Strength and lower body power in international rugby sevens players:

Seasonal variations and the effects of travel

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Abstract

Maintaining strength and power during a rugby sevens tournament, and across an international season, is deemed important, yet the time course of changes in these characteristics is unclear in forwards and backs. During an international season, players undertake high intensity physical training to prepare for the demands of travel and competition. The aim of this research is to quantify changes in strength and power across an international rugby sevens season, and the effects of long-haul travel on neuromuscular function and tournament running demands. Two experimental studies were conducted to address these issues.

Body composition, upper body strength, lower body strength and power were measured to quantify changes over an international rugby sevens season at three time points: initial, early season and late season. Subjects were 14 international male players – seven forwards, seven backs (age 21.4 ± 2.2y; mean ± SD). Forwards were taller (185 ± 4 cm), heavier (95 ± 6 kg) and possessed a greater lean body mass (55.5 ± 4.0 $M \cdot S^{-0.14}$; M is body mass (kg), S is sum of skinfolds (mm)) than backs (181 ± 8 cm, 88.5 ± 5.5kg, 51.9 ± 3.4 $M \cdot S^{-0.14}$). Over the full season, small (~5% ± 5%; mean ± 90% confidence limits) positive changes occurred in body composition with players having increased muscle mass with decreased fat mass. Lower body strength gained during the pre-season decayed in-season (~4% ± 3% below initial levels), whereas upper body strength increased moderately (~10% ± 3%) across the season. Forwards showed a small decrease in lower body peak power (relative and absolute). There was a moderate decrease in mean power over the season for the forwards (~6% ± 6%), but conversely a moderate increase for the backs (~8% ± 6%). In-season difficulties in maintaining and improving power qualities indicates prescription of training loads could be position-specific to optimise strength and power.

Lower body power and tournament running demands were monitored over 17 tournaments to assess between-subject changes following long-haul (>5 h) travel in international rugby sevens players (22 male international players - age 21.7 ± 2.7 y, mass 89.0 ± 6.7 kg, stature 180.5 ± 6.2 cm; mean ± SD). A countermovement jump was used to assess lower body power over repeated three week travel and competition periods (pre-travel, post-travel, and post-tournament). Small decreases in peak power were evident post-travel (-4.0%, ± 3.2%; mean, ± 90% confidence limits) for combined short and long-haul travel, with further reductions in peak (-4.5%, ± 2.3%) and mean power post-tournament (3.8%,

± 1.5%) culminating in a moderate decrease in peak power overall (-7.4%, ± 4.0%). In a within-subject analysis completed on a sub-set of 12 players who competed in a minimum of 8 tournaments, long-haul travel elicited a large decrease in both lower body peak (-9.4%, ± 3.5%) and mean power (-5.6%, ±2.9%) over the monitoring period, with a small decrease (-4.3%, ± 3.0% and -2.2%, ± 1.7%) post-travel and moderate decrease (-5.4%, ± 2.5% and -3.5%, ± 1.9%) post-tournament respectively. In long-haul tournaments the 12 players covered ~13%, ± 13% greater total distance (m) and ~11%, ± 10% distance above 5 $m \cdot s^{-1 \cdot}$ distance above 5 $m \cdot s^{-1}$ (via global positioning system) than short haul tournaments. Effective pre- and post-travel management strategies are indicated to reduce neuromuscular fatigue and running load demands following long-haul travel.

There are unique physical demands for players competing in international rugby sevens. During a competitive season, forwards may struggle to maintain lower body strength and power likely due to specific positional demands. Long-haul travel can increase neuromuscular fatigue and tournament running demands. Practitioners should develop training plans to develop and maintain strength and power across the season, and maximise post-travel/tournament recovery.

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Publications by the Candidate Relevant to the Thesis

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Chapter 1: Introduction

Rugby sevens is a collision-based, fast, exciting modified version of 15-a-side rugby union. International teams compete in the Sevens World Series which is regarded as the highest level of competition in which 15 core nations compete in nine tournaments played in nine different countries over a period of eight months. In recent years there has been an increase in research quantifying what it takes to be a successful elite rugby sevens player, with focus on player physical traits as distinct to rugby union players (49, 78), physiological capabilities, skill and tactical demands (48, 77) and provided valuable metrics on the demands of competing in rugby sevens tournaments (38, 91). The seasonal challenges of meeting the demands of training, traveling and competing in international tournaments has not been investigated. Research into these variables will benefit coaching and support staff seeking to develop optimal training, travel and recovery schedules.

