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Applied Sport Science for Male Age-Grade Rugby Union in England

Running Head: **Sport Science of Youth Rugby Union**

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Abstract

Rugby union (RU) is a skill-collision team sport played at junior and senior levels worldwide. Within England, age-grade rugby governs the participation and talent development of youth players. The RU player development pathway has recently been questioned, regarding player performance and wellbeing, which sport science research can address. The purpose of this review was to summarise and critically appraise the literature in relation to the applied sport science of male age-grade RU players in England focusing upon 1) match-play characteristics, 2) training exposures, 3) physical qualities, 4) fatigue and recovery, 5) nutrition, 6) psychological challenges and development, and 7) injury. Current research evidence suggests that age, playing level and position influence the match-play characteristics of age-grade RU. Training exposures of players are described as '*organised chaos*' due to the multiple environments and stakeholders involved in coordinating training schedules. Fatigue is apparent up to 72 hours post match-play. Well developed physical qualities are important for player development and injury risk reduction. The nutritional requirements are high due to the energetic costs of collisions. Concerns around the psychological characteristics have also been identified (e.g., perfectionism). Injury risk is an important consideration with prevention strategies available. This review highlights the important multi-disciplinary aspects of sport science for developing age-grade RU players for continued participation and player development. The review describes where some current practices may not be optimal, provides a framework to assist practitioners to effectively prepare age-grade players for the holistic demands of youth RU and considers areas for future research.

Key Points

- Age, playing level and position influence the match-play characteristics and training exposure of age-grade RU players within England. Coaches and administrators should understand the complexity of match-play and training within age-grade RU and carefully plan and schedule competition and training to optimise long-term player development and participation within the sport.
- A broad range of physical qualities including body size, speed, change of direction speed, high-intensity running ability, and muscular strength and power are important for player development alongside injury prevention and should be strongly considered within the programmes of age-grade RU players.
- The consideration of training exposure, fatigue and recovery, physical development, nutrition, psychological development and injury management are key topics that inform coach and key stakeholders education for maximising participation and long-term player development of age-grade RU players.

MAIN TEXT

1. Introduction

Rugby union (RU) is a field-based team sport with over 8.5 million players in member unions played across youth to senior and amateur to international levels worldwide [1]. The sport is a contact-skill based, intermittent, high-intensity invasion sport, involving periods of static exertions, collisions and running, interspersed with variable periods of lower intensity work and rest [2-5]. At the senior level, RU is contested between two teams over two 40 minute halves separated by a 10-15 minute break, with reduced playing time for junior levels dependant upon age [6]. The ultimate aim of a match is to score a greater number of points than the opposition in accordance with the laws of the game that are enforced by World Rugby, the international governing body of RU. A RU team consists of 15 players and a maximum of eight replacements, totalling a 23-man squad. Players are commonly split into two positional sub-groups ('backs' or 'forwards') or six sub-positions of front row ('prop', 'hooker'), second row, back row ('flanker', 'number eight'), scrum half, inside backs ('fly-half', 'inside centre', 'outside centre') and outside backs ('fullback', 'wing'). Typically, backs perform more running, whilst forwards undertake increased collision and contact activities [7].

Rugby union participation is higher in England than any other nation [8] with an estimated total of 2.1 million players [1]. England has its own structure of youth RU, known as age-grade rugby, whereby players participate within annual-age categories (e.g., Under-13 years of age [U13], Under-18 years of age [U18]). England RU's national governing body, the Rugby Football Union (RFU), governs age-grade rugby in relation to participation within the game alongside the identification and development of young talented players. Talent identification and development programmes are delivered via fourteen Regional Academies, normally aligned with professional RU clubs. Players are typically identified from community or school rugby and invited to train within a Regional Academy from 15 years of age, prior to potentially signing a professional contract at 18 years of age. Players may remain in an academy programme until their early twenties. Between 15 and 18 years of age, RU players may train and compete within multiple rugby programmes (i.e., club, school, representative and [regional] academy) alongside undertaking other sporting activities and school-based commitments (e.g., Physical Education; [9, 10]). Therefore, RU within England employs a late specialisation model [11], especially compared to other sports (e.g., soccer; [12]), resulting in a complex multi-sport, -environment and -coach development programme.

This programme has been previously termed as '*organised chaos*', whereby '*organised*' is defined as making arrangements or preparations for an event, and '*chaos*' is defined as the property of a complex system whose behavior is so unpredictable it appears random [13].

Recent consensus statements [14-16] suggest youth (or long-term) athletic development programmes should aim to develop healthy, capable and resilient young athletes, while attaining widespread, inclusive, sustainable and enjoyable participation and success across all levels of individual athletic achievement. Combined with England Rugby's aim to ensure all players enjoy rugby in a safe environment and develop a wide array of skills [17], this demonstrates that healthy youth athletic development is a necessity for all age-grade rugby players. Therefore, sustainable participation and player development within age-grade RU players is a focus for the RFU and World Rugby. However, due to the complex multi-sport, and -environment playing system within RU, questions have been raised regarding player wellness and performance to maintain participation and support player development towards the elite level within the sport [10].

Therefore, the purpose of this review article was to summarise and critically appraise the scientific literature in relation to the applied sport science of male age-grade RU focusing upon England. This included 1) match-play characteristics, 2) training exposures, 3) physical qualities, 4) fatigue and recovery, 5) nutrition, 6) psychological challenges and development, and 7) injury. The review focussed upon RU in England based upon the structure of their age-grade programme and the importance of context within sport science [18]. There are differences in the player development systems applied worldwide (e.g., concurrent playing pathways, age player obtains professional contract, academy structure and support, sport governance) with RU Nations (e.g., New Zealand, South Africa [19]). This review provides a framework to assist practitioners to effectively prepare age-grade players for the holistic demands, whilst considering areas for future research to enhance applied sport science within youth RU.

2. Method

To carry out this review a computer literature search of PubMed, Google Scholar, and Scopus was performed for English-language peer-reviewed articles from inception to January 2019 using the following key words and appropriate Boolean (AND/OR) phrases; 'Rugby Union', 'Youth', 'Junior', 'Adolescent', 'Age-Grade', 'Match Demands', 'Match Characteristics', 'Training', 'Training Load', 'Training Exposure', 'Anthropometric', 'Body Composition', 'Strength', 'Power', 'Speed', 'Aerobic Capacity', 'Fatigue', 'Recovery',

‘Nutrition’, ‘Psychological Development’, ‘Psychological Challenges’ and ‘Injury’. The electronic search was supplemented by hand searching the reference lists of articles, which met the study’s inclusion criteria.

The themes of the review represented the major applied sport science themes influencing age-grade RU performance including match-play characteristics, training exposure, physical qualities, fatigue and recovery, nutrition, psychological challenges and development, and injury. As the review sought to identify the applied sport science of male age-grade RU players within England, studies that investigated youth or age-grade RU players from different nations were excluded from the data tables but were discussed in the text. Studies were considered age-grade if they did not include adult rugby and therefore included studies at University and U20.

3. Match-Play Characteristics

In recent years, there has been an increase in research studies evaluating the match-play characteristics of team sports [20]. Such research is intended to inform training prescription whilst understanding the match-play characteristics within youth athlete development systems. Studies within senior [21-24] and youth [25-29] RU have been conducted using video-based time motion analysis or microtechnology devices including global positioning systems (GPS). Specific to male age-grade RU match-play within England, nine studies have been conducted across school [5, 9, 30], county representative [3], university [5], academy [9, 30-34] and international [35] playing levels. Table 1 summarises the locomotor related variables while Table 2 shows the speed threshold and PlayerLoad related variables for physical match-play characteristics.

Insert Table 1 near here

Insert Table 2 near here

3.1 Absolute and Relative Distance Measures

The total distance covered during match-play within England for age-grade RU players ranges from $3,841 \pm 700$ m in U16 school players [5] to $6,230 \pm 800$ m during U20 international competition [35]. Intensity, measured via average speed, ranges from 58.7 ± 8.1 m·min⁻¹ in U18 schoolboy forwards [9] to 79.8 ± 10.5 m·min⁻¹ in U16 county backs [3].

Total distance and average speed, assessed via GPS, were greater in backs than forwards [5, 9, 32, 35], which is consistent with findings in senior RU [22]. No differences

were identified in average speed between positions in U16 county players [3] while U16 school forwards covered more total distance than the backs [5]. These findings are consistent with research in South Africa [28] suggesting that differences in position specific physical characteristics may become more apparent as age increases. This finding might be attributable to inferior technical ability at younger age categories [36] resulting in backs having less game involvements at younger age categories.

