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SYSTEMATIC REVIEW

The Relationship Between Workloads, Physical Performance, Injury and Illness in Adolescent Male Football Players

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Abstract
Background The expectation that training enhances performance is well explored in professional sport. However, the additional challenges of physical and cognitive maturation may require careful consideration when determining workloads to enhance performance in adolescents.
Objective The objective of this study was to determine the state of knowledge on the relationship between workloads, physical performance, injury and/or illness in adolescent male football players.
Methods A systematic review of workloads, physical performance, injury and illness in male adolescent football players was conducted. Studies for this review were identified through a systematic search of six electronic databases (Academic Search Complete, CINAHL, PsycINFO, PubMed, SPORTDiscus, and Web of Science). For the purpose of this review, load was defined as the cumulative amount of stress placed on an individual from multiple training sessions and games over a period of time, expressed in terms of either the external workloads performed (e.g., resistance lifted, kilometres run) or the internal response (e.g., heart rate, rating of perceived exertion) to that workload.
Results A total of 2,081 studies were initially retrieved from the six databases, of which 892 were duplicates. After screening the titles, abstracts and full texts, we identified 23 articles meeting our criteria around adolescent football players, workloads, physical performance, injury and/or illness. Seventeen articles addressed the relationship between load and physical performance, four articles addressed the relationship between load and injury and two articles addressed both. A wide range of training modalities were employed to improve the physical performance of adolescent football players, with strength training, high-intensity interval training, dribbling and small-sided games training, and a combination of these modalities in addition to normal football training, resulting in improved performances on a wide range of physiological and skill assessments. Furthermore, there was some (limited) evidence that higher workloads may be associated with the development of better physical qualities, with one study demonstrating enhanced submaximal interval shuttle run performance with each additional hour of training or game play. Of the few studies examining negative consequences associated with workloads, increases in training load led to increases in injury rates, while longer training duration was associated with a greater incidence of illness.
Conclusion The combined capacity for adolescent males to grow, train and improve physical performance highlights and underscores an exciting responsiveness to training in the football environment. However, the capacity to train has some established barriers for adolescents experiencing high workloads, which could also result in negative consequences. Additional research on stage-appropriate training for adolescent male footballers is required in order to address the knowledge gaps and enhance safe and efficient training practices.

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1 Introduction

The training–performance relationship is of particular importance to coaches in determining the optimum amount of training required to attain peak performance [1, 2]. Bannister and colleagues [3–5] proposed a statistical model to describe an athlete's response to a given training stimulus. According to this model, the performance of an athlete in response to training can be estimated from the difference between a negative (fatigue) and a positive function (fitness). Studies have described the training–performance relationship as analogous with the dose–response relationship reported in pharmacological studies, with the primary goal of providing a training stimulus that maximizes performance potential and minimizes the negative consequences of training (i.e., injury, illness, fatigue, overtraining) [6]. Obtaining the ideal balance is a highly individual process that is heavily influenced by external and internal stressors independent of the workload itself. One such example is adolescence, during which young athletes undergo both rapid puberty-related physical and psychological growth. Despite this period being a critical time, not only for an individual's athletic career but also in shaping their future participation in sport and exercise, very little research has been conducted on the influence of athletic loads on performance and injury during adolescence.

Numerous studies have investigated the influence of training volume, intensity, and frequency on athletic performance in adult competitors, with performance generally improving as workload increases [2, 7]. Studies of the training–performance relationship in individual sports (e.g., swimming and running) have found a positive relationship between both greater training volume and performance [8], and higher training intensity and performance [9]. However, negative adaptations to exercise training are also reported to be dose-related, with the highest incidence of illness and injury occurring when workloads are highest [10–14]. While varying results have been observed among studies, psychological [15–17], biochemical [16, 17], physiological [18], neuromuscular [16, 19], and physical performance [16, 20] markers appear to be sensitive to changes in training and competition loads and for detecting overreaching in athletes.

Subsequently, negative adaptations to training have been demonstrated in team sport athletes. Specifically, relationships between training load and training injury rates have been reported in a variety of team sports [11, 21–23], suggesting that the harder these athletes train, the more injuries they will sustain. However, rugby league players who perform less than 18 weeks of pre-season training prior to sustaining an initial injury are at increased risk of sustaining a subsequent injury, while players with a low off-season maximal aerobic power ($\dot{V}O_{2max}$) are at increased risk of sustaining an injury [24]. Clearly, as with individual sports, training for team sports reflects a balance between the minimum workload required to elicit an improvement in fitness and the maximum workload tolerable before sustaining marked increases in injury rates.

The effects of football match-play on fatigue responses have also been investigated. Although the majority of research has focussed on the transient fatigue that occurs during football match-play [25–28] or match simulations [29, 30], relatively few studies have investigated the longer-term fatigue associated with competition [31–33]. Studies from senior rugby league competition have shown that players may experience neuromuscular and perceptual fatigue in the 24–48 hours after competition, with significant muscle damage lasting up to several days [33]. Similar findings have been shown in professional soccer [31]. Interestingly, in both soccer and rugby league, the magnitude of the fatigue response has been significantly associated with the number of game-specific actions completed by players [31, 33]. Despite the importance of fatigue and recovery on both playing performance and athlete well-being, the vast majority of studies investigating the effects of competition workloads on fatigue have been limited to senior professional competitors. Very few studies have assessed the effect of competition workloads on fatigue in adolescent football players, and studies of the effects of intensified competition (that commonly occur in adolescent competitors) are almost non-existent. Johnston et al. [34] measured countermovement jump performance (as an estimate of neuromuscular performance), creatine kinase (as an index of muscle damage), and perceptual fatigue in junior rugby league players (mean $\pm$ SE age 16.6 $\pm$ 0.2 years) competing in an intensified rugby league tournament (five games in 5 days). Over the first 3 days, there were progressive and large increases in neuromuscular fatigue and muscle damage, as well as reductions in perceived well-being. Match intensity, high-speed running, and frequency of repeated high-intensity effort bouts (all measured via global positioning system devices) decreased in the latter stages of the competition. The authors concluded that fatigue and muscle damage accumulate over an intensified competition, which is likely to contribute to reductions in high-intensity activity and work rates during match-play [34].

