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Review Article

Monitoring External and Internal Training Loads: Relationships with Injury Risk in Professional Soccer: A Review

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Abstract

This review examined the methods used to monitor external and internal training loads in elite-level soccer and their relationships with injury risk. Due to the significant financial and performance burden of injury incidence in professional soccer, recent research has focused its attention upon understanding the relationship between training load and injury risk. Training load is multifaceted, therefore in order to facilitate our understanding of it, load is commonly broken down into two sub-categories, the external and internal training load. Monitoring external training loads provides practitioners with an objective comprehension of a player's physical capabilities and their outputs in response to prescribed training load, irrespective of their physiological response. The quantification of physical outputs has simplified in recent years due to the advancement in load monitoring technologies and has therefore provided more insight into the relationship between movement patterns and muscular injuries. Monitoring the internal training load provides practitioners with an understanding of a player's physiological and psychological response to a physical stimulus. Monitoring methods such as HR monitoring, subjective questionnaires and biochemical analysis allow practitioners to measure levels of determinants of injury risk such as stress, fatigue and muscular damage that can predispose players to greater risk of injury. Although studies have examined the plausibility of integrating internal and external training loads in relation to fitness outputs in professional soccer, future research should explore its relationship with injury risk, as it may provide greater scientific insight into injury aetiology in elite-level men's and women's soccer.

Keywords: *Training Load; Injury; Soccer; Performance; Monitoring*

Introduction

As the demand for instant success and reward in professional soccer increases year upon year, greater importance is being placed upon ensuring players are suitably prepared for the high physical demands of training and match-play. This has led to an increased popularity in methods used to monitor players' quotidian training activities. Although monitoring training load has seen a significant rise in prominence in recent years, there is still much debate as to how to optimally quantify an athlete's training output to maximise performance, decrease fatigue and consequently reduce the risk of injury. Due to the significant physiological and performance differences across a team, and between male and female soccer players, ensuring each player receives the optimal training load to maximise performance has become a crucial part of the monitoring process [1-3]. Soccer is a team sport, therefore entirely individualising the training process is an unrealistic approach. However, slight adaptations to an individual's training load and recovery processes may help to reduce fatigue, over/undertraining and consequently reduce injury risk [4].

Halson [5] argues that the process of training load monitoring "has become a modern, scientific approach to understanding athletes training responses and competition readiness". With the significant inundation of modern load monitoring technologies in team sports in recent years, the process of measuring players' physical outputs has decidedly simplified. Nevertheless, in order to gain a thorough understanding of the significance of the data, practitioners need an understanding of the relationship between the external outputs and its physiological impact [2,5]. Research [2,4] suggests that training load can be broken down into two key elements, the internal training load and the external training load, with the relationship between the two considered to be symbiotic in nature. Every physical action has a physiological and/or psychological response, therefore in order to entirely comprehend the load an individual is being exposed to, it is crucial to monitor both the external and internal response to prescribed training. Significant research [2-4] has examined the quantification methods used to measure both the internal and external loads in professional male and female soccer players, however there has been little research [6,7] which has explored amalgamating these two key elements, and more specifically its relationship with injury risk.

Although there has been an amelioration in the methods used to monitor training load in professional soccer in recent years, there is still a significant amount of injuries that occur at the elite-levels of competition. Ekstrand., *et al*'s [8] study found that, on average, an elite-level soccer team of roughly 25 players "can expect about 15 muscle injuries each season with approximately two weeks missed for each injury". Admittedly injuries are a significant hindrance on a team's training and match availability, however it is the financial burden of injuries that can be the most severe. Woods., *et al*'s [9] study found that the financial cost of injuries in the 1999 - 2000 season across the English men's professional soccer pyramid, was an "estimated 118 million euros". The financial burden of injuries at both club and national level has been well documented historically in professional male and female soccer [9-11] however the impact of injuries on performance has only recently come to light in research. Research [8,12] has shown that injuries can have a significant negative impact upon a team's performance. Hägglund., *et al*'s [8] study found that teams with high seasonal injury rates performed significantly worse than those with reduced injury rates, across Europe's top divisions. As a result of the significant burden of injuries on a team's success and finances, there is increased pressure to adequately prepare players for the high demands of match-play in professional soccer.