Total distance typically increases with age although it appears this is specific to the playing level and position. School U16 forwards covered more distance than U18 school backs [9, 30]. The greater total distances in older age categories (i.e., U20 and university) is likely because of the longer playing durations at these ages. Conversely, average speed does not seem to increase with age as during match-play U20 international players had one of the lowest average speeds [35] while U16 county backs had the highest [3]. Such findings might be apparent due to the difference in body mass between age categories and the subsequent collision characteristics, although this is yet to be confirmed. Two studies have compared the match-play characteristics between playing levels [9, 30] showing academy players had a greater total and average speed than schoolboy players. This highlights the need for appropriate player preparation strategies, as players may represent both levels concurrently.

The research reviewed above (and in Table 1) only considers the characteristics of the whole match, whereas the ‘peak’ locomotor characteristics are of likely more importance for enhancing training prescription and player development [37]. Recent research has attempted to better understand match-play characteristics by accounting for ball in play time and the peak 1 minute periods. For example, the ball is in play for 37% of the match during U18 academy RU (63% ball out of play) with an average cycle (i.e., ball in play time prior to a break in play) time of 33 ± 24 s [34]. Attacking phases average speed ranged between 112.2 – 114.6 $\text{m}\cdot\text{min}^{-1}$ and defensive phases ranged between 109.0 – 114.5 $\text{m}\cdot\text{min}^{-1}$ [34]. Furthermore, the maximum average speed using a 0.1 s rolling mean for a 1 minute period during U18 academy RU ranged between 154 ± 17 (front row) and 185 ± 20 (scrum half) $\text{m}\cdot\text{min}^{-1}$ demonstrating substantially greater values than those presented in whole match analysis [31]. These values can be used when planning, ‘live’ monitoring and retrospectively analysing training so players are prepared for the ‘worst-case scenario’ during matches as recently completed in studies in senior international players [7, 38].

3.2 Speed Thresholds

Several studies have provided a breakdown of the distance covered using speed thresholds [3, 5, 9, 30, 33, 35]. Although, comparisons are difficult due to the different thresholds utilised (see Table 2), findings demonstrate that most distance in RU match-play is covered at low speeds and backs cover greater distances at higher speeds compared to forwards. These findings are consistent with senior RU [22, 23] and occur due to greater running velocities in backs alongside their ability to undertake more free running in match-play. The distances covered at high speeds (e.g., $>5.84 \text{ m}\cdot\text{s}^{-1}$) appear to increase with age in the educational pathway of school and university backs [5], whereas distance covered $>3.33 \text{ m}\cdot\text{s}^{-1}$ by county players is similar between ages in the backs and decreases as age increases in the forwards [3]. Comparisons of speed thresholds across playing levels are difficult, but current data show similar high speed distances between school and academy players [9, 30].

3.3 Collisions

The collision activity of youth RU players is yet to be extensively researched. Roe et al. [33] is the only study to date that has quantified the number of collisions in U18 academy RU match-play showing forwards and backs completed a similar number of carries (4 ± 3 vs. 4 ± 2) and defensive rucks (2 ± 2 vs. 1 ± 1). However, forwards performed more attacking rucks (11 ± 6 vs. 4 ± 3) and tackles (9 ± 5 vs. 6 ± 3), alongside the addition of 14 ± 5 scrums [33].

As the coding of performance analysis variables can be time consuming, researchers have used proxy measures of collision activity such as PlayerLoad (PL; a vector magnitude that sums the frequency and magnitude of accelerations in the three axial planes) and PlayerLoad slow (PL_{slow} ; data when the speed is $<2 \text{ m}\cdot\text{s}^{-1}$). Associations between PL, PL_{slow} and collision number have been established ($r=0.79$) [33]. Academy players accumulate greater measures of PL_{slow} than school players, potentially indicating greater collision activity [30]. Forwards accumulate greater PL and PL_{slow} during match-play than backs and these measures also increase with age. However, it is unknown if this is due to greater playing durations at older ages or due to a greater frequency or magnitude of collisions. While PL is used as a proxy measure of collisions, it also has a very strong ($r=0.94$) association with total distance covered [33]. Therefore, differences in PL might be due to the greater locomotor characteristics, alongside collisions.

3.4 Summary

Overall, the physical match-play characteristics that age-grade RU players are exposed to vary depending on playing level and age. Academy level RU appears to have greater physical match-play characteristics than school RU, thus players should be prepared for these match-play characteristics to ensure safe and optimal player development. Further research is required to understand the complexity of the physical match-play characteristics within RU. This will delineate the running and collision characteristics, that concurrently contribute to the physical characteristics of match-play, alongside considering the technical and tactical elements.

4. Training Exposure

In recent years, the focus on training monitoring of athletes has exponentially increased [39]. Within youth sport populations, research [14-16] has highlighted the importance of developing healthy, capable and resilient youth athletes, which promote positive outcomes (e.g., enhanced fitness) whilst minimising negative consequences (e.g., injury). Such a focus has resulted in training exposure research within age-grade RU [26, 40-44]. Within England, the complex multi-sport and -environment may not be optimal to manage associated positive and negative outcomes. This has resulted in eight studies examining training exposure across school [9, 45-47], club [47] and academy [9, 13, 45, 47-50] players (Table 3).

Insert Table 3 near here

4.1 All Training

Five studies [13, 45, 46, 48, 50] have quantified the total training exposure of age-grade RU players inclusive of rugby, gym, and other training activity. Total training exposure was reported as 190 hours per season in academy players compared to 72 hours in school players [45]. The average total weekly session rating of perceived exertion (sRPE) during training was $1,810 \pm 391$ AU for senior academy players during pre-season [50], $1,014 \pm 1016$ AU for school players during in-season [46], $1,217 \pm 64$ AU (excluding matches) and $1,425 \pm 545$ AU (including matches) for academy players during in-season periods [13, 48]. Findings suggest increased training exposure at higher playing levels, as expected, with exposures for U18 players below those reported within senior RU [51, 52].

4.2 Field Training

Field training exposure has been quantified by duration [45, 46], sRPE [13, 32, 47-49], locomotor (e.g., total distance; [9, 13, 47-49]) and internal (e.g., heart rate; [47]; iTRIMP; [49]) measures. Phibbs et al. [47] compared training exposures across age and playing levels, demonstrating that RU training duration and frequency increased with age. Training intensity was also greater at higher playing levels. Academy training was also more closely representative of match-play than schoolboy training due to position specificity [9] possibly due to greater coach experience and player ability [47]. For example, school RU backs' completed less total and high-speed locomotor distance in training than match-play whilst forwards completed less low speed activity and physical load in training. Furthermore, the peak speed achieved during training ranged from 86-89% of maximal sprint speeds, suggesting player opportunities to reach peak speeds are limited [9]. Therefore, coaches should consider whether the physical stimulus provided during training practices are optimal for long-term player development and preparing players for the respective match demands.

Weekly match and training exposure of academy rugby union players has been shown to be highly variable (CV=37%; [13]) with weekly total distance ranging from 7,805-21,801 m (excluding match-play) [48]. This is due to the multiple training and sporting commitments (e.g., school, academy, club rugby) and potential variable fixture scheduling (CV=96%) resulting in players potentially competing in none to three fixtures each week [13]. Furthermore, Taylor et al. [49] showed internal load (i.e., iTRIMP) had strong associations with changes in aerobic fitness over a 6-week period and therefore internal HR measures may be important monitoring tools in the future. Coaches and administrators should aim to appropriately monitor and prescribe both training and competitions to reduce variability in training exposure whilst considering the importance of other training modes (e.g., gym training) for long-term athlete development and minimizing injury.

4.3 Gym Training

Five studies have considered the gym training of youth RU players [13, 45, 46, 48, 50]. Academy players have greater absolute and relative (27% of training exposure) resistance training time compared to school players (13% of training exposure) [45] with similar total percentage exposure represented in senior academy players (approximately 33-50% per week [50]). Reduced gym exposure has been shown in season within U18 (72 ± 44 mins [51]; 86 ± 61 min, [13]) and school (78 ± 33 mins [46]) players suggesting the focus on physical development decreases in season.

Weakley et al. [46] presented the most comprehensive description of gym exposure in age-grade RU, considering the frequency of gym sessions, exercises and volume loads of 35 players across four schools. Findings demonstrated school RU players undertook 1.4 ± 0.6 gym sessions per week comprising of 3.0 ± 1.7 and 1.5 ± 0.8 upper and lower body exercises respectively. Consistent with field training, gym exposure was inconsistent and highly variable across the 12-week period, which may be sub-optimal for long-term physical development. The findings demonstrated strong relationships between the frequency of exercises completed and the volume load (kg's lifted) with changes in physical performance across a 12-week period. This suggests gym exposure is important for physical development when appropriately planned and implemented alongside the potential to decrease injuries in RU players [45].