Rugby sevens has become a highly regarded international sport that is now well established on the world sporting calendar with inclusion in the 2016 Olympic Games. With this increased profile and professionalism comes a greater responsibility of national and international unions to ensure the development of rugby sevens whilst fostering the transition of players from rugby union and other collision-based sports into rugby sevens. Consequently, rugby sevens has a number of game characteristics that differ from rugby union that should be considered by coaching staff when planning physical preparation programmes (46). It is important to understand the rule modifications, the differing game demands and player pathways from rugby union, as well as the differing positional requirements of rugby sevens.

In achieving a better understanding of the abbreviated form of rugby union, the initial scope of rugby sevens research was limited to characterising the work rate profiles of games (73), analysing the biological effects from games (52) and surveying injury profiles of players during tournaments (36, 60). This information provided the platform for researchers to further investigate the demands of rugby sevens including monitoring training and game loads (32), profiling the anthropometric and physiological profiles of players in relation to game analysis (49, 77), and running demands at domestic and international levels (48, 75). More recently investigators have considered the role of upper body strength (74), lower body power (74), the relationship between travel and injury (37), tournament induced neuromuscular damage (91), and game demands measured over multiple tournaments (76).

Presently, there is growing evidence available to coaching and support staff to prepare players to compete in competitive rugby sevens. However, the sport has experienced a marked increase in professionalism, with core nations now supporting full-time rugby sevens programmes. There is additional pressure to perform from sponsors, supporters and home unions providing a constant challenge for researchers to remain at the cutting edge of rugby sevens. The next phase in extending the knowledge of this sport is to assess lower body strength and quantify the effects of training, competing and travelling over an international rugby sevens season.

Statement of problem

The body of knowledge pertaining to rugby sevens has primarily focused on obtaining cross-sectional data on player, game and tournament characteristics. To date there has been no longitudinal research into the seasonal physical demands of competing in an international rugby sevens competition in elite rugby sevens players. A rugby sevens season will typically consist of a pre-season training period in which coaching staff will endeavor to enhance player physical, physiological, tactical and game-skill abilities. The in-season training period will focus on maintaining and where possible, enhancing the traits developed in the pre-season. The challenge of retaining physical traits across the competitive season becomes even more complex when considering trans-continental long-haul air travel, the effect it has on international rugby sevens players and in turn on tournament running demands post-travel.

The game characteristics of rugby sevens requires players to have highly developed physiological traits and sport-specific skills. In order to develop the combination of physical traits required for rugby sevens such as strength, power, speed, agility and endurance, players must undertake a concurrent training format. Concurrent training typically involves performing training modes with contrasting physical adaptations during the same training phase (e.g. strength and endurance) (55). As such international players may be required to complete up to 4 training sessions in a day during the pre-season to develop the physical characteristics required for successful competitive performance, with this figure reducing during the in-season competition phase to maintain the gains made in the pre-season (5, 75).

Maintaining high levels of muscular strength and power are considered critical to success in collision-based sports (45, 75). The knowledge of between- and within-player variation in strength and power across the season will provide valuable information to coaching staff in optimising, then maintaining these physical traits throughout an international rugby sevens season.

Competing in the Sevens World Series requires teams to undertake substantial travel varying from as little as one hour through to more than 24 hours of accumulated flight time to participate in tournaments. This extended period of flight time exposes players to travel fatigue and jet lag which have been associated with placing both a physical and emotional burden on players (37, 57). Currently there is no evidence to suggest that rugby sevens players are exposed to a greater risk of injury as a result of extensive air travel crossing numerous time zones (37). Although accummulated flight time has been deemed influential when considering neuromuscular fatigue in rugby sevens players (91), coaching staff anecdotally make training modifications, provide suggested travel plans and schedule recovery sessions in an attempt to combat the effects of long-haul travel on players without the benefit of quantitative data obtained over multiple tournaments, over multiple seasons.

Therefore quantifying changes in player strength and power traits across an international competitive season should facilitate optimal periodisation in a concurrent training environment. Further, knowledge of changes in lower body power and match running demands following long-haul air travel will assist the planning and preparation for travel and competing in tournaments optimising performance.