This article will review the literature surrounding the processes of monitoring training load in professional soccer, discussing in detail the research surrounding the quantification of both internal and external loads in professional soccer and their relationships with injury risk. This will be followed by an evaluation of the integration of internal and external training loads in team sports and discussing if integrating the two lends itself to a better understanding of load and injury risk in professional soccer.

Monitoring training load in professional soccer

In order to determine whether players are successfully amassing the necessary physical stimuli that is required for physiological adaptation, monitoring training load has become a vital cog in the training analysis process [3]. Monitoring training load provides practitioners with an understanding of how players are adapting to the demands of training and match-play and provides insight into players who may be over or under reaching [1,3]. By breaking down the training load into the internal and external load (as highlighted in figure 1 below), practitioners are able to measure the physiological stress the players are exposed to by the prescribed training [13]. The process of monitoring the external and internal load has become significantly more accessible in recent years due to the vast improvements in monitoring technologies. Global positioning systems (GPS), time-motion analysis and Heart Rate (HR) monitoring software are now all commonplace in elite-level soccer, and they provide great insight into the external and internal responses to training load.

The next section of this study will examine the ways in which training load is quantified in professional soccer. Firstly, the literature surrounding the process of quantifying the external load will be examined, analysing the varied methods discussed in research, and their relationships with injury risk. Secondly, the process of quantifying an athlete's internal response to training load will be cross-examined, evaluating the methods discussed in research and their relationship to injury risk. Finally, the research examining the amalgamation of external and internal loads will be discussed, evaluating the combination's potential relationship with determining injury risk in professional soccer.