4.4 Summary

Overall, training exposure of age-grade RU players increases with age and playing level but represents a highly variable structure over weekly periods previously described as '*organised chaos*'. Coaches and administrators need to consider increasing training session intensity and the inclusion of activities to elicit maximal velocities. Furthermore, the weekly and monthly training schedules of players should be designed to reduce week-to-week variability, considering the fixture schedule alongside implementation of gym exposure for the long-term development of physical qualities important for RU alongside minimizing injury risk within players. Future research should continue to explore training loads of age-grade RU players whilst considering the integration of fatigue, recovery, physical development and injury within such studies.

5. Physical Qualities

Due to the physical demands of RU, players require highly developed physical qualities, including anthropometry, body composition, linear and change of direction speed, high-intensity running ability, strength and power [6]. Previous research has presented the physical qualities of senior [53-56] and youth [53, 57-59] RU players across multiple ages, standards and positions. Specific to male age-grade RU players within England, ten studies [46, 49, 60-67] have presented data across various physical qualities making comparisons between age, position and playing level. Table 4 and 5 present the physical qualities for age-grade RU players from England and provide objective markers of physical development to support talent identification and development [68].

Insert Table 4 and 5 near here

5.1 Anthropometrics

Height and body mass have been shown to be important for RU [69]. Age-grade RU players height and body mass are greater for older players [62] and are higher in forwards than backs [63]. The height and body mass of U21 English players [62] appears similar to those reported for South African U20 players [59] and greater than those reported in U19 Portuguese forwards and backs [58]. Only one study has reported the anthropometric characteristics of players below 16 years old considering height, mass and maturity status in 14-17 year old English players [64] and shows youth RU players were above the 75th and 90th reference percentiles for height and mass respectively. These findings suggest advanced size and maturity may be advantageous for selection within RU, consistent with previous findings in Australia [70] which suggested measuring player height and mass prior to registration for potential player dispensation and grading.

5.2 Body Composition

Body composition is important for performance as excessive body fat is detrimental to acceleration and the metabolic cost of exercise [6]. However, only two studies are available within English academy players [62, 63] presenting data via the sum of 8 skinfolds. Findings show similar skinfolds across age categories [62] but higher skinfolds at U16s for forwards and U18 for backs [63]. Forwards have greater skinfolds compared to backs [63]. Findings are similar to studies [57, 71] utilizing dual-energy x-ray absorptiometry presenting body fat percentage values of 13-14% and 16-19% in backs and forwards, respectively.

5.3 Speed and Change of Direction Speed

Linear and change of direction speed are important physical qualities for RU and are associated with line breaks, evading and beating defenders and metres advanced in senior players [72]. Six studies are available within age-grade England RU players [46, 61-636] presenting initial (i.e., 5, 10 m), maximal sprinting (i.e., 30, 40m) and sprint momentum data. However, only one study presents change of direction speed via the 505 test [62]. Age does not differentiate between initial [61, 62] or 20m speed except in forwards [63], which was increased at older age categories. Forty metre speed was superior at older age categories in backs and forwards [62, 63]. Initial [62, 64] and maximal [63] sprint momentum increased

with age suggesting this should be measured and tracked. Change of direction speed was also greater at U21 age categories compared to U16 and U18 [62].

Backs were faster than forwards across initial and maximal sprint distances [63]. Academy level players outperformed aged-matched school players for 20 m speed when compared across studies [46, 62], although small differences were only apparent at 40 m and for sprint momentum in direct comparisons [65]. When compared to other studies, English age-grade RU players are slower than South African U20 internationals [59] and professional players [73, 74].

5.4 Aerobic Capacity

Enhanced aerobic capacity is important for RU due to the the need to recover quickly from high-intensity efforts [75]. Five studies present the aerobic capacity qualities of age-grade RU players using the Yo-Yo intermittent recovery level 1 [62, 63, 65], 30-15 intermittent fitness [60, 62, 63] and a laboratory based VO₂max [49] test. Small differences in aerobic capacity, which were greater at older age categories, were shown [62, 63] and these differences increase when body mass is accounted for within the statistical analysis [60]. Body mass should therefore be considered when measuring and tracking aerobic capacity in youth players. Comparisons between playing position and standard demonstrate backs generally have greater aerobic capacity than forwards [63] consistent with other research [58, 59] and academy players outperform school players [65].

5.5 Muscular Strength & Power

Muscular strength and power are key attributes of RU performance due to the contact and collision element of the sport [75]. Six studies have presented strength and power data in age-grade RU players via Wattbike peak power output [64], countermovement jump [46, 62] or isoinertial strength tests [46, 62, 65-67]. Strength and power are greater at older age categories [62, 64] supporting data in rugby league [53, 68]. Furthermore, strength and power differentiate between playing standard [65] and resistance training experience [67].

5.6 Summary

Overall, physical qualities increase with age and playing level and differ between forwards and backs demonstrating the importance of their development in age-grade RU players. However, current evidence and normative data is limited by studies only utilising one club. Future research should aim to develop and implement a national standardised

fitness testing battery allowing the quantification of the physical qualities of age-grade RU players throughout England for talent identification, player monitoring and development. A further focus on players aged below 16 years is required, while considering maturity status, alongside implementing longitudinal research designs [76, 77] and considering the importance of physical qualities for match performance and long-term career outcomes.

6. Fatigue and Recovery

Understanding the fatigue and recovery profiles of RU players following training and match-play provides important information for planning appropriate training and competition schedules [78]. Studies within senior RU players have demonstrated that post-match fatigue may manifest as acute reductions in neuromuscular function [79, 80], elevations in markers of muscle damage [81, 82], alterations in immune and endocrine function [79, 83, 84] and negative changes in mood [79, 80] up to 60-hours post match-play. In addition to studies conducted in other youth RU populations [85, 86], six studies were identified investigating fatigue markers post match-play [32, 87] and training [50, 88-90] within male age-grade RU players from England (Table 6).

Insert Table 6 near here

6.1 Match-Play Fatigue

Fatigue and recovery post academy RU match-play has been assessed using the adductor squeeze [87], markers of lower-body (countermovement jump) and upper-body (plyometric push-up) neuromuscular function, subjective assessment of wellness, and proxy methods of skeletal muscle damage (e.g., creatine kinase concentrations [CK]) [32]. With the exception of adductor squeeze, which showed trivial reductions in response to match-play [87], markers of neuromuscular function, wellness and muscle damage all demonstrated peak changes in the first 24 hours post-match [32]. Lower-body neuromuscular function remained substantially reduced at 48 hours post-match, while both [CK] and wellness were still substantially altered at 72 hours following match-play, although recovering at this time [32]. Such findings are consistent with findings in senior RU, and age-grade RU players [85, 86] and other youth sports (e.g., rugby league, [91]; Australian Football; [78]). These findings suggest that young RU players should be afforded a minimum of one recovery day (i.e., active or passive) following competition before returning to training at 48 hours post-match. However, practitioners should aim to monitor player recovery on an individual basis due to

the large inter-individual responses to match-play reported, in order to appropriately plan individualised training schedules. Unfortunately such practice is not always adopted in English age-grade RU, based on the reported training and match practices [13, 48].

6.2 Training Fatigue

Four studies have evaluated fatigue and recovery responses to training, considering training volume [90], session order [89], contact training [88] and longitudinal responses over an 11-week pre-season period [50]. All studies have demonstrated a fatigue response to training with the magnitude of response dependent upon the training undertaken. For example, Noon et al., [90] demonstrated greater perceptions of fatigue following high vs. low training volume. Roe et al., [88] demonstrated substantially greater upper body neuromuscular fatigue, a decrease in wellness and elevated [CK] following contact training, whilst lower body neuromuscular fatigue was substantially increased following non-contact training, indicative of the greater running volumes and intensities. Session order [89] did not affect fatigue responses post speed-weights or weights-speed training (i.e., 6 x 50 m sprints with 5 min recovery; 5 sets x 4 repetitions at 85% 1RM with 4 min rest of back squat and Romanian deadlift). However, speed was enhanced when this was performed following (1.76 ± 0.08 s) rather than prior to a weights session (1.80 ± 0.11 s) possibly due to a postactivation potentiation effect [89]. During an 11-week pre-season, lower-body neuromuscular fatigue was present throughout the majority of the observational period, however was greatest during the periods of higher training volume. Despite this, improvements in 3RM front squat strength and maximum sprint velocity were observed, suggesting enhancements in physical performance can still be achieved when fatigue, as measured by a countermovement jump, is present [50]. These findings provide a challenge to all practitioners in planning appropriate training to prepare players for weekly match-play whilst still maintaining a long-term athlete development focus.