While the above studies advance our understanding of the association between workloads and injury in team sports, the majority of these studies were conducted on adult competitors. Although training may elicit positive training adaptations in adolescent athletes, it is also likely that due to variations in biological or psychological development, adolescent athletes may respond differently than adults to a given training stimulus, resulting in different fatigue, stress, injury, or illness responses. In adolescent athletes, undesirable training responses may impact on normal growth and maturation as well as development in sport [35]. Therefore, a major challenge for those working with young athletes is to determine the magnitude and nature of stressors necessary to induce positive responses and balance these stressors with adequate recovery to avoid maladaptations [36–38]. A variety of methods exist for determining load that include subjective and/or objective measures of volume and intensity. An understanding of the objective demands of competitive games have been recently described in adolescent rugby union [39–41], Australian rules football [42, 43] and soccer [44]; however, few studies have linked workload with on-field performance and negative outcomes in adolescents.

Coordinated by the neuroendocrine system, adolescence is a unique stage of growth and development in which accelerated physical, physiological, and psychological changes advance the process of maturation [45]. Rapid increases in height and mass, neuroendocrine function, and psychological development make adolescents well suited to the training and competitive demands of sport. By virtue of physical growth and maturation (e.g., lungs, heart, muscles), functional capacities, and consequently athletic performance, improve during adolescence [46]. The adolescent-related 'trigger hypothesis' suggests that a marked increase in trainability coincides with pubertal growth, particularly in males for whom hormonal changes become permissive of training adaptations [47] with muscle mass almost doubling between the ages of 10 and 14 years [48]. Despite limited data, endurance performances generally show improvements during the circumpubertal years in response to training [49]. Metabolic, haematological and hormonal adaptations to training result in improved efficiency in oxidative metabolism and support the notion that adolescents are well equipped to adapt to aerobic training [50], resulting in $\dot{V}O_{2\max}$ scores similar to adults in relative, but not absolute values. Absolute and relative anaerobic power increase during adolescence, particularly in boys whose anaerobic power is associated with similar improvements in muscle size and biochemical and neurological adaptations [51, 52]. Similarly, growth and development-related muscle morphological, neurological, and hormonal adaptations that occur during puberty result in increased strength [53]. Strength in adolescents may increase disproportionately to muscle hypertrophy as a result of more optimal muscle angle of pennation, improved motor unit recruitment, motor coordination, biochemical, and hormonal adaptations [54]. Although significant improvements in functional capacity can be achieved during puberty, the magnitude of anaerobic strength and power performances generally appears lower than in adults.

Performance-related benefits from growth and improved training ability can come at the expense of increased exposure to injury risk through greater frequencies and intensities of training loads among a more vulnerable age group. More specifically, growing tissues, accelerated growth and development, behavioural changes, and changes in participation patterns appear to be some of the major contributors to the increased injury risk during adolescence [55, 56]. In addition to the injury risks associated with contact team sports (e.g., the football codes), participation with intensive demands, including early specialization and inadequate recovery, increase players' risks of sustaining injuries. However, the dose-response relationship of workloads and injury is poorly understood. For example, injury incidence has been shown to quadruple in adolescents exposed to more than 3 hours of training, but more than 5 hours of training may have a protective effect [57]. The consequences of injuries among adolescent athletes could include longer-term deleterious outcomes such as complete cessation of participation in sport and physical activity, disruption to normal growth and development, physical disability or dysfunction, premature onset of degenerative diseases, lost opportunities to succeed in sporting pursuits, as well as possible negative psychological manifestations.

Successful performance in team sports requires a careful balance between training stimuli and recovery processes relative to an individual athlete's capacity to adapt [40]. In practice, determining an optimal balance is challenging in any sport and for any age group, but adolescent athletes are a particularly vulnerable population and provide unique challenges. Current adolescent training approaches and sporting pathways have an increased focus on attaining peak performance and identifying and developing talent. These approaches may have concomitantly increased the risk of young athletes not performing optimally.

The purpose of this paper was to perform a systematic review to determine the state of knowledge on the relationship between workloads, physical performance, injury and/or illness literature in adolescent male football players. The major football codes (American football, Australian rules football, Gaelic football, rugby league, rugby union and soccer) were chosen in order to minimize the variation in player attributes, performance characteristics, and injury types found across team sports, whilst at the same time maximizing the amount of research available for review. The football codes are also the most popular team sports, in terms of participation, for male children and adolescents across a number of countries and therefore have the greatest impact on this demographic. It was envisaged that such a review would provide coaches, sport scientists, and strength and conditioning staff with an unbiased perspective on the evidence relating to workloads, physical performance, injury, and illness in adolescent male football players.

2 Methods

2.1 Literature Search Strategy

Studies for this review were identified through a systematic search of six electronic databases. Academic Search Complete, CINAHL, PsycINFO, PubMed, SPORTDiscus, and Web of Science were searched, using combinations of the following groups of keywords: (i) 'training'; (ii) 'load', 'intens*', 'volume', 'duration', 'days', 'weeks'; (iii) 'rugby', 'soccer', 'football'; (iv) 'adolescen*', 'youth', 'young', 'junior', 'academy', 'teen', 'teenage', 'school'; (v) 'perform*', 'physical activity', 'sport performance', 'fitness'; (vi) 'injur*', 'accident', 'risk*', 'incident*', 'overreach*', 'burnout', 'staleness', 'recovery', 'stress'. Terms were connected with OR within each group. Two searches were conducted in each database by combining groups (i), (ii), (iii), and (iv), with either group (v) or (vi) using AND. The results from the two searches were then combined using OR. The search was restricted to articles published in English between 1980 and 2012.

2.2 Selection Criteria

The process used for selecting articles is outlined in Fig. 1. One of the authors initially scanned the titles and abstracts of the retrieved articles and excluded duplicates and those clearly outside of the scope of the study (e.g., professional or collegiate football players). For the purpose of this review, load was defined as the cumulative amount of stress placed on an individual from multiple training sessions and games over a period of time, expressed in either terms of the external workloads performed (e.g., resistance lifted, kilometres run) or the internal response (e.g., heart rate, rating of perceived exertion [RPE]) to that workload. The abstracts were then assessed by four authors and excluded if (i) the participants were not males aged between 12 and 18 years; (ii) the participants were not members of a football team (i.e., rugby union, rugby league, soccer, American football, Australian rules football, Gaelic football); (iii) the articles focused on injury prevention or treatment; (iv) the participants were disabled athletes; (v) the articles focused on traumatic or collision injuries; (vi) the articles investigated nutritional strategies; or (vii) the articles did not include measures of performance or load. Any disagreements were discussed and resolved. The complete manuscript of remaining studies were then retrieved and additional studies excluded by consensus, using the same criteria. The references of the selected articles were then