Aims

The aims of the experimental studies contained within this thesis were to investigate changes in strength and power during a rugby sevens season and examine the effects of long-haul travel on rugby sevens players. The specific aims of each experimental study are as follows:

1. Quantify changes in body composition, upper body strength, lower body strength and lower body power over a season of international rugby sevens.

2. Profile lower body strength in international rugby sevens players, identify the differences between playing positions (i.e. forwards and backs) and compare these results with previously published values in collision-based sports.

3. Identify differences in strength and power qualities between playing positions in international rugby sevens players and the magnitude of changes across the season in forwards and backs.

4. Establish the effects of short- and long-haul travel combined with the demands of competing in a rugby sevens tournaments on lower body power.

5. Quantify and compare the differences in tournament running demands following short- and long-haul travel, and whether any differences were related to opposition quality and/or tournament finishing position.

Significance of thesis

The outcomes of the thesis will influence the development and planning of annual training programmes for rugby sevens. Examination of strength and power qualities will allow for the effective individualisation of pre-season and in-season physical training programmes. The outcomes of this thesis will guide coaching staff in specific player positional selection, the prescription of position specific skills and physical development training best suited to each phase of the annual training plan.

In combination with the physical training plan, consideration will be given to the effects of long-haul international travel. Coaching staff will have quantitative data identifying the potential decrement in lower body power following long-haul travel and the likely effect this will have on tournament running demands. Knowledge garnered from this thesis will allow modifications to training programmes pre- and post-travel, in conjunction with appropriate recovery methods to reduce the likely decrements in neuromuscular function.

Synopsis of thesis

This thesis contains six chapters. Each experimental chapter of the thesis (chapters three and four) is presented in manuscript format according to the requirements of the scientific journal to which it was submitted, with corresponding Abstract, Introduction, Methods, Results and Discussion sections. Consequently, there is some repetition between the chapters contained within this thesis. All references are located at the end of the thesis to improve the flow of the document.

Chapter One – Introduction.

Chapter Two –Review of Literature details a current view of the major physical and performance related topics in rugby sevens. The review includes game characteristics, physiological demands, strength and power characteristics, monitoring fatigue and the effects of long-haul travel.

Chapter Three – Variable changes in body composition, strength and lower body power during an international rugby sevens season profiles the differences between forwards and backs in relation to body composition, lower and upper body strength and lower body power and the changes that occur over an international rugby sevens season.

Chapter Four – Responses of lower body power and match running demands following long-haul travel in international rugby sevens players examines the relationship between long-haul travel and the effects of neuromuscular fatigue on tournament running demands over consecutive international rugby sevens seasons.

Chapter Five – Discussion reviews the impact of this thesis and its importance in the progression of knowledge pertaining to strength, power and travel in rugby sevens.

Chapter Six – Research Outcomes presents the primary findings of the thesis, practical outcomes and application of new knowledge, limitations of the research and suggestions for further research in the field.

Chapter 2: Literature Review

Strength and lower body power in international rugby sevens players: seasonal variations and the effects of travel

Introduction

Rugby sevens is a collision-based, high intensity modified version of 15-a-side rugby union first conceived in Melrose, Scotland – 1883 (63). Since this time, amateur and professional teams have competed in this annual club-level tournament. The growth in popularity of rugby sevens began internationally in 1973 with a centenary tournament held at Murrayfield stadium in Scotland, this was followed in 1975 with the inaugural Hong Kong sevens tournament. The first rugby sevens world cup was held 1993, and continues to be held throughout the world every four years. In 1998, rugby sevens became part of Commonwealth Games, and in 2009 rugby sevens was accepted to participate in the 2016 Olympic Games. Since 1999, the Sevens World Series has been regarded as the highest level of rugby sevens competition in which 15 core nations compete each year in nine tournaments played in nine different countries over a period of eight months. This intensive schedule requires international rugby sevens players to undergo a concurrent physical training programme in order to have highly-developed speed, mobility, power and endurance to tolerate the demands of tournament-style competition (48, 72).

In recent times the body of knowledge pertaining to rugby sevens has continued to grow as nations across the world prepare players for Olympic competition. This review will focus on the following topics relating to international men's rugby sevens:

- Game characteristics
- Physiological demands
- Strength and Power characteristics
- Monitoring fatigue
- Effects of long-haul travel.