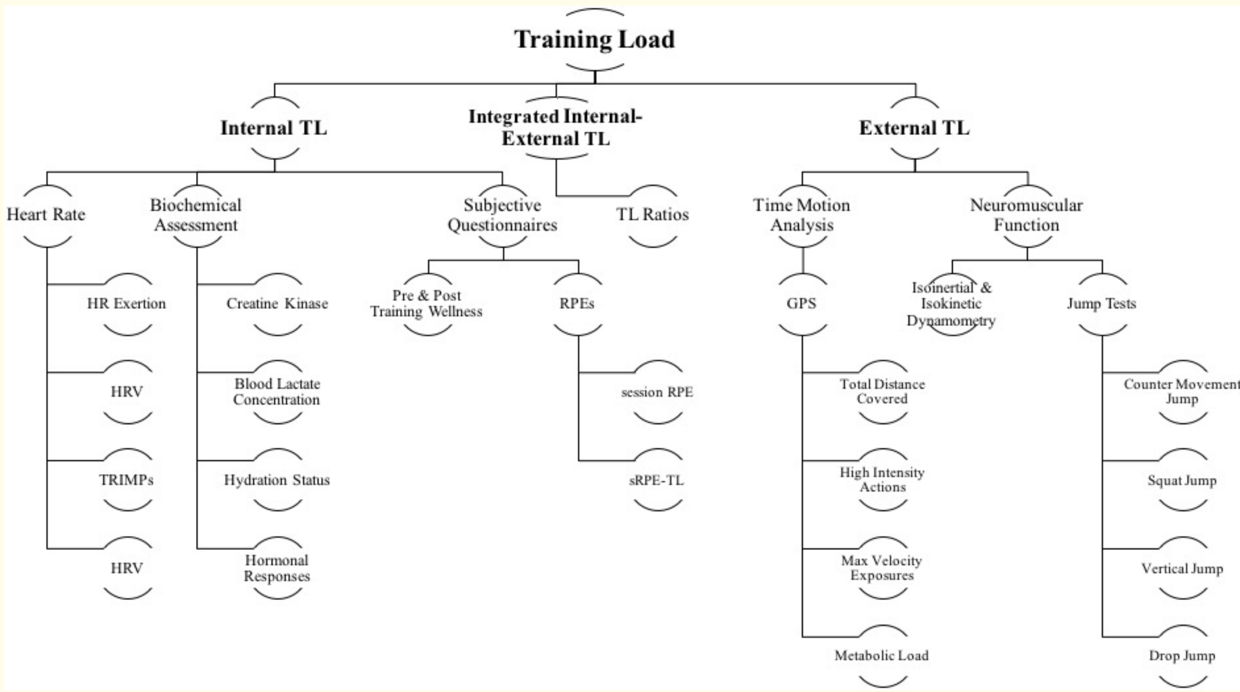

Figure 1

Quantifying the external training load and relationships with injury risk

The external load refers to "the work completed by an athlete, measured independently of his or her internal characteristics" [14]. Although quantifying the internal load presents practitioners with an indication of how an athlete is adapting to the physiological stress of a prescribed physical stimulus, the external load enables practitioners to establish whether specific performance outcomes are being completed by each individual [5,14]. Additionally, the external load helps to determine the physical capacity and capabilities of each athlete, a process which has been facilitated in recent years as a result of the introduction monitoring technologies such as global positioning systems (GPS) and time-motion analysis software. GPS is considered to be the most reliable and accurate method of quantifying external load outputs, such as distances covered at different speeds, in soccer [15] and has consequently become essential for practitioners in elite-level soccer. Castellano., *et al.* [16] argue that by having an understanding of the demands of soccer-specific movements, through the use of GPS technology, adaptations can be more successfully performed and result in improved performance. Until recently GPS use in competitive games was prohibited, therefore there has been a lack of research that has assessed a more holistic view of training load, with training and competition data incorporated collectively. Owen., *et al.*'s [17] novel research analysing the differences in load across a typical microcycle in professional soccer, relative to individual maximum match outputs, provided insight into how match data can be used to tailor loads within the training week. To be able to effectively monitor a player's training load it is therefore essential that training and match-play data is analysed holistically.

As a result of recent advances in GPS technology and regulations, practitioners are able to better determine the demands of competitive match-play. Consequently, periodisation strategies are increasingly being adapted, with the aim of improving the training process, and to better prepare the players for the physiological demands of match-play. Research [18] suggests that altering the number of players, and pitch sizes, allows practitioners to gain different physiological and technical outputs from their drills. Owen., *et al.*'s [18] research examined the differences in GPS markers of volume and intensity across various-sided games in elite-level soccer. The research indicated that the physiological demands of Small-Sided Games (SSGs), Medium-Sided Games (MSGs) and Large-Sided Games (LSGs) differed significantly when pitch sizes and player numbers were altered [18,19]. This research would suggest that, alongside weekly load monitoring, GPS analysis of the within-session demands of specific drills allows practitioners to gain a greater understanding of the both the volume and intensity demands placed upon players in specific training situations. Analysing a session as a whole does not provide an indication of the intensity players are exposed to in specific training situations, therefore analysing the GPS outputs of particular drills can provide practitioners with comparative intra-squad data on physiological markers such as fitness, exertion and fatigue [19]. Owen., *et al.* [20] revealed correlations between intensity and injury risk in soccer match-play, through heart rate (HR) intensity banding. Therefore, it may be suggested that by individualising the drill analysis process, practitioners are able to better understand the intra-squad differences in intensity of effort, and consequently provide a superior insight into players' potentially at a greater risk of injury than others.

Over the past few years, there has been a significant advancement in the digestible GPS metrics at the disposal of practitioners at elite-level soccer. As a result of the multitude of different GPS metrics currently at hand, Fernandez., *et al.* [21] discussed the concept of separating the metrics into different physiological categories, "locomotor, metabolic and mechanical". Fernandez., *et al.* [21] argue that by categorising the GPS metrics, practitioners are better able to select the metrics that provide the most insight into players' physical outputs, in order to allow for better training and recovery adaptations. Research [22,23] has examined the impact of specific GPS metrics, such as total distance covered, high intensity running and metabolic load, on physical performance and match outcomes, however little research, until recently, has analysed their impact upon injury risk. The primary reason being due to the inability to successfully quantify match data in the training load monitoring process.

Recent research [24-26] has observed that there may be links between certain external load outputs and heightened injury risks. Malone., *et al.*'s [26] research into Gaelic football, revealed there to be a strong correlation between near maximum velocity exposures and injury risk. Malone., *et al.*'s [26] study determined that a low number (< 6), and a high number (> 10), of near maximum velocity (> 95%) exposures per week resulted in a significantly greater risk of injury than players who hit a moderate number of exposures per week (6-10). Research [26-28] seems to suggest that there is a correlation between high speed outputs and injury risk in team sports. Furthermore, a recent study by Duhig., *et al.* [28] using Australian Rules Footballers, uncovered there to be a relationship between heightened injury risk and high weekly levels of High Speed Running (distance covered greater than 19.8km/h). Concurring with these findings, Small., *et al.*'s [29] study found similar results within soccer, highlighting relationships between fatigued, overloaded hamstrings, and hamstring strain injuries when sprinting within a soccer match-play. On the other hand, Buchheit., *et al*. [30] argue that by quantifying high speed running in isolation, practitioners are unable to gain a true understanding of the load that is being placed upon players during training and competitive match-play. Buchheit., *et al.* [30] argue that by monitoring a player's metabolic load distance or power, practitioners are able to better comprehend the true energy cost of training and match-play, as it takes into account low speed actions such as accelerations and decelerations, that also impose a great demand on soccer players.