6.3 Summary

Overall, fatigue is present in age-grade RU players following match-play and training. Following U18 academy RU match-play, peak changes in markers of fatigue are seen in the first 24 hours, with some taking more than 72 hours to return to baseline levels. Furthermore, fatigue responses following training can be affected by training volume, activities (e.g., contact) and session order. These factors are further confounded by the large inter-individual fatigue responses following match-play and training. Such findings provide an interesting

challenge to practitioners in planning and delivering training schedules. Practitioners should aim to provide a minimum of one recovery day (e.g., active or passive) following competition before returning to training at 48 hours post-match, and monitor player recovery on an individual basis where possible. Future research should explore the consequences of changes in measures of fatigue (i.e., injury, reductions in performance) whilst exploring fatigue responses following combined match-play and training schedules over longitudinal periods.

7. Nutritional Requirements

Performance nutrition is another key aspect of supporting the adaptations to training and match-play alongside maintaining appropriate growth and health of the age-grade RU player [92]. Whilst research exists exploring the nutritional requirements, intakes and expenditures of adult male players [51, 93, 94], there are only two studies that exist within English male age-grade players [95, 96].

7.1 Energy Requirements

Using doubly-labelled water, the mean total energy expenditure of fourteen English age-grade players was $4,369 \pm 979$ kcal day⁻¹ [96] suggesting higher energy expenditure (approximately 500 kcal day⁻¹) than estimated via traditional equations (e.g., Harris-Benedict [97]). Increased energy expenditures may be apparent due to the metabolic cost of the collision identified in youth rugby league [98].

7.2 Energy Intakes

Only one study to date [95] has assessed the energy intakes of age-grade RU players. Using a four-day food diary, mean energy intake for the U16 players was $3,269 \pm 766$ kcal·day⁻¹, with protein and carbohydrate intakes reported relative to body mass as 1.9 ± 0.6 and 4.8 ± 1.1 g·kg⁻¹·day⁻¹ respectively. For the U19 players (n=21), their mean energy intake was $3,412 \pm 670$ kcal·day⁻¹ while mean protein was 2.3 ± 0.5 g·kg⁻¹·day⁻¹ and mean carbohydrate intake was 4.7 ± 1.4 g·kg⁻¹·day⁻¹. Energy intakes were lower than reported energy expenditure values [96], although the players met the standard guidelines for energy and macronutrients. This is similar to data from Australian rugby players of the same age [99].

7.3 Micronutrient Requirements

To date, there are no published data in English RU age-grade players to guide specific micronutrient requirements or their corresponding dietary intakes and therefore the standard healthy guidelines should be used. When considering dietary quality (and its correlation to micronutrient intakes), Smith et al., [95] showed that U19 players achieved the recommended servings of fruit and vegetables per day, while U16 players did not within Yorkshire, England.

7.4 Summary

Research exploring the energy intakes and expenditure of age-grade RU players is limited. In the absence of specific data, sports nutrition guidelines for adults can be used in combination with nutrition periodization and frequent monitoring. Practically, dietary intake assessments, using novel methods (e.g., Snap-and-Send; [100]) along with serial measurements of growth, physiological development, strength, and self-reported fatigue and recovery may be an optimal combination to assist with adapting a standard nutritional prescription rather than the use of any static targets.

8. Psychological Challenges and Development

Psychology is acknowledged as a key determinant in the realization of potential and long-term success in sport [101], especially RU [102]. However, despite this importance, the prevalence of systematic psychological inquiry into both senior and youth populations worldwide in the sport is scarce. To date, five studies have investigated the psychological challenges and developmental demands faced by age-grade English RU players. These studies have focused upon the stress and coping experiences of players [103-105] and the psychological factors contributing to successful talent development [102, 106] (Table 7).

Insert Table 7 near here

8.1 Stress and Coping Experiences

Nicholls and Polman [105] examined the stressors, coping strategies, and perceived coping effectiveness among England U18 international RU players. The most frequently-cited stressors were making a mental or physical error, receiving coach/parental criticism, and injury. Coping strategies included blocking, increasing effort, and taking advice, with blocking and technical adjustment strategies rated as being more effective. Two studies have also considered the impact of the personality variable of perfectionism upon physical and

mental health symptoms. According to the stress–injury model [107] personality factors which predispose athletes to elevated levels of stress (e.g., perfectionism) may increase the risk of injury. A prospective study, examined the perfectionistic strivings, perfectionistic concerns and injury [104] showing whilst perfectionism positively predicted injury, only perfectionistic concerns emerged as a significant positive predictor. Perfectionism, and the frequency of the experience of perfectionistic cognitions, has also been identified as a psychological trait which is an antecedent of athlete burnout and a precursor to sport dropout. An investigation of male RU players from youth teams [103], reported frequency of perfectionistic cognitions explained 3–4% variance in symptoms of athlete burnout, after controlling for self-oriented and socially prescribed dimensions of perfectionism. Collectively, these findings suggest that individuals who have perfectionistic concerns are at a greater risk of injury. In addition, the frequency with which perfectionistic cognitions are experienced may also be an antecedent of athlete burnout. Perfectionistic cognitions should, therefore, be considered in future models of the relationship between perfectionism, injury and athlete burnout.

8.2 Psychological Factors Contributing to Successful Talent Development

Acknowledging psychology in providing important information for talent identification and successful development to the elite level, Hill [102] interviewed English RU academy coaches and directors to identify the positive and negative issues influencing talent development. While support was found for a range of positive constructs (e.g., planning and self-organisation, commitment, resilience) as facilitators of effective development, negative and dual (inappropriately applied ‘positive’) characteristics (e.g. obsessive passion, perfectionism) had a negative impact on development. One concept highlighted extensively within the sports science literature as influencing talent selection and identification within sports is the relative age effect (RAE). McCarthy [106, 108] investigated this initial bias in professional RU academies and found a reversal of the RAE effect, whereby relatively young players were less likely to be selected into their respective national academy systems but more likely to transition into senior professional squads. The role of adversity in promoting growth and flourishing was suggested as a psychological explanation for such an effect, with exposure to adversity considered as an element of a successful talent system.

8.3 Summary

RU players face a range of psychological demands and adopt numerous strategies to cope with these challenges. Perfectionistic cognitions are a potential factor predisposing young players to an increased injury risk and should be considered when designing interventions to reduce perfectionism and burnout. Understanding the psychological characteristics that facilitate and derail progression can enhance coaches' player assessment when identifying and supporting youth RU players. Given the limited literature to date, future research should seek to examine in greater depth the psychological demands age-grade RU players from England face, the skills/strategies deployed to successfully transition to the elite professional level, and the factors (e.g., personal, situational, organizational, cultural) that mediate this progression.

9. Injury

Injury risk across RU has drawn public and academic interest, with concerns that the associated injury risk is high at youth levels coinciding with calls to modify the game by removing playing events such as the tackle [109-111]. Descriptive epidemiological studies of injury patterns are regarded as a foundation from which potential injury risk factors can be identified and preventive strategies formulated [112]. Studies describing injury patterns exist within senior elite [113-115], senior community [116-118], academy [45, 119], and youth community [45, 119-121] RU players within England. Within age-grade RU specifically, four studies described injury patterns within England [45, 119-121], and one further study investigated the efficacy of a preventive measure [124]. Table 8 summarises the key findings of descriptive epidemiological studies in English age-grade RU.