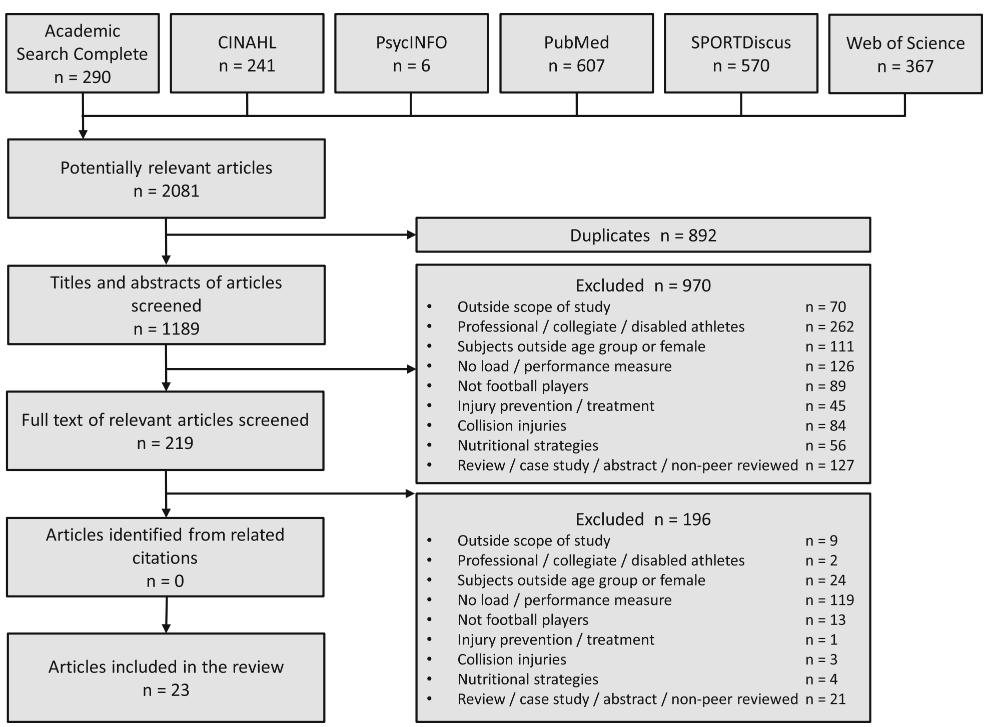

Fig. 1 Flowchart of the selection process for inclusion of articles in the systematic review

scanned to identify any potentially relevant articles not identified by the original search.

2.3 Article Scoring

The quality of the controlled trial studies included in the review was evaluated independently by two of the authors using the Physiotherapy Evidence Database (PEDro) scale [58]. All studies initially received a score out of ten based on meeting the following criteria: random allocation into treatment groups, allocation concealment, similar measures of key dependent variables at baseline, blinding of participants, blinding of coaches and trainers, blinding of investigators, obtaining key outcome measures in >85 % of participants, intention-to-treat analysis performed, between-group statistical analysis performed on at least one key outcome, and both point measures and measures of statistical variability reported. Any discrepancies in scores were resolved through discussion. Since blinding of participants and trainers/coaches is not possible when using exercise interventions, the highest possible score studies could attain in the present review was eight.

3 Results

A total of 2,081 studies were initially retrieved from the six databases, of which 892 were duplicates. After screening the titles, abstracts, and full texts, 23 articles met the criteria for inclusion in the review (Fig. 1). Seventeen articles [59–75] addressed the relationship between load and performance (Table 1), four articles [15, 40, 76, 77] addressed the relationship between load and injury (Table 2) and two articles [78, 79] addressed both. The mean reported age range of participants was 12.0–18.1 years in the load and performance articles and 15.8–16.9 years in the load and injury-related studies. Soccer was the most commonly studied sport ($n = 18$ articles) [15, 59–63, 65–76], followed by rugby league ($n = 3$ articles) [64, 78, 79], then Gaelic football ($n = 1$ article) [77] and rugby union ($n = 1$ article) [40].

PEDro scores were determined for the 15 studies that used either a quasi-experimental or experimental design [60, 62–66, 68, 69, 71–75, 78, 79]. The average PEDro score was 3.6 (range 2–5). All studies included between-group statistical comparisons and measures of variability and all but one [79] had similar baseline values between groups. However, it should be noted that this particular study examined the difference in performance changes in junior and senior rugby league players, making this criterion inappropriate. Only six of the studies [65, 66, 68, 69, 71, 74] indicated participants were randomly allocated to treatment groups.

4 Discussion

The aim of this review was to determine the state of knowledge on the relationship between workloads, physical performance, injury, and/or illness in adolescent male football players. From the studies reported in this review, it is clear that adolescent athletes have significant scope for improvements in physical performance using targeted training strategies; however, there is a pressing need for a better understanding of the workloads experienced by adolescents and how these may impact physical performance and injury in both the short and long term.

4.1 Workloads in Adolescent Athletes

The importance of documenting training and competition workloads of football players is well established in professional sport. However, few studies have described the training and competition demands of adolescents participating in popular football codes [39, 40, 42, 70]. Hartwig et al. [39] showed that junior rugby union players (aged 14–18 years) recorded up to 515 minutes per week of sport and physical activity, with individual players participating in as many as three competitive matches and eleven training sessions per week. Similarly, Jastrzebski et al. [70] reported a typical training week for 16-year-old soccer players involved ~400 minutes of physical activity divided between four training sessions and one match. Neither of these studies recorded the effect of workload on positive and negative outcomes.

4.2 Workload and Positive Outcomes

4.2.1 Physical Performance

The purpose of strength and conditioning, and indeed, the majority of training programs, is to improve physical performance. To date, a wide range of training modalities have been employed to improve the physical performance of adolescent football players. Strength training in isolation [62, 78], high-intensity interval training [73], dribbling and small-sided games training [67], and a combination of these modalities in addition to normal football training [60, 65, 71] have been used to improve physical performance. Furthermore, performance has been assessed using a variety of physical performance tests, including sprint [72], repeated-sprint [74], countermovement [65, 74], squat [72], and hopping [60] jump tests, agility [79], strength and power [63], submaximal and maximal aerobic qualities [61, 70], high-intensity intermittent running ability [60], cycling peak power [62], sport-specific skill assessments [69, 71], and physical match performance [68].