The significant aerobic demands placed on elite-level soccer players is well-documented, however Lehance., *et al.* [31] argue that "the most decisive actions are made by means of anaerobic metabolism". The ability to perform anaerobic power activities, such as repeated sprints, jumping actions and rapid changes of directions, is of great importance in elite-level soccer due to the high intensity nature of the modern game. Nevertheless, these high intensity actions have a significant neuromuscular impact, and can frequently result in injury incidence in both soccer training and match-play [31]. Due to the increased availability of advanced monitoring technologies, practitioners are more readily able to objectively measure players' neuromuscular functions, from both a physical capacity and injury risk perspective. Halson [5] argues that the most common methods used to monitor neuromuscular function include "the jump test (CMJ/squat jump), sprint performance and isokinetic and isoinertial dynamometry". Research [31-33] suggests that there is a significant relationship between strength and speed, and injury risk in elite-level team sports. Malone., *et al.*'s [33] research noted that strong, powerful and fast athletes were more able to tolerate 'spikes' in training load than slower and less strong players. Testing measures of neuromuscular function such as jump height, peak force/power and sprint performance, allows practitioners to gain an understanding of players' levels of strength, power and speed, and in turn, provides an insight into players' potentially at risk of injury. Jump tests such as the Counter Movement Jump (CMJ) are simplistic, in-expensive and effective methods of monitoring neuromuscular function, lower body strength, sprint performance, adaptations to training load, and subsequently levels of injury risk.

As a result of the recent literature in this area [25,26,28], it would seem that through the monitoring of external GPS and time-motion analysis outputs, practitioners are able to gain a valid physiological understanding of a player's capabilities and it provides significant insight into potential injury risk. Additionally, the research indicates that by effectively monitoring a player's external physical outputs, it is possible to both maximise performance and reduce the risk of non-contact, overuse type injuries in elite-level soccer.

Quantifying the internal training load and relationships with injury risk

Impellizzeri., *et al.* [13] argue that in order to effectively adapt and monitor the training process, it is necessary to determine the external outputs, but also be aware of the internal physiological response the outputs are having upon the individual. Halson [5] argues that the internal load refers to "the relative physiological and psychological stress imposed" on the athlete as a result of the external load prescribed. This would suggest that there is a cause and effect relationship between the external and internal load, and it is therefore necessary to monitor the internal load, to further understand how players are adapting to the prescribed stimulus [34]. Although there are only a few ways of measuring the external load, there are a multitude of different methods of quantifying a player internal response to load, both objectively and subjectively.

One of the most common measures of internal load in professional soccer is monitoring Heart Rate (HR) response. Monitoring HR is common place across all sporting disciplines, and provides one of the most reliable internal indicators of exercise intensity and fatigue [5,35]. Due to the linearity of the relationship between HR and the rate at which oxygen is consumed during steady paced exercise, monitoring HR provides a good indication of aerobic capacity, and consequently fitness levels [5]. This relationship has led practitioners to utilise HR monitoring to quantify physical performance and capacity in high intensity interval, soccer specific, drills, such as small sided games (SSGs) [15,20,35,36]. Owen., *et al.* [20] suggest that although high intensity intermittent style drills, such as SSGs, have many fitness benefits, they also impose an increased level of internal physiological stress, "with heart rates of > 85% often being elicited". This would suggest that in order to reduce the risk of injury and to increase the fitness benefits of various-sided games, a combination of monitoring HR response and GPS metrics would provide greater insight into the extent of the external (GPS) and internal (HR) demands of these high intensity intermittent drills.