Insert Table 8 near here

9.1 Injury Risk

Within age-grade RU in England, match injury rates ranged between 24 and 77 injuries per 1000 player-match-hours (using a greater than 24-hour time-loss injury definition) [122, 123]. These injury rates broadly correspond with documented match injury rates (using a comparable injury definition) from male age-grade RU in Northern Ireland (Ages 16-18 years: 29/1000 player-match-hours [124]) and South Africa (Ages 12-18 years: 20/1000-player-match-hours [125]). Match injury rates from English age-grade rugby also largely fall within the range outlined in the findings of a meta-analysis across both RU and rugby league in children and adolescent players (aged <21 years) from a range of settings that

revealed a pooled overall match injury incidence rate of 27 injuries/1000 player-match-hours (95% Confidence Limits 13-54), irrespective of injury definition [110]. The lower limb has been shown to be the most frequently injured body location in age-grade RU players, accounting for 33-55% of all match injuries, followed by the upper limb (24-32%), head/neck region (14-32%), and trunk (3-10%) [119-121]. Additionally, joint and ligament injuries are commonly reported injury types among young RU players (39-51%), followed by musculotendinous injuries (18-24%), lacerations/contusions (18-19%), and bone fractures (6-8%) [119]. The knee and shoulder joints have been shown to be at a particularly high risk of severe injuries such as ligament injuries (sprains), fractures, and dislocations [119], while concussion has recently been recognised among the most common and severe injury diagnoses experienced by male age-grade RU players [121]. The tackle situation is the most commonly recorded match event associated with injury and accounts for 51-57% of match injuries [119, 121]. In contrast to match injury rates, the limited amount of evidence relating to training injuries in English age-grade RU show rates to be much lower at between 1.4 and 2.1 injuries per 1000 player-training-hours [45].

While acknowledging the limited number of studies at present, data from included studies represents a limited number of settings, namely U18 male players in academies or schools. Consequently, the nature and pattern of injuries experienced by other RU-playing populations is uncertain, particularly within youths and children, and community club rugby.

9.2 Prevention Strategies

A number of approaches have been reported to positively affect injury risk across RU, including law alterations [125, 126], coach and referee education [127-130], and protective equipment [131, 132]. While these preventive measures can readily apply to English youth players, only one study has been conducted to directly assess the efficacy of preventive measures. A recent study in Schoolboy RU players (aged 15-18 years) revealed that a targeted pre-activity preventive exercise programme over one playing season (August-December) containing balance and bodyweight resistance exercises reduced measures of upper limb injury (by 34%) and concussion (by 29%) amongst players when compared with a standard of practice (control) exercise programme [133]. The mechanisms underlying the observed reductions are unclear, but may relate to training effects on joint kinematics and force-handling capabilities in the upper body [134-135], while developing or preserving aspects of neck function, such as strength, may have contributed to the reduction in concussion incidence [136-137]. Furthermore, when comparisons were made across teams

that regularly used the respective exercise programmes three or more times per week, those assigned to the targeted preventive exercise programme suffered 72% fewer match injuries when compared with the control exercise programme, with a noticeable reduction of 59% in concussion risk [133]. This suggests targeted preventive exercise programmes may be effective as injury prevention methods.

9.3 Summary

Despite a limited number of studies at present, documented injury patterns in English age-grade RU appear similar to other RU populations. The relatively high incidence of soft tissue injuries and concussion in this population highlights a need to focus on reducing the risk of these priority injury types. Recent evidence supports including targeted preventive exercise programmes into age-grade RU as a means of reducing soft-tissue injury and concussion risk. Future research should explore the exact nature of injuries arising from prominent match events such as the tackle situation, which may inform strategies to reduce injury risk in age-grade RU players.

10. Conclusions

International associations (e.g., International Olympic Committee) and national governing bodies (e.g., RFU) have emphasised the importance of designing and implementing healthy youth athletic development programmes. Within RU in England, this is even more important due to the employment of a late specialisation sporting system resulting in a complex multi-sport, -environment and –coach development programme. Although such a system has potential benefits, it also challenges the optimisation and maintenance of health, participation and player development within RU in England. This review provides a first attempt to present current evidence on the applied sport science of male age-grade RU players within England and summarizes and critically appraises the literature in relation to the 1) match-play characteristics, 2) training exposures, 3) physical qualities, 4) fatigue and recovery, 5) nutrition, 6) psychological challenges and development, and 7) injury.

Current evidence suggests that match-play characteristics are influenced by age, playing level and position. However, no information is available considering the technical and tactical elements of match-play that are common within the adult game [138-140] and is therefore a future research direction. Youth players weekly and monthly training exposure represents a highly variable structure with reduced week to week stability due to potential misalignment of fixtures, which may cause potential negative outcomes (e.g., injury). Alongside this, considering it can take 72 hours for fatigue markers to return to baseline post-match means consideration of training and competition frequency, volume and intensity is important for maximising positive and negative responses. The training exposure and physical qualities of players increase with age and playing level and differ between forwards and backs. However, it could be questioned whether appropriate strategies (e.g., training load variability, training modality gym exposure) are implemented to maximise player development. In addition to physical factors, the psychological challenges and development facing age-grade RU players are widespread with the evidence base alluding to perfectionism and burnout as two major factors potentially predisposing players to injury. Finally, injury risk and the energy demands of young players are high and therefore require careful consideration within practice.

Based on the above, all coaches, administrators and stakeholders should consider the applied sport science and research evidence base in the appropriate and healthy development of age-grade RU athletes. This includes appropriate scheduling and inclusion of training and match-play activities that aim to maximise athlete development (e.g., physical qualities) whilst reducing and minimising the negative consequences (e.g., injury, burnout). Through

the planning and delivery of age-grade RU training, players should be provided a minimum of one rest day (active or passive) post competition with players ideally monitored on an individual basis. Further exposing players to structured sprint training, resistance training within a microcycle, the management of training and competition exposure and the assessment of potential psychological behaviors (e.g., perfectionism) should be high priorities. Recent interventions implemented by the RFU including the half game rule [141] may help achieve this aim while ensuring both participation and player development opportunities.

Although the current evidence base is emerging, most studies are limited by the inclusion of only one club, potentially challenging the reach of the findings. The implementation of national research projects including standardised fitness testing, load and recovery monitoring and injury audits may enhance the understanding and evaluation of programmes for ensuring healthy athletic development. Furthermore, research exploring the interactions and integration between match-play characteristics, training load, physical qualities, fatigue recovery and injury would be deemed important rather than evaluation within isolation. A greater focus upon the psychological and holistic developmental needs of age-grade players (e.g., nutrition, illness, maturity, technical and tactical performance) are directions for future research that would inform coach and stakeholder education within RU.

Abbreviations

AU: Arbitrary Units

CK: Creatine Kinase

CV: Coefficient of Variation

GPS: Global Positioning Systems

PL: PlayerLoad

PL_{slow}: PlayerLoad slow

RAE: Relative Age Effect

RFU: Rugby Football Union

RU = Rugby Union

sRPE: Session Rating of Perceived Exertion

DECLARATIONS

Ethics approval and consent to participate

Not Applicable

Consent for publication

Not applicable

Availability of data and materials

Not applicable

Competing Interests

Kevin Till, Jonathon Weakley, Dale Read, Padraic Phibbs, Josh Darrall-Jones, Greg Roe, Sarah Chantler, Stephen Mellalieu, Michael Hislop, Keith Stokes, Andrew Rock and Ben Jones declare that they have no competing interests. Keith Stokes is the medical lead at the Rugby Football Union and Mike Hislop is employed by World Rugby but these positions did not influence the article in any way.

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Table 1. The locomotor characteristics of young rugby union players during match-play within England

Study	Level of Play	Age	Position	Sample Size (<i>n</i>)	Playing Time (min)	Total Distance (m)	Average Speed (m·min ⁻¹)	
Cunningham et al. [35]	International	U20	Forwards	21 (81)	87.6 ± 9.7	5370 ± 830	61.5 ± 8.0	
			Backs	19 (80)	90.4 ± 8.1	6230 ± 800	69.1 ± 7.6	
Phibbs et al. [9]	Academy	U18	Forwards	16	62.9 ± 17.8	4128 ± 1232	65.0 ± 5.7	
			Backs	15	69.2 ± 0.2	4770 ± 741	69.4 ± 5.5	
	School	U18	Forwards	15	61.1 ± 16.9	3884 ± 1255	58.7 ± 8.1	
			Backs	15	65.5 ± 14.0	4457 ± 1009	66.9 ± 8.4	
Read et al. [5]	School	U16	Forwards	16	62.5 ± 2.3	4364 ± 654	69.7 ± 9.2	
			Backs	15	58.8 ± 7.8	3841 ± 700	66.4 ± 9.4	
	University	U18	Forwards	18	66.2 ± 15.5	4232 ± 985	64.2 ± 5.4	
			Backs	16	65.7 ± 17.8	4489 ± 1299	68.3 ± 5.7	
		University	U18	Forwards	17	70.7 ± 21.4	4683 ± 1377	66.6 ± 5.0
				Backs	14	82.4 ± 10.7	5889 ± 719	71.1 ± 5.5
Read et al. [3]	County	U16	Forwards	20	49.3 ± 18.5	-	77.8 ± 5.4	
			Backs	15	52.1 ± 20.3	-	79.8 ± 10.5	
	County	U18	Forwards	21	51.1 ± 19.4	-	74.9 ± 6.8	
			Backs	19	52.9 ± 18.4	-	78.7 ± 7.0	
		U20	Forwards	18	59.9 ± 22.8	-	65.3 ± 3.2	
			Backs	19	61.8 ± 23.2	-	70.9 ± 8.7	
Read et al. [30]	Academy	U18	Forwards	7 (21)	76.4 ± 3.7	5461 ± 360	71.7 ± 6.6	
			Backs	12 (24)	76.4 ± 3.8	5639 ± 368	74.0 ± 6.6	
	School	U18	Forwards	25	74.1 ± 4.1	4881 ± 388	66.0 ± 5.0	
			Backs	25	74.2 ± 3.8	5260 ± 441	71.0 ± 5.4	
Roe et al. [33]	Academy	U18	Forwards	12 (43)	66.0 ± 13.0	4747 ± 1002	-	
			Backs	14 (38)	70.0 ± 11.0	5201 ± 810	-	
Roe et al. [32]	Academy	U18	All	14	73.6	4691 ± 878	74.0 ± 6.0	