Rugby sevens has progressed from an amateur club-level of competition to a highly regarded professional international sport. Research into rugby sevens has only recently become of interest following the sport's acceptance into the 2016 Olympic games. Research has primarily centred on game characteristics and physiological demands. To date there has been limited research into player strength and power characteristics, their changes over the course of a season and the implications of a demanding international playing schedule and travel on player physical preparation.

Characteristics of rugby sevens

Rugby sevens has a number of game characteristics that differ from rugby union that should be considered by coaching and support staff when planning physical preparation programmes. It is important to understand the rule modifications, the differing game demands and player pathways from rugby union, as well as the differing positional requirements of rugby sevens.

Rugby sevens is played on a standard size rugby field, with a reduced number of players and playing rule modifications providing a very open style of rugby. Games are played in a tournament-style format, typically consisting of up to a maximum of six games played over two to three days (48, 82). Games are comprised of two by seven minute halves with a two minute break for half-time. The time between games may vary from as little as 90 minutes through to 180 minutes. During international competition, teams are permitted 12 players of which only seven may take the field at one time. The substitution law permits seven starting players and up to five substitute players for all international rugby sevens games. These modified playing conditions dictate the type of rugby player and the physical characteristics they require to meet the demands of rugby sevens.

Rugby sevens players have traditionally come from a background of 15-a-side rugby union, which has implications for players and coaching staff when considering the physical preparation of rugby sevens players at the domestic and international level. Rugby union is characterised by repeated high intensity efforts with most periods of physical work lasting 4–15 secs with rest periods of up to 20 secs extending to 100 sec for outside backs (30). Research quantifying the running demands of rugby union games reports players covering up to ~7000 m in an ~80 min game at a rate of ~84 $m\cdot min^{1}$ with inside backs working at a rate of 76 $m\cdot min^{-1}$ and outside backs at 65 $m\cdot min^{-1}$ (9, 27). In contrast, rugby sevens players have higher relative running demands covering on average ~113 $m\cdot min^{-1}$, 45% greater distance per minute than rugby union with a higher proportion of that distance at high velocity (>6 $m\cdot s^{-1}$) (48).

Rugby sevens players spend 13% of game time in high intensity running (>5.5 m·s^{-1}), somewhat more than rugby union players who spend only 11% of game time in high intensity running (27, 83). These increased demands have been reported in both men's and women's rugby sevens (82, 83). It has been estimated that a game of rugby sevens played over the same time as a rugby union game would find rugby sevens players covering up to ~9000 m (27, 83). Table 1.1 provides a summary of match running differences between rugby union and rugby sevens. Further, there is a marked difference between running intensities at the domestic and international levels of rugby sevens with players in international tournaments having 6% higher maximal running velocities, covering 16–27% greater distance, and up to 39% more accelerations and decelerations (48, 75).

Table 1.1 Comparison of match running demands between rugby union and rugby sevens.

Match running variable	Rugby Union	Study	Rugby Sevens	Study
Work:rest ratio	1:5 to 1:6 (outside backs)	Austin et al., 2011	1:0.5	Suarez-Arrones et al., 2012
Distance covered (m)	~7000 (80 min game)	Austin et al., 2011	~9000 Tournament – 6 x 14 min games	Suarez-Arrones et al., 2012
Average speed (m·min^{-1})	65	Cunniffe et al., 2009	113	Suarez-Arrones et al., 2012
High speed running	11% of game time	Cunniffe et al., 2009	19% of game time	Ross et al., 2009

Rugby sevens players typically commence their playing career in rugby union as flankers, inside or outside backs before transitioning in adolescence to rugby sevens (75). Adolescent 15-a-side rugby union players cover a greater distance in games with more high intensity sprint efforts than in training (43). This decreased training intensity and preparation in adolescents is typically below the level required to meet the demands of rugby union. Rugby sevens players demonstrate acceleration, speed, muscular power, and endurance qualities similar to, or better than, professional rugby union players (49). Due to the higher intensity physical demands of rugby sevens, training intensity may need to be altered for adolescents and senior players transferring from rugby union. As such coaching and support staff will need to be cognisant of the potential physical preparation gap in running intensity between rugby union and rugby sevens (47, 48). Preparing to meet the increased running intensity has proved problematic whereby in one report citing a training analysis of 63 on-field rugby sevens training sessions, it was concluded that technical and game simulation drills failed to replicate the physical and physiological demands of competition (50). In that, relative to competition, training was characterised by less distance covered (large to extremely large differences), similar or lower maximal velocities (unclear to very large differences), less impacts (moderate to large differences), and similar or fewer accelerations (unclear to large differences). Additionally, there were fewer decelerations in training compared with games for all training drills except for forwards during moderate- to high-intensity skill-refining drills. Heart rate-based indicators of the physiological load of training activities were lower than during matches (50). It appears that for rugby sevens players to play at the highest level they must undertake a demanding training schedule replicating and exceeding the demands of rugby sevens games.