Although monitoring HR is more frequently used to evaluate exercise intensity, more recently practitioners are monitoring HR in order to determine how players are adapting to the prescribed training. Methods include Heart Rate Recovery (HRR) and Heart Rate Variability (HRV) to name a few. HRR assesses the level at which an athlete's HR declines, minutes post-exercise [37], while HRV is calculated, at a resting state, to assess "cardiac autonomic modulation" [38], consequently determining an internal response to training load. Research [39] suggests that, generally, higher HRV values signify greater levels of fitness, while Buchheit., *et al.* [40] argue that reductions in HRV and/or HRR indices can typically indicate that players are in a state of "detraining, chronic fatigue, non-functional overreaching or overtraining". This would suggest that methods such as HRR and HRV can help provide practitioners to determine players' fitness and fatigue states, and consequently provide insight into potential injury risk.

An alternative method that is commonly used to monitor training load in team sports is the Training Impulse (TRIMP). The TRIMP "is calculated using training duration and maximal, resting, and average HR during the exercise session" [5]. The initial TRIMP model was proposed by Banister and Calvert [41], however more variations on the method have come to light in recent years, with the latest research assessing the impact of an individualised TRIMP (iTRIMP) in team sports, such as soccer. Akubat., *et al.* [42] argue that individualising the internal training impulse provides practitioners with a greater understanding of changes in fitness in youth elite-level soccer players, than previous TRIMP variations, highlighting the importance of individualising the internal load monitoring process. Although there has been significant research [41-43] into the effects of the Training Impulse, and its many variations, on aerobic fitness in elite-level team sports, there has been little research examining its impact on injury risk.

While measures such as HR monitoring provide practitioners with an objective quantification of exercise intensity, research [5,35,44] suggests that psychological, subjective measures of quantifying intensity are of equal validity. Malone., *et al.*'s [45] study uncovered there to be a relationship between reductions in perceived wellbeing and reduced physical performance in training. Research [45] suggests that through the use of subjective wellness questionnaires, practitioners are able to gain an insight into a player's readiness to train and compete. The impact of perceived well-being and effort on physical performance has been well report [44-46] however minimal research to date has explored its impact on injury risk.

One of the most commonly used methods of measuring the perceived impact of training is the Rating of Perceived Exerting (RPE) scale. Little., *et al.* [44] argue that using RPE is an inexpensive and simple method of quantifying training intensity, and there are strong correlations between RPE and objective measures of exercise intensity, such as aerobic capacity and HR. Although RPE is deemed fairly simplistic and unable to provide as much detail as objective markers [5], it is argued that it is a valid and reliable method of monitoring the internal load, as a result of its evident correlation with HR and aerobic capacity [4,5,44]. Although there are clear correlations between perception of effort and both HR and aerobic capacity, Djaoui., *et al.* [47] argue that perception of effort scales, such as RPEs, should only be used to quantify the effort of a task and not as a measure of fatigue. On the other hand, Smith., *et al.* [48] argue that mental fatigue increases the rating of perceived effort of a task. Consequently, further research is needed in order to uncover the precise relationship between mental fatigue and perception of exertion scales such as RPEs. Alexiou., *et al.* [49] found similar results in female soccer players, uncovering significant correlations between session Rating of Perceived Exertion (sRPE) and methods of quantifying training load, supporting the findings from previous research in elite-level men's soccer.

The Rating of Perceived Exertion-Training Load (RPE-TL) calculation, a derivation of the combination of sRPE and total session duration, is a commonly used, and in-expensive, method of quantifying both the external and internal training load in elite-level soccer [4,50]. Casamichana., *et al.*'s [4] research uncovered there to be a strong association between total distance covered (TDC) and RPE-TL values in soccer players. This would indicate that the use of subjective questionnaires, such as sRPEs, can provide practitioners with an inexpensive and reliable method of monitoring both internal and external training load in elite-level male and female soccer players.