Data are displayed as mean ± SD. Sample size is the number of participants in the study, followed by the total number of observations in brackets if different

Table 2. The speed threshold and PlayerLoad characteristics of young rugby union players during match-play within England

Study	Level of Play	Age	Position	Sample Size (n)	Speed Thresholds				PL	PL _{slow}
					Threshold 1	Threshold 2	Threshold 3	Threshold 4		
Cunningham et al. [35]	International	U20	Forwards	21 (81)				$>5 m \cdot s^{-1}$		
			Backs	19 (80)				$284 \pm 135 m$		
Phibbs et al. [9]	Academy	U18	Forwards	16		$<61\% MSS$	$61-90\% MSS$	$\geq 90\% MSS$	AU	
			Backs	15	$3901 \pm 1202 m$	$220 \pm 111 m$	$5 \pm 10 m$	$420 \pm 130 AU$		
	School	U18	Forwards	15	$4489 \pm 720 m$	$280 \pm 96 m$	$15 \pm 15 m$	$431 \pm 98 AU$		
			Backs	15	$3698 \pm 1217 m$	$138 \pm 114 m$	$0 \pm 1 m$	$399 \pm 141 AU$		
Read et al. [5]	School	U16	Forwards	16	$0-1.94 m \cdot s^{-1}$	$1.95-3.33 m \cdot s^{-1}$	$3.34-5.83 m \cdot s^{-1}$	$>5.84 m \cdot s^{-1}$	AU	AU
			Backs	15	$2007 \pm 218 m$	$1278 \pm 291 m$	$993 \pm 295 m$	$87 \pm 86 m$	$456 \pm 47 AU$	$231 \pm 24 AU$
	U18	Forwards	18	$2011 \pm 304 m$	$865 \pm 325 m$	$843 \pm 342 m$	$165 \pm 101 m$	$332 \pm 76 AU$	$152 \pm 34 AU$	
		Backs	16	$2099 \pm 546 m$	$1044 \pm 318 m$	$995 \pm 370 m$	$94 \pm 93 m$	$437 \pm 96 AU$	$224 \pm 51 AU$	
	University	Forwards	17	$2307 \pm 647 m$	$854 \pm 264 m$	$1009 \pm 444 m$	$319 \pm 176 m$	$395 \pm 118 AU$	$172 \pm 49 AU$	
		Backs	14	$2235 \pm 699 m$	$1271 \pm 400 m$	$1112 \pm 442 m$	$64 \pm 65 m$	$504 \pm 157 AU$	$250 \pm 76 AU$	
Read et al. [3]	County	U16	Forwards	20	$0-3.33 m \cdot s^{-1}$	$>3.34 m \cdot s^{-1}$		$AU \cdot min^{-1}$	$AU \cdot min^{-1}$	
			Backs	15	$55.2 \pm 4.1^*$	$22.6 \pm 2.9^*$		$7.3 \pm 0.6^{**}$	$3.1 \pm 0.3^{**}$	
		U18	Forwards	21	$52.1 \pm 5.1^*$	$27.7 \pm 7.7^*$		$6.8 \pm 1.2^{**}$	$2.4 \pm 0.3^{**}$	
			Backs	19	$54.9 \pm 4.3^*$	$20.2 \pm 6.9^*$		$7.6 \pm 1.0^{**}$	$3.3 \pm 0.3^{**}$	
		U20	Forwards	18	$53.2 \pm 5.4^*$	$25.5 \pm 4.6^*$		$7.2 \pm 1.1^{**}$	$2.7 \pm 0.4^{**}$	
			Backs	19	$50.7 \pm 4.8^*$	$14.5 \pm 3.4^*$		$6.9 \pm 0.7^{**}$	$3.4 \pm 0.4^{**}$	
					$50.4 \pm 6.2^*$	$20.6 \pm 3.9^*$		$6.1 \pm 1.0^{**}$	$2.6 \pm 0.4^{**}$	

Data are displayed as mean \pm SD. Sample size is the number of participants in the study, followed by the total number of observations in brackets if different

PL = PlayerLoad. PL_{slow} = PlayerLoad slow. MSS = Maximal sprint speed. AU = Arbitrary units. * $m \cdot min^{-1}$, ** $AU \cdot min^{-1}$

Table 3. The Training exposure of young English rugby union players

Study	Level of Play	Age Group	Sample Size (n)	Study Duration	Results
Palmer-Green et al. [45]	School	U18	250	2 seasons (2006-2007; 2007-2008)	72 h/season comprised of 58% rugby, 15% conditioning, 13% weights, 6% speed, 5% prehab, 3% other
	Academy	U18	222		190 h/season comprised of 37% rugby, 11% conditioning, 27% weights, 4% speed, 12% prehab, 9% other
Taylor et al. [49]	Academy	U18	10	6 weeks in season (178 training sessions / matches)	Mean weekly - training duration = 205±96 mins. The mean weekly internal loads were sRPE = 877±273 AU, bTRIMP = 271±97 AU, eTRIMP = 360±104 AU, luTRIMP = 295±92 AU, iTRIMP = 479±199 AU. Mean weekly external loads were total distance = 9939±2989 m, PL = 941±324 AU, iHSD = 3081±844 m, 15HSD = 2317±752 m, and 18HSD = 738±210 m.
Roe et al. [50]	Academy	U21	14	11 weeks pre-season	Mean weekly sRPE = 1810±310 AU
Weakley et al. [46]	School	U18	35	12 weeks in-season	Gym Frequency = 1.4±0.6, Training Load (sRPE) = 1014.0±1016.0 AU, Gym Training Time = 78.0±33.2 mins, Non-Gym Training Time = 120.0±151.0 mins, Training Time = 188.0±144.0, Lower Body Exercises Completed 1.5±0.8, Lower Body Volume Load Completed 1967.0±1352.0 kg, Upper Body Exercises Completed = 3.0±1.7, Upper Body Volume Load Completed = 3477±2248, Volume Load Complete = 5443.0±3423.0 kg
Phibbs et al. [47]	School	U16	31	1 week in-season	Duration = 50.1±6.6, sRPE = 123±39, avg HR = 145±8, total distance = 2672±456, average speed = 54.9±12.3, HSR = 751±242 and PL = 262±41.
		U18	39		Duration = 56.8±11.9, sRPE = 168±55, avg HR = 134±9, total distance = 2925±467, average speed = 54.59±10.4, HSR = 678±179 and PL = 270±42.
	Club	U16	36		Duration = 63.9±9.7, sRPE = 231±73, avg HR = 145±11, total distance = 3619±664, average speed = 56.8±7.4, HSR = 955±256 and PL = 354±74.
		U18	30		Duration = 70.3±8.8, sRPE = 230±67, avg HR = 148±14, total distance = 3845±577, average speed = 54.9±7.5, HSR = 597±246 and PL = 371±75.
	Academy	U16	18		Duration = 48.3±5.1, sRPE = 211±50, avg HR = 151±12, total distance = 2903±434, average speed = 59.9±5.7, HSR = 590±219 and PL = 316±53.
		U18	16		Duration = 62.0±0.0, sRPE = 236±42, avg HR = 151±12, total distance = 4176±433, average speed = 68.1±7.3, HSR = 1279±288256 and PL = 424±56.