Table 1 Summary of results from studies investigating the link between training load and positive consequences (e.g. performance improvements) in adolescent football players

Study	Training status, age (mean ± SD), and number (*n*) of participants	Experimental design and training prescription	Findings	PEDro score
Brink et al. [59]	18 elite male soccer players (age 17.0 ± 0.5 years)	Prospective cohort. Training and competition loads recorded using session-RPE and total quality of recovery scores recorded over a competitive season. Submaximal interval shuttle run test completed each month	Each additional hour of training or game play resulted in enhanced field test performance. The duration of training and game play in the 2 weeks before field test performance was most strongly related to interval endurance capacity	Not determined
Buchheit et al. [60]	15 elite male soccer players (age 14.5 ± 0.1 years)	10 weeks of normal soccer training and addition of either (a) repeated sprint (2–3 sets of 5–6 × 15–20 m repeated sprints) or (b) explosive strength (4–6 series of 4–6 lower-body power exercises). Sprint, repeated-sprint, countermovement jump and hopping test performances measured pre- and post-training	10- and 30-m sprint performances improved to a similar extent (2.1 %) in both groups. Repeated-sprint training improved repeated-sprint performance (2.9 %); explosive strength training improved countermovement jump (14.8 %) and hopping test (27.5 %) performances	3
Chamari et al. [61]	18 elite male soccer players (age 14.0 ± 0.4 years)	Prospective cohort. 8 weeks of soccer-specific dribbling and small-sided (4 vs 4) games training, 2 sessions each week. Each session consisted of 4 × 4 min of activity (at an intensity of 90–95 % of HR_{max}) interspersed with 3 min of active recovery (at 60–70 % of HR_{max})	Significant improvements in $\dot{V}O_{2max}$ (7.5 %), running economy (14 %), and submaximal running heart rate (decreased by 9 beats/min). Distance covered in a soccer-specific dribbling test increased by 9.6 %	Not determined
Chelly et al. [62]	22 male soccer players. 11 players (age 17.0 ± 0.3 years) allocated to a resistance training group, while the remaining 11 players (age 17.0 ± 0.5 years) acted as controls	In addition to normal soccer training (4 sessions per week), 2 sessions of back half-squat strength training for 8 weeks at 70–90 % of 1RM	Resistance training improved cycling peak power, squat jump, and 5-jump test performances, and acceleration (5-m sprint) and maximum velocity (40-m sprint) qualities. Leg and thigh muscle volume and cross-sectional area were unchanged following training	4
Christou et al. [63]	18 male soccer players. 9 players (age 13.8 ± 0.4 years) allocated to a strength-soccer training group, while the remaining 9 players (age 13.5 ± 0.9 years) were allocated to a soccer training group. 8 males (age 13.3 ± 0.7 years) recruited as controls	Both groups performed 5 × 90-min soccer training sessions (incorporating technical and tactical skills and physical development), plus an official game each week. The strength-soccer training group performed an additional 2 whole-body resistance training sessions per week for 16 weeks at 55–80 % of 1RM	After 16 weeks of training, 1RM leg press, 10 × 5 m shuttle-run speed, and soccer technique were higher for the strength-soccer and soccer groups than for the control group. 1RM bench press and leg press, squat jump and countermovement jump, and 30-m speed were higher for the strength-soccer group than the soccer and control groups	4
Coutts et al. [64]	42 rugby league players (age 16.7 ± 1.1 years). 21 players (age 16.8 ± 1.0 years) underwent a supervised resistance training program, while the remaining 21 players (age 16.6 ± 1.2 years) underwent an identical program, in an unsupervised environment	Both groups performed 3 strength training sessions per week, corresponding to an intensity of 55–88.5 % of 1RM for 12 weeks. One group was supervised by an accredited strength and conditioning coach, while the other was not	12 weeks of resistance training increased body mass, strength, strength-endurance, lower-body power, and speed in both groups. The percentage change in 3RM bench press, squat, and maximum chin-up strength was greater in the supervised group than the unsupervised group	4

Table 1 continued

Study	Training status, age (mean ± SD), and number (*n*) of participants	Experimental design and training prescription	Findings	PEDro score
Gabbett [78]	45 rugby league players (age 17.9 ± 0.4 years) and 9 non-exercising controls (age 18.1 ± 0.5 years)	Prospective cohort. Training and competition loads recorded using session-RPE over a competitive season. Anthropometry, speed, muscular power, agility, and $\dot{V}O_{2max}$ measured in the off-season, pre-season, early-competition, and late-competition phases of the season	Increases in training loads in pre-season period lead to increases in $\dot{V}O_{2max}$ and muscular power and reductions in skin-fold thickness. Performance was maintained throughout the season despite reductions in training and match loads	3
Gabbett [79]	36 junior (age 16.9 ± 0.6 years) and 41 senior (age 25.5 ± 6.1 years) rugby league players	Prospective cohort. Both groups performed a 14-week field training program, consisting of 2 sessions per week	Improvements in agility, muscular power, and $\dot{V}O_{2max}$ were observed in both groups. Training loads were higher in the senior players, however the improvement in $\dot{V}O_{2max}$ and muscular power was greatest in junior players	2
Gorostiaga et al. [65]	19 regional soccer players (age 17.2 ± 0.6)	Prospective cohort. 11 weeks of usual soccer training and either (i) circuit training and stretching or (ii) explosive strength training	Explosive strength training increased performance in loaded counter-movement jump but did not improve 5- or 15-m sprint times	5
Hill-Haas et al. [66]	25 elite soccer players (age 14.6 ± 0.9 years). 14 players were allocated to a mixed generic training group, while 11 players were allocated to a small-sided games training group	7 weeks of training consisting of either (a) generic training (aerobic power, prolonged intermittent high-intensity running, speed, and repeated-sprint training) or (b) small-sided games training (ranging from 2 vs 2 to 7 vs 7)	Higher training loads in generic training group. Significant improvements in Yo-Yo intermittent running test performance, with no differences between groups. Speed, repeated-sprint ability, and $\dot{V}O_{2max}$ did not change in either group	4
Huijgen et al. [67]	267 soccer players (age range 13.5–14.5 years)	Longitudinal study assessing shuttle sprint and dribble, and slalom sprint and dribble performances. Pearson's correlation coefficients were used to assess the association between shuttle sprint and dribble, and slalom sprint and dribble performances and possible factors influencing technical performance (e.g., cumulative years of soccer experience, soccer practice per week, and additional practice per week)	The total hours of practice was significantly associated with dribbling performance; players who practiced for 10 h were predicted to improve their dribbling performance by 0.20 s a year	Not determined
Impellizzeri et al. [68]	29 soccer players (age 17.2 ± 0.8 years). 15 players were allocated to a generic training group, while 13 players were allocated to a small-sided games training group	12 weeks of training consisting of either (a) generic training (4 × 4 min at 90–95 % HR_{max}, interspersed with 3 min of active recovery at 60–70 % HR_{max}) or (b) small-sided games training (consisting of 3 vs 3, 4 vs 4, and 5 vs 5)	No difference between groups for weekly training load or total mood disturbance. Similar improvements in $\dot{V}O_{2max}$, lactate threshold, and soccer-specific endurance Ekblom's circuit)	4
Impellizzeri et al. [69]	21 soccer players (age 17.8 ± 0.6 years). 11 players were allocated to an interval training group, while 10 players acted as controls	4 weeks of interval training consisting of 4 × 4 min at 90–95 % HR_{max}, interspersed with 3 min of active (jogging) recovery. Yo-Yo intermittent recovery test performances and $\dot{V}O_{2max}$ measured pre- and post-training. Short-passing ability measured before and after a 5-min high-intensity simulation, reproducing the most intense phase of a match	Training improved Yo-Yo intermittent recovery test performances and $\dot{V}O_{2max}$ and reduced the decline in short-passing performances in response to a high-intensity simulation	4