Biochemical assessment

Utilising inexpensive measures of monitoring the internal training load, such as HR monitors and questionnaires, have become the norm in team sports such as soccer, however with the additional investment in load monitoring techniques in recent years, practitioners are now able to utilise further advances in technology to monitor biochemical responses to exercise. One of the predominant reported biochemical measures monitored in professional soccer in recent times is Creatine Kinase (CK). CK is "an intracellular protein commonly associated with muscle damage" [51]. Russell., *et al.*'s [51] study found that levels of CK were at their highest 24 hours after a soccer game, and these levels remained 48 hours post-game. This would suggest that levels of muscle damage were at their highest between 24 and 48 hours post-match-play, indicating that players are not fully recovered until more than 48 hours after a game. Measures such as CK differ depending on the individual, and therefore can provide insight into an individual's recovery process, and consequently when the player is at greatest risk of incurring an injury [51,52]. Thorpe and Sunderland's [53] study found there to be a significant correlation between the number of sprints and distances covered at high intensity during competitive soccer match-play and muscle damage. This would argue that players who perform a greater number of sprints and high intensity distance in competitive match-play acquire a greater concentration of CK, and consequently require more time to recover [53]. Research [53] would suggest that there is value in quantifying high intensity actions to aid the recovery, fatigue and injury risk assessment processes.

Increasing interest in research [46,54,55] is being placed upon the analysis of hormonal responses to training load in elite-level soccer. Measuring hormonal status can be performed through the analysis of both saliva and blood samples and is commonly used to evaluate responses to exercise and stress [46]. Peñailillo., *et al.* [55] argue that practitioners are able to gain an insight into the internal physiological stress being placed upon soccer players through measuring the status of endocrine markers, such as testosterone and cortisol. Slimani., *et al*. [46] argue that levels of testosterone and cortisol fluctuate significantly depending on exposure to certain physiological and psychological stressors. Thorpe and Sunderland's [53] study found that that testosterone and cortisol levels increased post, in comparison to pre, competitive match-play in semi pro soccer players, arguing that this may be due to factors such as "hemoconcentration, a decrease in metabolic clearance rate, and an increase in secretion". On the other hand, Thorpe and Sunderland's [53] research also uncovered that while testosterone increases significantly post-match, cortisol increased, but not significantly, due to the large variability between individual players tested.

Research [46,64] found there to be limited differences between gender when hormonal response was measured post competitive soccer match-play. Zouhal., *et al.* [56] found that gender hormonal responses to stress differed mainly pre-activity, with a greater hormonal concentration in men at rest than women, while men's psychological stress was also greater than women's before being exposed to a particular stressor. Zouhal., *et al.* [56] also argue that there were "differences in body composition (e.g. higher fat mass in women) and/or in sexual hormonal status". The findings in research would therefore suggest that there is value in monitoring hormonal status in both male and female soccer players, as it provides a significant indicator of internal psycho-physiological responses to exercise stimuli and the intra-individual differences in recovery and fatigue status.

Although there is evidence to suggest that there is a value in analysing hormonal responses to training load, recent research [46,53] argues that it also has several potential limitations. Slimani., *et al.* [46] argue that fluctuations in cortisol and testosterone in soccer players may be as a result of several environmental and social factors, as supposed to the effects of the exercise stimulus. Research [46,54] suggests that factors such as the time of day competitive matches are played at, the programming of the training microcycle, the time the samples were collected, as well as the circadian rhythm effect, all had an impact on fluctuations in cortisol and testosterone. This would that suggest that although monitoring the levels of endocrine markers such as cortisol and testosterone, provides practitioners with an insight into how players are adapting and recovery from the prescribed training and match-play, more research is needed to uncover the true effects of the psycho-physiological responses of both training and match-play [46].

Quantifying the physiological response to training load through the analysis of blood lactate concentration is an additional monitoring method used in elite-level soccer. Djaoui., *et al.* [57] argue that analysing blood lactate concentration, via lactate thresholds, enables practitioners to gain an understanding of an individual's aerobic capacity. Consequently, analysis of blood lactate concentration allows for a more scientific-based evaluation of a player's readiness to perform, and can subsequently help to determine intra-squad variability in aerobic capacity and fitness. Typically, male and female soccer players cover approximately 9 - 12 km in competitive match play [58], "at an average intensity of around 75% of their maximal oxygen uptake" [47]. This would suggest that there is a link between physical performance in competitive match-play and levels of aerobic capacity in elite-level soccer. McMillan., *et al.* [59] argue that the greater a player's aerobic capacity, and consequently lactate threshold, the longer a player is able to maintain a high level of intensity during competitive match-play without accumulating lactate. Research [60] suggests that having a high aerobic capacity can act as a protective barrier against injury incidence in team sports, therefore blood lactate analysis can also provide an indication of players' potentially at risk of injury. In conclusion, analysing blood lactate concentration allows practitioners to gain an understanding of a player's ability to perform consistently at a high intensity, their level of injury risk, and subsequently evaluate the impact of the prescribed training load.