Phibbs et al. [9]	School	U18 F	15	In-season (8 matches and 15 training sessions)	Duration = 76.7±12.9, total distance = 3433±300, LS = 3238±327, HSR = 276±71, VHSR = 21±30, MSS = 7.1±0.7, and PL = 345±43.
		U18 B	15		Duration = 76.7±12.9, total distance = 3821±386, LS = 3739±197, HSR = 275±105, VHSR = 4±9, MSS = 7.2±0.6, and PL = 350±48
	Academy	U18 F	16		Duration = 68.1±1.4, total distance = 4031 ± 755, LS = 3719±649, HSR = 252±120, VHSR = 5±9, MSS = 7.2±0.6, and PL = 345±43.
		U18 B	15		Duration = 68.3±1.3, total distance = 4678 ± 356, LS = 4393±348, HSR = 345±160, VHSR = 5±20, MSS = 7.9±0.6, and PL = 476±53.
Phibbs et al. [48]	Academy	U18	20	10 weeks in-season (97 complete weeks)	Total duration = 301±92 mins, Total sRPE = 1217±364 AU; Rugby duration = 214±64 mins, Rugby sRPE = 845±263 AU, Gym duration = 72±44 mins, Gym sRPE = 315±180 AU, Total distance = 11629±3445 m, VHSR = 20±38 m, PL = 1124±330 AU, PLslow = 542±165 AU
Phibbs et al. [13]	Academy	U18	20	14 weeks in-season (1,960 daily observations)	Total duration = 349±128 mins, Total sRPE = 1425±545 AU; Rugby match duration = 50±44 mins, Rugby match sRPE = 263±255 AU, Rugby training duration = 178±115, Rugby training sRPE = 662±465, Gym duration = 86±61 mins, Gym sRPE = 339±269 AU, Other duration = 36±62 mins, Other sRPE = 120±195 AU

Data are displayed as mean ± SD. Sample size is the number of participants in the study. F = Forwards, B = Backs, h/season = hours per season, sRPE = session rating of perceived exertion, bTRIMP = Banister training impulse, eTRIMP = Edwards training impulse, luTRIMP = Lucia training impulse, iTRIMP = individualised training impulse, AU = Arbitrary Unit, PL = PlayerLoad, iHSD = individualised high speed distance (> velocity at OBLA), 15HSD = high speed distance (>15km/h) and 18HSD = very high speed distance (>18 km/h), kg = kilograms, avg HR = average heart rate, LS = low speed running distance, HSR = high speed running, distance, VHSR = very high speed running distance, MSS = maximal sprint speed

Table 4. Sum of skinfolds, linear speed, momentum, change of direction speed and aerobic capacity qualities of youth rugby union players categorized by age and playing position (data presented as mean and standard deviation)

Age Category	Level and Position	Sample Size (n)	Sum of 8 Skinfolds (mm)	5m (s)	10m (s)	20m (s)	40m (s)	Initial Sprint Momentum (kg.s ⁻¹)	505 (s)	Yo-Yo IRTL1 (m)	30:15 (km.h ⁻¹)
Under 14	Academy [64]	5						446±114			
Under 15	Academy [64]	19						529±60			
Under 16	Academy [62]	29	88.8±41.9	1.05±0.09	1.82±0.12	3.10±0.19	5.66±0.37	426±67	L = 2.51±0.17 R = 2.54±0.14	1,145±337	18.4±1.3
	Academy Forwards [63]	15	109.7±44.6	1.09±0.11	1.88±0.12	3.21±0.18	5.87±0.30			971±328	18.0±1.4
	Academy Backs [63]	14	64.2±20.2	1.01±0.05	1.77±0.08	2.99±0.15	5.45±0.31		1,347±221	18.8±1.1	
	Academy [64]	23						563±75			
	Academy [60]	48								18.9±1.1	
Under 17	Academy [64]	4						609±57			
Under 18	Academy [62]	23	86.7±21.3	1.06±0.04	1.81±0.06	3.09±0.12	5.51±0.24	482±54	L = 2.57±0.12 R = 2.52±0.13	1,225±374	18.6±1.1
	Academy Forwards [63]	12	98.2±20.1	1.07±0.05	1.84±0.06	3.14±0.10	5.63±0.21			1,080±240	18.2±1.1
	Academy Backs [63]	12	72.7±12.9	1.05±0.04	1.79±0.06	3.02±0.10	5.34±0.17		1,467±451	19.2±1.0	

	School [65]	129			1.84±0.11	3.15±0.18	5.67±0.31			1,022±515
	Academy [65]	55			1.82±0.08	3.10±0.13	5.52±0.27			1,245±451
	Academy [61]	14	1.04±0.04		1.80±0.06	3.12±0.10	5.57±0.22			
	School [46]	35			1.90±0.09	3.23±0.13	5.80±0.24	443±58		
	Academy [60]	27								19.1±1.1
Under 21	Academy [62]	15	105.3±35.4	1.07±0.07	1.79±0.10	3.07±0.13	5.43±0.21	535±70	L= 2.41±0.10 R = 2.37±0.15	
	Academy Forwards [63]	9	119.4±34.0	1.09±0.07	1.82±0.10	3.12±0.11	5.52±0.17			
	Academy Backs [63]	6	84.1±27.5	1.05±0.07	1.76±0.12	3.02±0.15	5.32±0.22			
	Academy [60]	15								19.2±1.0

505 = Agility 505 Test; Yo-Yo IRTL1 = Yo-Yo Intermittent Recovery Test Level 1; 30-15 = 30-15 Intermittent Fitness Test; L = Left; R = Right. Please note initial sprint momentum was calculated at 8-12m [64] and 0-10m [62], respectively.

Table 5. Muscular strength and power qualities of youth rugby union players categorized by age, level and playing position (data presented as mean and standard deviation)

Age Category	Participants including Level, position and reference	Sample Size (n)	PPO Watt Bike test (W)	CMJ height (cm)	3RM Back Squat (kg)	3RM Front Squat (kg)	3RM Split Squat (kg)	3RM Bench Press (kg)	3RM Prone Row (kg)	3RM Chin Up (kg)
Under 14	Academy [64]	5	1054 ± 263							
Under 15	Academy [64]	19	1208 ± 193							
Under 16	Academy [62]	29		33.5 ± 4.8						
	Academy [64]	24	1242 ± 166							
Under 17	Academy [64]	4	1443 ± 41							
Under 18	Academy [62]	23		39.5±6.1		88.6±10.8	L = 62.2±13.1 R = 62.2±13.1	82.6±10.8	84.6±10.8	101.0±10.2
	School [65]	129						67.7±15.5		90.3±12.6
	Academy [65]	55						88.3±12.7		96.3±12.6
	School [46]	35		33.8±5.20	77.4 ± 32.6			68.5±12.8		88.0±11.2
	School Experienced* [67]	14				103.0±17.4		92.1±16.5		103.7±14.7
	School In-experienced** [67]	11				87.5±12.8		95.0±13.0		73.2±15.7
Under 21	Academy [66]	15		47.1±3.6		118.2±17.8	L = 112.8±15.6 R = 113.9±14.1	108.2±14.1	96.8±8.2	125.3±13.2

W = Watts; CMJ = Countermovement jump; 3RM = Three repetition maximum; L = Left; R = Right; *>2 years resistance training experience; ** >6 - <12 months resistance training experience .

Table 6. Fatigue and Recovery Profiles post match-play and training in male youth RU players from England