Table 1 continued

Study	Training status, age (mean ± SD), and number (n) of participants	Experimental design and training prescription	Findings	PEDro score
Jastrzebski et al. [70]	19 young male soccer players (age 16.6 ± 0.3 years, >6 years training experience). Divided into first team (n = 10) players and substitutes (n = 9) based on total game time over the season (>70 %)	Training loads based on time spent in HR zones were monitored over a 40-week season. $\dot{V}O_{2max}$, Wingate test, sprint test and 150 m shuttle run performance measures completed pre- and post-season	Relative peak power and 150 m shuttle run improved over the season whereas 5 m sprint performance declined. First team players $\dot{V}O_{2max}$ increased midseason compared wih substitutes but there was no difference at the end of season	Not determined
Jelusic et al. [71]	20 male junior soccer players (age 16 years)	15 weeks of either (i) normal training or (ii) normal training supplemented by twice weekly kicking-specific strength training	Kicking-specific strength training increased ball velocity	4
Maio Alves et al. [72]	23 elite soccer players (age 17.4 ± 0.6 years). Players allocated into either (a) a complex and contrast group training 1 day per week (n = 9), (b) a complex and contrast group training 2 days per week (n = 8), or (c) a control group (n = 6)	Players completed a 6-week strength training program of complex and contrast training, performing either 1 or 2 training sessions per week. General exercises, multiform exercises, and specific exercises were performed	Training improved 5- and 15-m sprint times and squat jump performances in both training groups. Performance improvements were not influenced by the number of sessions performed per week	3
Sperlich et al. [73]	19 male soccer players (age 13.5 ± 0.4 years)	Players performed either (a) high-intensity interval (i.e. ~90 % HR_{max}) or (b) high-volume (i.e. ~60–75 % HR_{max}) training groups, Each group performed 3–4 sessions per week for 5 weeks. Performance measures included $\dot{V}O_{2max}$, 1-km time trial, 40-m sprint, drop jump, squat jump, and countermovement jump	$\dot{V}O_{2max}$ improved by 7.0 % in the high-intensity interval training group, but not in the high-volume training group. 1-km time trial performance decreased by 10 and 5 s for the high-intensity interval and high-volume training groups, respectively. Improvements in sprint performance occurred in both groups	3
Tonnessen et al. [74]	20 elite male soccer players (age 16.4 ± 0.9 years). Players divided into a repeated-sprint training group (n = 10) and control group	Players performed 1 repeated-sprint training session per week for 10 weeks. Performance measures included 40-m sprint, 10 × 40 m repeated-sprint, countermovement jump, and $\dot{V}O_{2max}$	Repeated-sprint training resulted in improvements in acceleration and maximum velocity qualities, repeated-sprint ability, and countermovement jump	4
Wong et al. [75]	51 junior soccer players allocated into combined soccer, strength, and power training (age 13.5 ± 0.7 years) and isolated soccer training (age 13.2 ± 0.6 years) groups	In addition to normal soccer training, the training group performed upper and lower body strength and power training twice per week for 12 weeks. Performance measures included 30-m sprint, vertical jump, Yo-Yo intermittent endurance test, running economy, $\dot{V}O_{2max}$, and ball shooting speed	Improvements in vertical jump, 10- and 30-m sprint, Yo-Yo intermittent endurance test, $\dot{V}O_{2max}$, running economy, and ball shooting speed occurred in the combined soccer, strength, and power training group. No changes were observed for any of the performance variables in the isolated soccer training group	3

HR_{max} maximum heart rate, *PEDro* Physiotherapy Evidence Database scale, *RM* repetition maximum, *RPE* rating of perceived exertion, *SD* standard deviation, *$\dot{V}O_{2max}$* maximal aerobic power

Table 2 Summary of results from studies investigating the link between training load and negative consequences (e.g. injury, illness, stress, and fatigue) in adolescent football players

