigated and association with future injuries is then determined via prospective injury registration. In addition, the risk assessment was expanded and also looked into the underlying mechanism, by studying the visual field of players (Williams & Andersen, 1997). Associations between stress levels and narrowing of the visual field appeared to be present. However, just like training load, stress and recovery are known to be unstable factors that vary during the course of a season. Therefore, several authors decided to implement regular assessments of psychosocial stress and recovery across a season, using the Recovery-Stress Questionnaire for Athletes (Kellmann & Kallus, 2001, 2016; Nederhof et al., 2008). High stress levels and poor recovery were present before and at the time of injury occurrence (Brink et al., 2010; Laux et al., 2015). More recently, Van der Does et al. (2017) studied individual change in stress and recovery six and three weeks before injuries. Both traumatic and overuse injuries were included and analysed separately. Reduction in general recovery, such as social recovery and general well-being, was related to a higher risk of traumatic injuries. Relevant changes were seen six weeks before injury occurrence. For overuse, reduced sport-specific recovery was related three weeks before injury occurrence. These findings support the need for using a holistic approach in which physical load and recovery as well as psychosocial stress and recovery should be monitored closely over time to unravel the complex mechanisms that lead to traumatic or overuse injuries.

**Future research**

Future research should focus first on the development of theoretical models that include training load, and psychosocial stress and recovery factors, and then describe the underlying mechanism for both traumatic and overuse injuries. Well-designed empirical studies should follow thereafter, particularly in the area of recovery in relation to injury. This requires reliable and valid tools to quantify both external and internal recovery outside the training context, preferably on a 24/7 basis. Once these tools are available, research should link different recovery indicators with time-varying covariates using a dynamic, non-linear, and personalised approach (Hill et al., 2018; Van Geert, 2014). After identification of sensitive indicators, a holistic view should be adopted to assess the combination of physical and psychosocial risk factors. It should be considered that physical and psychosocial stress and recovery interact and that these interrelations are relevant to determine injury risk. Different causal pathways need to be considered for traumatic injuries and overuse injuries (Kalkhoven et al., 2021).

The integration of stress and recovery parameters could be an alternative for multifactorial analyses; for example, by taking recovery before training into account when interpreting sRPE afterwards. The assumption is that if two players perceive training as equally intense, the actual load of a player with perfect recovery before training is higher, compared to a player with poor
recovery. Maximal actual load of training is when a player reports perfect recovery before training and maximal perceived exertion after training. Although it is probably a utopia to expect that one single number could capture all relevant elements, this approach may simplify analyses and interpretation. This is especially important with dynamic longitudinal data sets where large amounts of information are stored on a daily basis. This requires analyses of time series at the individual level with advanced modelling techniques such as automated data analysis (Bartlett et al., 2017; Shyr & Spisic, 2014). Finally, evidence-based feedback needs to be developed and presented in an individual player’s dashboard. Effectiveness of these feedback interventions must be assessed to provide support for use of these monitoring systems in reducing injuries.

**Conclusion and recommendations for practice**

Careful and systematic monitoring of the recovery-stress balance has the potential to reduce injury risk. Monitoring systems should include physical load of training and recovery afterwards, as well as psychosocial stress and recovery items. At the elite level, recent technological development allows for advanced tracking of players, but the link of these load indicators with injuries has not been established so far. Simple solutions such as sRPE appear to be relevant at all playing levels and can be used across different time frames from one week up to four weeks. Potential associations should not be interpreted as ability to predict, but they need to be considered in the context of the training programme, taking individual differences into account. Training load monitoring needs to be extended with recovery indicators to evaluate the contribution of recovery to the recovery-stress balance. Finally, to assess changes in psychosocial stress and recovery, regular assessment across a season is required to be able to warn players at risk and adopt intervention strategies if needed. It should be noted that indicators and time-varying covariates that derive from injury research are not necessary the same as indicators that relate to enhanced performance. Monitoring systems are likely to have separate and shared indicators that link to performance and injuries.

In conclusion, injuries frequently occur in team sports and can have serious physical, psychosocial, and financial consequences. This supports the need for prevention strategies. It is known that the cause of injuries is multifactorial and consists of external and internal risk factors. Stress and recovery are relevant risk factors and can be both physical and psychosocial. Since stress and recovery continuously change over time, methodological designs are needed that allow to assess variation across the season. Over the last years, technological developments have led to daily monitoring of training load in professional sports. Research into the load-injury relation provided insight in the sensitivity of these load indicators as well as the application of different time-varying covariates. However, evidence appears inconsistent, and future studies require better methodological and statistical approaches (Dalen-Lorentsen et al., 2021). Furthermore, there is a need for new load indicators that take individual variation
into account. Besides, the role of recovery in relation to injuries needs to be included in well-designed studies. For a complete understanding, the role of psychosocial stress and recovery needs to be assessed so that relevant indicators can be added to the monitoring system. Whether the use of structured feedback and prevention strategies based on these models will result in more resilient athletes and a reduction of injuries is yet to be determined.

References


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