Rugby sevens players are categorised into two distinct playing positions, i.e. forward or back (75, 81). There are three forward playing positions comprised of a loose-head prop, hooker, tight-head prop and four back playing positions half back, fly-half, centre and winger. Numerous studies report no clear delineation between playing positions in rugby sevens in terms of measured aerobic/anaerobic capacities, upper body strength and relative counter movement jump power (49, 76). However, in training and competition rugby sevens forwards perform exclusive skill sets such as scrummaging, line outs and restarts. Game analyses indicate rugby sevens forwards spend 19% more time jogging and backs spend 8% more time running (73, 75). To date there has not been any investigation into forwards and backs in rugby sevens that specifically addresses lower body strength and a possible relationship with game specific skill sets.

Although there have been several investigations into the game characteristics of rugby sevens, there are a number of areas that require further investigation. First, game and tournament running demands utilising objective measures should be quantified using global positioning systems (GPS) across multiple tournaments over multiple seasons to determine if there are any trends specific to tournament locations, intensity and travel time. Additionally, given the different training and game demands of rugby union and rugby sevens it appears appropriate to develop specific physical performance standards for both forms of rugby (49). Finally, the exclusive skills sets of rugby sevens forwards and backs require careful consideration when planning the training programme to maximise the expression of lower body strength and power.

Physiological demands

Given the intermittent nature of rugby sevens, players are subjected to both aerobic and anaerobic energy system demands that exceed those of rugby union, requiring a specific anthropometric profile (high lean mass, low body fat) that is best suited for the game.

A well developed aerobic energy system enhances recovery after high-intensity repeated sprints experienced in rugby sevens games (75, 87). The aerobic energy demands of rugby sevens is reflected in heart rate responses observed during game play. Player heart rates will typically fall between 81–90% of HR_{max} for the majority of the game with a work to rest ratio of 1:0.5 (83). This higher intensity of effort contrasts the work to rest ratios identified in rugby union which range from 1:5 to 1:6 for backline players (9). Additionally, forwards will spend ~35% at >90% HR_{max} with backs spending ~28% at > 90% HR_{max}. This distribution of workload is similar in women's rugby sevens where players also spend 30% of game time at > 90% HR_{max} (48). Further, in an international rugby sevens game over ~14 min involving frequent sprinting, accelerating and decelerating players typically cover ~1600 m with ~19% at speeds exceeding 5 $m \cdot s^{-1}$ (75). Collectively these outcomes highlight the need for players to have a well developed aerobic capacity to undertake the training and tournament requirements of rugby sevens.

Aerobic energy demands in rugby sevens has been previously assessed using the Yo-Yo intermittent recovery 1 test (32, 49). This test consists of a sequence of a 20 m shuttle run followed by a 10 s rest, with this process continued until the player is no longer able to complete the 20 m shuttle in the allotted time. Studies performed in other sports indicate that the Yo-Yo intermittent recovery test is a more accurate predictor of on field performance in intermittent field-based sports, differentiating between athletes of different levels and for evaluating training programmes (56). It has been reported that rugby sevens players undertaking a Yo-Yo intermittent recovery 1 format covered a mean distance of 2256 m (49). In a subsequent study using the Multi Stage Fitness Test [consisting of continuous 20 m shuttle runs to exhaustion] rugby sevens forwards covered a mean distance of 2360 m with backs covering 2322 m with no clear difference between the two positions (78). Further international level rugby sevens players covered ~11% greater distance than data reported for professional rugby union backs (78). Due to the neuromuscular fatigue induced from participating in rugby sevens tournaments, the ability to improve player aerobic capacity would likely aid in maintaining physical performance throughout the tournament (83, 91). The ability to monitor fatigue levels pre, during and post tournaments in conjunction with aerobic capacity assessment will assist practitioners in evaluating pre-tournament preparation training programmes.