Study	Training status, age (mean ± SD), and number (*n*) of participants	Experimental design and training prescription	Findings	PEDro score
Brink et al. [15]	53 elite male soccer players (age 16.5 ± 1.2 years)	Prospective longitudinal cohort design. Training and competition loads recorded using session-RPE and psychological stress and recovery recorded using REST-Q survey over 2 competitive seasons. Injuries and illnesses recorded by club medical staff	Physical training load was related to both injury (OR 1.01–2.59) and illness (OR 1.12). Psychological stress was related to illness (OR 2.27), but the risk of illness was reduced when players perceived they were in better 'shape' (OR 0.56). In addition, the risk of illness was reduced with greater social (OR 0.66) and physical (OR 0.62) recovery	Not determined
Schmikli et al. [17]	7 soccer players (and 1 long-distance runner) with a minimum performance decrement of 1 month (age 16.9 ± 1.1 years) and 7 controls (4 middle-distance runners and 3 soccer players) (age 18.7 ± 1.6 years)	Cross-sectional comparison between athletes experiencing a persistent (minimum of 1 month) performance decrement and control athletes without a performance decrement	The performance decrement group scored higher on depression and anger, and had lower cortisol concentrations than controls. Correlations between negative mood subscales (tension, fatigue, and depression) were observed in the performance decrement group that were not observed in controls	Not determined
Gabbett [78]	45 rugby league players (age 17.9 ± 0.4 years) and 9 non-exercising controls (age 18.1 ± 0.5 years)	Prospective cohort. Training and competition loads recorded using session-RPE. Injury rates documented over entire competitive season	Increases in training loads in pre-season led to increases in injury rates	3
Gabbett [79]	36 junior (age 16.9 ± 0.6 years) and 41 senior (age 25.5 ± 6.1 years) rugby league players	Both groups performed a 14-week field training program, consisting of 2 sessions per week	Training loads were higher in the senior players (470 units) than the junior players (356 units). Injury rates were higher for the senior players (121 per 1,000 training hours) than the junior players (56 per 1,000 training hours)	2
Hartwig et al. [40]	106 male rugby union players aged 14–18 years. Players competed in one of three levels of participation: schoolboy (age 15.2 ± 0.6 years), national representative (age 15.4 ± 0.7 years), and talent (age 16.9 ± 1.5 years) squads	Training loads estimated using training diaries. Psychological stress and recovery were determined using the REST-Q	The mean training volume for schoolboy, national representative, and talent squads was 372, 607, and 424 min. Of the participants in the 80th percentile for highest volume, highest stress, and poorest recovery, 7 individuals were identified as being in at least 2 of the 3 categories	Not determined
Lovell et al. [76]	19 elite soccer players (age 16.1 [range 15–17] years)	Bone marrow edema at the pubic symphysis assessed using magnetic resonance imaging. Relationships between training and osteitis pubis were assessed using a log-odds model, and by making inferences about the substantiveness of a true effect by interpreting the confidence limits of the effect in relation to the thresholds for clinically important effects	The risk of groin pain was greatly reduced (OR per 4 sessions of training, 0.003) with more training prior to entering the soccer program	Not determined
Watson [77]	150 Gaelic football players (age 16.9 ± 0.8 years)	Self-reported survey of injuries sustained during training and competition	Lack of fitness was given as the second most common contributor to injury (11.2 %)	Not determined

OR odds ratio, *PEDro* Physiotherapy Evidence Database scale, *REST-Q* Recovery Stress Questionnaire for athletes, *RPE* rating of perceived exertion, *SD* standard deviation

4.2.2 Strength Training and Physical Performance in Adolescent Football Players

Seven of nineteen (37 %) training–performance studies in adolescent football players assessed the influence of strength and/or explosive power training on sprint and power performances, with a variety of training protocols employed. Chelly et al. [62] allocated 22 adolescent soccer players to either resistance training or a control (usual training) group. In addition to normal soccer training (four sessions per week), 8 weeks of back half-squat strength training, performed twice per week at 70–90 % of the participant's 1 repetition maximum (1RM), was performed in the resistance-training group. Resistance training improved cycling peak power, squat jump and 5-jump test performances, as well as acceleration (5 m sprint) and maximum velocity (40 m sprint) qualities. Leg and thigh muscle volume and cross-sectional area were unchanged following training. The effect of direct supervision from an accredited strength coach on subsequent performance outcomes has also been investigated [64]. While greater improvements in three RM bench press, squat, and maximum chin-up strength were found in athletes undergoing direct supervision, these participants also performed a greater number of training sessions than the unsupervized group, possibly explaining, at least in part, the superior improvements in physical performance. Wong et al. [75] compared the effects of combined soccer, strength, and power training and isolated soccer training on 30 m sprint, vertical jump, Yo-Yo intermittent endurance test, running economy, $\dot{V}O_{2max}$, and ball-shooting speed performances in under-14 soccer players. In addition to normal soccer training, the training group performed upper and lower body strength and power training twice per week for 12 weeks. Improvements in vertical jump, 10 and 30 m sprint, Yo-Yo intermittent endurance test, $\dot{V}O_{2max}$, running economy, and ball-shooting speed occurred in the combined soccer, strength, and power training group. No changes were observed for any of the performance variables in the isolated soccer training group. Collectively, these findings demonstrate the capacity of male adolescent athletes to positively adapt to a resistance training stimulus when prescribed in addition to their regular football training.

4.2.3 Sprint, Repeated-Sprint, and Power Training and Physical Performance in Adolescent Football Players

Few studies (2 of 19, 11 %) have assessed the effect of speed, agility, or power training on physical performance in adolescent football players. Buchheit et al. [60] performed 10 weeks of normal soccer training with the addition of either repeated-sprint (2–3 sets of 5–6 × 15–20 m repeated sprints) or explosive strength (4–6 series of 4–6 lower body power exercises) training, performed once per week. Sprint, repeated-sprint, countermovement jump and hopping test performances were measured pre- and post-training. Acceleration and maximum velocity performances improved to a similar extent (2 %) in both groups. Repeated-sprint training improved repeated-sprint performance (3 %), explosive strength training improved countermovement jump (15 %) and hopping test (28 %) performances; highlighting the specificity in training-induced improvements in physical performance. Tonnessen et al. [74] investigated the effects of one repeated-sprint training session per week for 10 weeks on 40 m sprint, 10 × 40 m repeated-sprint, countermovement jump, and $\dot{V}O_{2max}$ performances in ten elite male soccer players (mean ± SD age, 16.4 ± 0.9 years). Repeated-sprint training resulted in improvements in acceleration (<1 %) and maximum velocity (2 %) qualities, repeated-sprint ability (2 %), and countermovement jump (8 %). However, consistency in the prescription, duration, and evaluation of programs was lacking among the studies that added sprint, repeated-sprint and power training to the workload of adolescents in football.

4.2.4 High-Intensity Interval Training and Physical Performance in Adolescent Football Players

Studies investigating the effects of high-intensity training on physical performance in adolescent football players have employed both generic running programs [73] and small-sided sport-specific training games [66, 68] to demonstrate changes in a range of different physical performance measures. Sperlich et al. [73] compared 5 weeks of high-intensity interval training (i.e., ~90–95 % maximum heart rate [HR_{max}]) with a high-volume training program (i.e., ~50–70 % HR_{max}). Each group performed three to four sessions per week. $\dot{V}O_{2max}$ improved by 7 % in the high-intensity interval training group, but not at all in the high-volume training group. One-kilometer time trial performance decreased by 10 seconds (effect size 0.72) for the high-intensity interval and 5 seconds (effect size 0.31) for the high-volume training groups. Small to large improvements in sprint performance occurred in both groups (effect size 0.47–1.03), without between-group differences. These findings support the use of high-intensity interval training as a time-efficient method of conditioning adolescent football players.