Blood lactate analysis is a useful method of indicating lactate threshold, aerobic capacity and adaptations to training load, however research [5,61] argues that an accumulation of lactate can be also be as a result of several other internal, external, modifiable and non-modifiable factors, and not exclusively the training load they are being exposed to. Halson [5] suggests that these factors include "the ambient temperature, hydration status, diet, glycogen content, previous exercise, and amount of muscle mass utilised". Research [47,61] also argues that the process of its collection on a quotidian basis is highly inconvenient and invasive, and requires a certified member of staff to administer the process. As a result, practitioners tend to resort to using more simplistic, non-expensive and non-invasive methods of monitoring internal training load, such as sRPE and HR monitoring [5,47].

As a result of the highly intense nature of soccer training and match-play, players are regularly subjected to periods of hypo-hydration and significant fluid losses, particularly in warm environments. Phillips., *et al.* [62] argue that elite-level soccer players are commonly in a state of hypo-hydration prior to the beginning of training, and regularly do not intake the necessary fluid in order to offset the fluids lost through sweating. Although players are able to perform in a hypo-hydrated state, research [62-64] suggests that exercising in a de-hydrated state places players under significant physiological strain, and can consequently lead to a diminution in physical performance and heightened risk of injury. Practitioners commonly quantify hydration status through the analysis of pre-training values of urine specific gravity (USG). Analysing urine samples pre-training allows practitioners to implement hydration strategies to players that are dehydrated, and it prevents players from entering training in a severely hypo-hydrated state, which can consequently impair physical performance and increase the risk of injury incidence.

Research [5,35,44,51] would suggest that there is great value in monitoring the internal training load in professional soccer, and that an appreciation of the internal response to the external physical outputs will allow practitioners to gain a more comprehensive understanding of an individual's performance, physical capacity and injury risk.

Integrating the internal and external training loads and their relationship with injury risk

Multiple studies [4,5,21] have discussed the importance of monitoring external training loads in conjunction with internal training loads, to provide a more comprehensive appreciation of the load a player is exposed to, and the physiological and psychological adaptations that occur as a result. Nevertheless, until present there has been very limited research [6,7] that has discussed the idea of integrating the internal and external training loads to create a combined training load value. Akubat., *et al.* [6] discussed the concept of integrating external GPS metrics with an individualised Training Impulse (TRIMP) to create a Training Load (TL) ratio, with the aim of assessing its relationship to measures of fitness in soccer. Akubat., *et al.* [6] concluded that integrated TL ratios could be used to effectively assess levels of fitness in soccer players. Malone., *et al.*'s [7] study elaborated on the previous study and assessed the relationship between integrated TL ratios and aerobic fitness in Hurling. Malone., *et al.* [7] found similar results, and supported the use of integrated TL ratios in assessing fitness in team sports.

Although previous research [6,7] has explored the possibility of integrating internal and external loads in team sports with regards to fitness, no research to date has examined its potential relationship with injury. As research [7,26,28,40,51] would suggest, there seems to be clear correlations between both external and internal load measures and injury risk in professional soccer. This would suggest that there is therefore more scope to investigate whether an integrated approach may provide a better insight into potential injury risk than analysing internal or external load measures in isolation.

Conclusions

The findings from the current body of literature surrounding training load monitoring in professional soccer would suggest that there is great value in monitoring training load from both a performance and injury risk perspective. The literature would suggest that the internal and external training loads complement one another, and that an appreciation of a player's internal response to training load is necessary in order to make the training adaptations required to maximise physical performance and reduce the risk of injury. An amalgamation of the internal and external training loads in professional soccer has been discussed in previous research [6,7] and been validated as a method of monitoring training load, however no study to date has analysed this approach in relation to injury risk. Future research should further explore integrated external and internal training loads in relation to fitness in professional soccer, however more emphasis should be placed on investigating its relationship with injury risk. Injury incidence in elite-level professional soccer is a significant financial and performance burden, therefore more research is needed in order to better understand the aetiology of soccer-related injuries, and the impact that training load may have upon injury incidence in elite-level male and female soccer.

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None.

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