Anaerobic metabolism is required in rugby sevens to execute power-based movements such as tackling, scrummaging, intense accelerations, jumping, and application of force during rucking and mauling (46). The development of a high anaerobic capacity is paramount to the ability to sustain and repeat high-intensity activity. Energy expenditure and metabolic power has been assessed in rugby sevens using centre of mass/limb kinematics and running speed (via GPS). In this study, rugby sevens players had a greater anaerobic energy contribution compared to Australian Rules Football (36%) and soccer (18%) during a competitive game (38). The repeated high intensity sprints combined with game specific contact demands of scrums, rucks, mauls all contribute to the overall anaerobic energy needs of rugby sevens players (75). This ability to reproduce high intensity efforts has previously been assessed using a 6 x 30 m repeated-sprint ability test where players start each of the 6 sprints every 30 s (49). In research conducted using this protocol, players had a mean combined time of 24.76 s over 6 sprint efforts, however they were not differentiated by playing position (49). A further rugby sevens study using a 10 x 40 m repeat sprint ability protocol commencing every 30 s, found a very large difference between international and domestic level players with an unclear difference between forwards and backs (78). It appears that in both aerobic and anaerobic based testing protocols there is a clear delineation between international and domestic level rugby sevens players with no clear differences shown between forwards and backs. This suggests that conditioning training undertaken by rugby sevens players may be targeted towards the level of competition and not specifically addressing the differing skill sets of forwards and backs.

Speed and acceleration are regarded as critical components in rugby sevens and are associated with greater attacking performances (e.g. line breaks, tries scored, defenders beaten) (77). However, to date information pertaining to agility measures and success in rugby sevens has not been documented. Rugby sevens players have 10m sprint times (1.69 – 1.73 s) similar to those of rugby union backs (49). When rugby sevens players were differentiated between playing positions, backs were moderately faster over 5, 10 and 40 m (78). International players were faster over 5 m (small), 10 m (moderate) and 40 m (large) than provincial level players (78). During match play backs demonstrated a higher maximal velocity per game (moderate) and per tournament (moderate) than forwards (76). The link between sprint, jump and repeat sprint performance has been associated with defensive effectiveness and ruck play during games (77). As such ensuring the ability of players to enhance and maintain these qualities across the rugby sevens season is vital.

Anthropometrical measures such as body mass, height and body composition are commonly used in sport. These measures have been used in rugby sevens to distinguish between players at different levels, positional groups and to evaluate player physical and training programme progress (29, 49). Early studies in international rugby sevens players identified a mesomorphic somatotype to be negatively correlated with work-rate components such as work to rest ratios, distance, intensity and time (72, 73). However, in recent years there has been a trend towards international players being heavier than reported in 1996, with backs ~7 kg heavier and forwards 4 kg (49, 75). Rugby sevens players possess similar body mass (85–93 kg) and height (180–183 cm), while being substantially leaner (15–61% sum of seven skinfolds) than backs in professional rugby union (49). Forwards in rugby sevens are typically taller (~4%) and heavier (~11%) than backs, although the magnitude of difference is less than in rugby union, while international players are taller (~4 cm) and heavier (~7 kg) than provincial level players with backs reported to be ~9% leaner than forwards, as assessed in a sum of eight skinfold measurement (78). The use of a dual-energy X-ray absorptiometry (DXA) to measure the regional distribution of fat, non-osseous lean and bone mineral mass in rugby sevens is becoming more prevalent. Higham et al., (2014) reported forwards were typically heavier and exhibited higher absolute regional fat (20% to 26%), non-osseous lean tissue (6.9% to 8.4%) and bone mineral (5% to 11%) mass when compared to backs (44). In rugby union there is an advantage in having heavier and taller forwards for scrummaging, rucks, mauls and line outs whilst being highly mobile with a lighter body mass for rugby sevens (66). While there appears to be a clear delineation between forwards and backs in terms of anthropometry, an investigation into the effect body mass has on relative strength and power characteristics would be valuable to assist in determining appropriate training variables and in the selection of rugby sevens players.