Researchers have also used game-based training and high-intensity aerobic interval training to examine the effects on $\dot{V}O_{2max}$, lactate threshold, running economy at lactate threshold, soccer-specific endurance (measured via Ekblom's circuit test), and indices of physical performance during soccer matches (total distance covered, and time spent standing, walking, and running) in junior soccer players [66, 68]. The authors reported no between-group differences for any of the measured variables, including the soccer-specific tests. Interestingly, the heart rate responses at high intensities [68] were greater, and perceived effort was lower [66] during small-sided training games. Collectively, the results suggested that small-sided games and generic training were equally effective in improving physical performance in adolescent soccer players. Chamari et al. [61] had elite male soccer players perform 8 weeks of soccer-specific dribbling and small-sided (4 vs 4) games training, for two sessions each week. Each session consisted of 4 × 4 minutes of activity (at an intensity of 90–95 % of HR_{max}) interspersed with 3 minutes of active recovery (at 60–70 % of HR_{max}). Following training, significant improvements in $\dot{V}O_{2max}$ (8 %), running economy (14 %), and submaximal running heart rate (decreased 9 beats/min) were observed. In addition, distance covered in a soccer-specific dribbling (i.e., Hoff) test [80] increased by 10 %. Finally, Impellizzeri et al. [69] assigned eleven soccer players to perform 4 weeks of interval training consisting of 4 × 4 minutes at 90–95 % HR_{max}, interspersed with 3 minutes of active (jogging) recovery. Yo-Yo intermittent recovery test performances and $\dot{V}O_{2max}$ were measured pre- and post-training. In addition, players completed a short-passing ability test (i.e., Loughborough soccer passing) measured before and after a 5-minute high-intensity simulation that replicated the most intense phases of a match. Training improved Yo-Yo intermittent recovery test performance and $\dot{V}O_{2max}$, and also reduced the decline in short-passing performances following the high-intensity soccer simulation. The collective findings of these authors [61, 66, 68, 69, 73] highlight the potential for improvements in performance in response to both generic and sport-specific training. The intensity of the training employed appears to be critical to physical performance outcomes [73]. Moreover, the improvements in physical qualities following high-intensity interval training had the potential to improve game-specific sporting performance [69]. In summary, while the majority of research has investigated the influence of training on physical performance, further studies investigating the influence of training and competition loads on playing performance, team selection, longevity, and other positive health outcomes are warranted.

4.2.5 Training Dose–Response Relationships in Adolescent Football Players

While the training–performance relationship is of great importance to coaches in order to ascertain the minimum amount of training required to elicit improvements in physical performance, the training dose–response relationships of adolescent football players and the effect of additional training on physical performance is poorly understood. Brink et al. [59] investigated the relationship between training and competition loads and field test performance in elite adolescent soccer players. Training and competition loads were documented using the session-RPE method, and total quality of recovery scores were recorded over an entire competitive season. A submaximal interval shuttle run test was completed each month. Each additional hour of training or game play resulted in enhanced field test performance. Collectively, these results suggest that higher workloads may be associated with the development of better physical qualities in adolescent soccer players. Conversely, Maio Alves et al. [72] compared sprint times and squat jump performances in adolescent soccer players in response to either 1 or 2 days of complex and contrast strength training. Participants had limited (2 weeks) strength training experience prior to the study. Training improved 5- and 15-m sprint times and squat jump performances in both training groups. However, physical performance improvements were not influenced by the number of sessions performed per week. While these findings were in contrast to those of Brink et al. [59], it is unclear whether similar improvements would be observed in athletes with greater strength training experience, or if the magnitude of improvements in sprint and squat jump performances would be greater with a greater training dose (e.g., 4 days per week). In the only other study to investigate the training dose-response relationships of adolescent football players, Huijgen et al. [67] tracked the longitudinal shuttle sprint and dribble, and slalom sprint and dribble performances of 267 soccer players aged 13.5–14.5 years over a 5-year period. Pearson's correlation coefficients were used to assess the association between shuttle sprint and dribble, and slalom sprint and dribble performances and possible factors influencing technical performance (e.g., cumulative years of soccer experience, soccer practice per week, and additional practice per week). Age, lean body mass, and total hours of practice were the only variables contributing to the predictive model of dribbling performance. Total hours of practice were significantly associated with dribbling performance; for example, players who practiced for 10 hours were predicted to improve their dribbling performance by 0.20 seconds a year.

4.3 Workload and Negative Outcomes

Relative to the number of studies investigating training and physical performance, few studies have investigated the negative outcomes of workloads in adolescent football players. Of the available studies, negative consequences were reported as either injury [15, 76, 78], illness [15], or stress and recovery [15, 40].

4.3.1 Workload, Injury, and Illness

Of the few studies examining negative consequences associated with workload, most (3 of 6) have used injury as the outcome measure [15, 76, 78]. Brink et al. [15] found significant positive relationships between physical stress (encompassing training duration, load, monotony, and strain) and traumatic injury (odds ratio 1.01–2.59). In addition, training duration was significantly associated with illness (odds ratio 1.12). Interestingly, physical workload was not related to overuse injuries. In a study of adolescent rugby league players, training and competition loads and injury rates were recorded over an entire season [78]. Increases in workloads, particularly during the pre-season period, lead to increases in injury rates. However, despite the high injury rates, training resulted in significant reductions in skinfold thickness, and improvements in agility, lower-body muscular power (vertical jump) and estimated $\dot{V}O_{2max}$. Watson [77] surveyed injuries during Gaelic football training and competition in 150 Gaelic football players. Lack of fitness was given as the second highest contributor to injury (11.2 %), although it should be noted that no data on the physical qualities of athletes were provided, and risk factors and causes of injury were self-reported by injured athletes. In contrast, Lovell et al. [76] assessed bone marrow edema at the pubic symphysis in 19 asymptomatic elite soccer players, aged 15–17 years, using magnetic resonance imaging. The risk of groin pain was greatly reduced (odds ratio per four sessions of training, 0.003) with more training prior to entering the soccer program, and increased with larger increases in workloads after entering the soccer program. The practical applications of these findings are two-fold: first, high workloads may offer a protective effect against groin pain in adolescent football players, and second, athletes with a short training history may benefit from a gradual progression in workloads in an attempt to prevent groin pain. At present, the literature remains obscure about the magnitude of high-intensity training that may result in elevated injury risk.