Study	Sample Level	Training / Match-Play	Measures	Results
Johnston et al. [89]	U21 Academy (n=15)	Training (Comparison of Speed-Weights vs Weights-Speed Training order)	CMJ, Muscle Soreness, Blood lactate, CK, testosterone and Cortisol	<p><i>Speed-Weights</i> CMJ – Pre = 0.40±0.05, 24 h = 0.37±0.06 m; CK – Pre = 485±420, 24 h = 1161±816 u/l; Testosterone – Pre = 16.3±3.7, 24 h = 17.4±4.0 mmol/l; Cortisol – Pre = 491±103, 24 h = 520±106 mmol/l; Lactate – Pre = 1.50±0.72, 24 h = 0.89±0.49 mmol/l; Soreness = 1.7±0.8, 24 h = 3.8±1.2 AU</p> <p><i>Weights-Speed</i> CMJ – Pre = 0.39±0.06, 24 h = 0.37±0.06 m; CK – Pre = 508±306, 24 h = 1122±946 u/l; Testosterone – Pre = 17.1±4.9, 24 h = 17.7±4.6 mmol/l; Cortisol – Pre = 516±199, 24 h = 514±100 mmol/l; Lactate – Pre = 1.25±0.66, 24 h = 1.31±0.77 mmol/l; Soreness = 1.9±0.9, 24 h = 3.7±1.1 AU</p> <p>Sig (p<0.05) time effects but no time vs protocol interactions found</p>
Noon et al. [90]	U18 College (n=10)	Training (Comparison of low vs high training volume)	CMJ, Wellbeing, Resting HR, HRV	Motivation (AU) Low = -0.7±1.7 High = -1.9±1.9; Sleep quality (AU) Low = 0.3±1.1 High = -1.0±1.1; Recovery (AU) Low = -0.2±1.7 High = -2.4±1.8; Appetite (AU) Low = 0.0±1.7 High = 0.7±0.9; Fatigue (AU) Low = 0.2±1.6 High = 0.9±1.6; Stress (AU) Low = 0.2±0.2 High = 0.6±1.6; Muscle soreness (AU) Low = 1.1±1.5 High = 2.0±1.7; CMJ Low = 37.2 ±4.4, High = 37.2±4.4 cm; Rest HR – Low = 58±1, High = 64±4 bpm; In SDNN – Low = 1.96±0.09, High = 1.88±0.13; In rMSSD – Low = 1.94±0.18, High = 1.81±0.18
Roe et al. [87]	U18 Academy (n=14)	Match-Play	Adductor Strength	Immediately = -1.3±2.5 %; ES = -0.11±0.21; 24 hours = -0.7±3%; ES=-0.06±0.25; 48 hours = -3.8±1.9%, ES = 0.32±0.16; 72 hours = 3.1±2.2%, ES = 0.26±0.18
Roe et al. [32]	U18 Academy (n=14)	Match-Play	CMJ, PPU, Plasma CK and perception of wellbeing	CMJ mean power immediately = -5.5±3.3%, 24 h = -7.0±3.9 %, 48 h = -5.8±5.4 %, 72 h = -0.8±3.8 %; PPU flight-time - Immediately = -15.3±7.3%, 24 h = -11.5±5.7%, 48 h = 3.5±6%, 72 h = -0.9±5.4%; Wellbeing - 24 h = -24±4.3%, 48 h = -8.3±5.9%, 72 h = -3.6±3.7%; CK - Immediately = 138.5±33.1%, 24 h = 326±77.6%, 48 h = 176.4±62.4%, 72 h = 56.7±34.5%
Roe et al. [88]	U18 Academy (n=20)	Training (Contact vs No Contact Training)	CMJ, PPU, CK, 6-item Wellbeing	CMJ mean power – 24 h post contact = -2.3±2.4 %, 24 h post non-contact = -5.4±5.2 % (<i>possibly</i> greater non-contact); PPU flight time - 24 h post contact = -7.3±24.7 %, 24 h post non-contact = 2.7±5.9 % (<i>very likely</i> greater contact); CK - 24 h post contact = 88.2±40.7 %, 24 h post non-contact = 0 % (<i>almost certainly</i> greater contact); Wellbeing - 24 h post contact = -8.0±4.8 %, 24 h post non-contact = -3.4±2.2 % (<i>likely</i> greater contact)

Roe et al. [50]	U20 academy (n=14)	Training (Pre-season changes)	CMJ flight time, mean power and mean force, maximum velocity and 3RM Front Squat	<p>CMJ Mean power – Likely, very likely or almost certain reductions at week 2 and 5 to 11</p> <p>CMJ Flight time – Likely, very likely or almost certain Reductions at week 2, 4 to 6 and 9 to 10.</p> <p>CMJ mean force – All findings trivial</p> <p>40 m Maximum Velocity – Very likely improvements in 40 m sprint velocity ($5.5 \pm 3.6\%$) occurred between week 1 and week 10</p> <p>3RM Front Squat - Possible improvements in lower body strength ($5.8 \pm 2.7\%$) were made from week 1 to week 10,</p>
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U = Under, CMJ = countermovement jump, CK = Creatine Kinase, HR = Heart rate, HRV = Heart rate variability, In rMSSD = root square of the mean squared differences of successive R-R intervals, In SDNN = natural logarithm of the standard deviation of R-R intervals, PPU = Plyometric Push Up, ES = Effect Size.

Table 7. Psychological challenges and development in male youth RU players from England

Study	Sample	Level	Measures	Results
Nicholls & Polman [105]	11	U18 National Squad	Stressor checklist, Coping responses, Perceived coping effectiveness	Most frequently-cited stressors: Making a mental or physical error, receiving coach/parental criticism, and injury; Coping strategies: Blocking, increasing effort, and taking advice: Blocking and technical adjustment rated as more effective strategies
Madigan et al. [104]	13	Further education Academy athletes	Perfectionism, Injury	Perfectionism positively predicted injury; only perfectionistic concerns emerged as a significant positive predictor; likelihood of sustaining injury increased twofold for each 1 SD increase in perfectionistic concerns
Hill & Appleton [103]	202	U19 Youth	Athlete burnout, Multidimensional perfectionism, Perfectionistic cognitions	Frequency of perfectionistic cognitions positively related to all symptoms of athlete burnout; Frequency of perfectionistic cognitions explained 3–4% unique variance in symptoms of athlete burnout after controlling for self-oriented and socially prescribed dimensions of perfectionism
Hill et al. [102]	15	Premiership Academy directors and Head coaches	Interview guide explored psychological aspects that may facilitate or derail talent development processes positive	Positive psychological characteristics: Cognitive ability, competitiveness, confidence & self-belief, consistency, courage, cultural identity, developmental awareness, driving group standards, effective communication, emotional intelligence, flexibility & adaptability, game understanding, grit. Dual-effect psychological characteristics: Aggression, obsessive passion, over-commitment, over-confidence, perfectionism, preestablished frameworks & beliefs, work-life balance. Negative Psychological Characteristics: Avoidance-based coping strategies, complacency, disorganised, expectation & entitlement, failure to overcome challenge, inappropriate goals, lack of awareness, lack of commitment, loss of focus/easily distracted, mental health, negative attitude, poor communicators, psychological burnout, self-doubt, self-handicapping, shyness.
McCarthy et al. [106]	821	U18 Academy	Player birth month distribution	Skewed birth date distribution across quartiles between observed and expected values; clear bias with Q1 (n = 336, 41%) and Q2 (n = 175, 22%), different to Q3 (n = 176, 21%) and Q4 (n = 134, 16%)

Q = Quartile (Q1=September-November, Q2=December-February, Q3=March-May, Q4=June -August).

Table 8. Summary of descriptive epidemiological studies of injuries conducted in youth RU players from England

Study	Study Length	Sample Level	Number of players	Number of exposure hours	Number of injuries	Results
Match Injury - greater than 24-hour time-loss						
Haseler et al. [120]	1 playing season (9 months)	U9 to U17 Club	210	1,636 player-match-hours	39	Overall match injury incidence – 24 / 1000 player-match-hours Mean severity – 32 days By injury location: Head/neck – 26%; Upper Limb – 31%; Trunk – 10%; Lower Limb – 33%
Palmer-Green et al. [119]	2 playing seasons	U18 Elite Schoolboy	222	3,843 player-match-hours	134	Overall match injury incidence – 35 / 1000 player-match-hours Mean severity – 27 days By injury location: Head/neck – 18%; Upper Limb – 24%; Trunk – 10%; Lower Limb – 47%
	2 playing seasons	U18 Academy	250	2,343 player-match-hours	109	Overall match injury incidence – 47 / 1000 player-match-hours Mean severity – 33 days By injury location: Head/neck – 14%; Upper Limb – 28%; Trunk – 3%; Lower Limb – 55%
Barden & Stokes [121]	3 playing seasons	U18 Elite Schoolboy	132	595 player-match-hours	46	Overall match injury incidence – 77 / 1000 player-match-hours Mean severity – 20 days By injury location: Head/neck – 32%; Upper Limb – 32%; Trunk – 10%; Lower Limb – 25%
		U18 Sub-elite Schoolboy		1,698 player-match-hours	57	Overall match injury incidence – 34 / 1000 player-match-hours Mean severity – 19 days By injury location: Head/neck – 15%; Upper Limb – 26%; Trunk – 6%; Lower Limb – 53%
Training Injury – greater than 24-hour time-loss						
Palmer-Green et al. [45]	2 playing seasons	U18 Elite Schoolboy	222	15,877 player-training-hours	34	Overall training injury incidence – 2.1 / 1000 player-training-hours Mean severity – 27 days By injury location: Head/neck – 9%; Upper Limb – 15%; Trunk – 32%; Lower Limb – 44%
	2 playing seasons	U18 Academy		250		47,431 player-training-hours