4.3.2 Workload, Psychological Stress, Recovery, and Over-Reaching

Three instruments have been used to quantify the psychological stress, recovery, and over-reaching of adolescent football players. The Recovery-Stress Questionnaire for Athletes [15, 40], Total Quality of Recovery scores [15], and the Profile of Mood States (POMS) questionnaire [17] have been used successfully to identify non-functional over-reaching and other negative consequences associated with training in adolescent football players. Brink et al. [15] and Hartwig et al. [40] used the Recovery-Stress Questionnaire for Athletes to assess psychological stress and recovery in adolescent soccer and rugby union players. Brink et al. [15] also monitored total quality of recovery scores, reporting significant positive relationships between psychological stress and recovery scores, and the occurrence of illness (odds ratio 0.56–2.27). Hartwig et al. [40] monitored 106 male rugby union players competing in one of three levels of participation: schoolboy, national representative, and high-performance talent squad players. The mean training time for schoolboy, national representative, and talent squads was 372, 607, and 424 minutes per week, respectively. To determine the relationship between load and psychological stress and recovery, players were grouped into quintiles for weekly training time, stress scores, and recovery scores. Of the players in the 80th percentile for highest amount of training time, highest stress, and poorest recovery, seven individuals were in at least two of the three categories. These individuals possibly represented players not adapting optimally to the demands associated with participation in rugby.

4.4 Quality of Studies Reviewed

In the absence of a well established tool to describe the quality of mostly non-randomized intervention trials, we applied the PEDro scale [58] to 15 of the selected intervention studies comparing two well matched groups of athletes before and after interventions. Overall, studies scored well on criteria relating to the reporting of results in well recognized 'points of measure' such as means and standard deviations to show differences between groups. Descriptive characteristics and eligibility criteria of participants were generally well reported, but not all studies listed inclusion/exclusion criteria. The intervention trials also scored well on the matching of important descriptive characteristics between groups at baseline.

Although diversity in biological maturation perhaps best defines the challenges in adolescent sport, only 2 of the 19 studies in Table 1 reported Tanner staging [60, 63]. Estimating maturation via Tanner Staging requires highly specialized medical support which is often difficult to arrange in field-based testing. Self-reporting of maturational stage with large groups of adolescent boys can also be problematic but without this level of quality reporting, it may be more difficult to explain differing levels of fatigue, stress, injury, or illness. Skeletal maturation may also impact on injury potential through growth-related conditions such as Osgood Schlatter and Severs disease, but measurement of this requires specialized laboratory equipment and personnel to perform. Traditionally, advanced biological maturity in males has been a predictor of talent in team sport [81]; however, some more recent studies are describing maturation as a predictor of obesity in this age group [82]. While we acknowledge obtaining measures of biological maturation add an additional burden to both the investigator and participant, more detailed information on participant maturation would add considerably to the quality of any reporting on adolescent performance in sport.

Randomization and blinding procedures to minimize bias in research procedures and outcomes comprise 5 of the 10 'scorable' criteria of the PEDro scale. Such procedures are not always feasible in field-based research. Random allocation of groups occurred in only six trials [65, 66, 68, 69, 71, 74]. Blinding of participants to interventions is particularly difficult when athletes belong to the same training squad. Also, blinding of administrators of the intervention and blinding of the assessors to the groupings of athletes have limited feasibility due to the small number of investigators involved. It is, however, possible that blinding of participants to group allocation, and blinding of administrators and assessors may have occurred, but were not reported in any of the studies.

To their credit, all studies reported baseline numbers of participants; however, many did not report the numbers tested at the end of the trial. It could not be assumed that starting and finishing numbers remained the same throughout the intervention as several studies had large dropout rates [66, 68, 69]. With greater attention to detail, reporting of quality criteria in intervention trials with adolescents in the football codes could improve in several but not all of the criteria for the PEDro scale.

5 Conclusion

This review of literature pointed to the positive and negative effects of high workloads in adolescent males participating in football. The majority of studies were conducted on semi-elite training squads, so external validity for recreational players may not be strong. Testing and training protocols have trends towards high specificity of match performance. Moreover, there are some indications that highly specific regimens such as small-sided games can be just as effective at increasing external workload in players while simultaneously reducing the internal load as reported by lower ratings of perceived exertion. Periodization is infrequently discussed in the literature with a few studies examining the possibilities of altering preseason programs, but only one recognizing other phases of training beyond the competitive season. Literature linking physical and psychological injuries/illness to performance is also scarce, yet physical immaturity and experiences of substantial increments in training are characteristic of adolescent athletes.

The combined capacities for adolescent males to grow, train, and improve physical performance highlight and underscore an exciting responsiveness to training in the football environment. However, the capacity to train has some established barriers for adolescents experiencing high workloads, which could also result in negative consequences. Despite a limited number of studies reporting dose responsiveness, fewer rather than more additions to training could be just as effective as intensive, frequent loading. Improved results with supervision point to the characteristic learning phase synonymous with the adolescent stage of development and could also improve player longevity and injury prevention. The divide between what is required to maintain or improve skill versus physiological performance and minimizing the risk of injury is not well understood. Additional research on stage-appropriate training for adolescent male footballers is required in order to address the knowledge gaps and enhance safe and efficient training practices. In terms of future research, information on the periodization strategy employed in training programs should be provided in all studies documenting the effects of workloads on positive and negative outcomes. Both external and internal workloads would provide information on the dose of training, as well as information on how the adolescent responds to those workloads. Moreover, given that the stress imposed on athletes is relative to their age and individual physiological capacities (e.g., $\dot{V}O_{2max}$, maximum velocity), reporting data as absolute workloads may over-estimate the relative stress imposed on older, fitter players and under-estimate the relative stress imposed on younger, unfit players. Finally, given that the relationship between workloads, physical performance, injury, and illness is not linear, and that the individual response to a given workload is highly variable, the use of linear modeling to determine relationships between workloads, and positive and negative outcomes may be inappropriate. Future studies should consider the use of non-linear statistical models and/or machine learning techniques (e.g., neural networks) when determining the relationships between workloads, physical performance, injury, and illness.

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