Strength and power characteristics

Strength and power training are integral components of the rugby sevens training programme and have been identified as critical for success during attacking and defensive play (45, 75). A player's strength and power relative to body mass are related to acceleration, running velocity, and the ability to quickly change direction (69, 93). Absolute strength and power are essential to apply high forces rapidly in contact situations such as tackling, rucks, mauls and scrummaging (71). Strength is characterised by high load, low velocity movements with maximal force being generated by a muscle or groups of muscles at a specified velocity (54, 68). Strength in rugby sevens players is typically evaluated using a gym-based assessment of weightlifting exercises. Maximal strength is commonly assessed using the bench press exercise for the upper-body, and the back squat exercise for the lower-body (45). The performance in these exercises is often reported as a one-repetition maximum: the maximum weight lifted for a single repetition (1RM). This value can be measured directly or estimated based on the weight lifted for a higher number of repetitions (58). The results from these measurements are used to evaluate player strength levels, prescribe resistance training loads and provide direction in developing the desired qualities of strength and power required for rugby sevens.

High levels of muscular strength and power are considered critical to success in collision-based sports (75). Field-based contact team sports, such as rugby union and rugby league, are characterised by frequent high-intensity sprints and a high degree of physical contact (80). In rugby league, high levels of strength and power are required in order to effectively perform tackling, lifting, pushing and pulling tasks, and to tolerate the heavy tackles and collisions that occur during a match (40). To emphasise the importance of strength and power in collision-based sports, rugby union and rugby league have reported similar ranges for both lower and upper body strength in players – see Table 1.1 (2, 3, 5, 6, 11, 14, 19). Forwards in rugby union are generally stronger in absolute terms than backs in the lower (~12%) and upper body (~6%), likely due to requirements of strength in scrums and a higher frequency of tackles and rucks (2, 70, 81). However, when strength is assessed relative to body weight, backs are stronger in the back squat by ~3% and bench press by ~11% (1). When rugby union players have undergone strength assessments in the pre-season and end of the season and differentiated by playing ability, backs identified as having high playing ability [by the coach] had ~7% higher absolute lower body strength (as measured by a 1RM back squat) suggesting a relationship between lower body strength and playing performance (1).

Table 1.2 Comparison of absolute and relative squat scores between rugby codes with relative percentage difference

Study	Rugby Code	n	Body mass (kg)	Squat Absolute (kg)	Squat Relative (w.kg^{-1})
Appleby et al., 2009	Rugby Union	8**	94.3 ± 9.5	166.7 ± 27.3	1.8
Argus et al., 2009	Rugby Union	32	104.0 ± 11.2	194.0 ± 33.0*	1.8
Argus et al., 2010	Rugby Union	14	102.3 ± 10.3	172.4 ± 30.7*	1.7
Argus et al., 2011	Rugby Union	18	103.8 ± 10.6	147.9 ± 26.8*	1.4
Bevan et al., 2010	Rugby League	47	101.3 ± 12.8	181 ± 24.0	1.8
Baker et al., 2001	Rugby League	32***	91.7 ± 11.8	165.1 ± 19.1	1.8
Comfort et al., 2012	Rugby League	19	97.7 ± 11.1	200.8 ± 21.0	2.05 ± 0.2

*Box squat ** High level ability players only ***Professional and semi-professional players.

Given the high collision nature of rugby sevens, assessment of strength and power qualities would be advantageous in determining player readiness to participate in high collision activities. In rugby sevens, international players were ~17% stronger in the upper body than provincial level players and forwards were ~5% stronger than backs (78). Although cross-sectional comparisons are beneficial, coaches and support staff require more information on the patterns of within-and-between player changes, and variances in lower body and upper body strength that may occur and the effect on power across a full international rugby sevens season.

Power is expressed as the rate of performing work, calculated as the product of force and the velocity of movement and is demonstrated through the skills of sprinting, jumping and tackling in rugby sevens (54, 75). The vertical jump and its derivatives such as the squat jump, drop jump and countermovement jump have previously been used to assess power in sport (22, 86). Many different protocols and devices have been used to assess jump performance including maximal vertical jump height stand, contact mats, optical encoders, rotary encoders, accelerometers and force platforms. Force platforms are regarded as the “gold standard” in force measurement, however their lack of portability and sensitivity to vibration is problematic in preserving the integrity of the signal outside of the laboratory environment (26). A linear position transducer is reported to have acceptable validity, reliability and portability to estimate power similar to a force plate when measuring jump performance (26).

Power in rugby sevens is typically assessed in a countermovement jump using a linear position transducer to measure speed of movement and distance (75, 78) or using a vertical jump test (49). The primary variables of interest when analysing neuromuscular fatigue and performance in rugby sevens are peak power and relative peak power (78, 90). Using a vertical jump test, international rugby sevens players were shown to have similar, or better vertical jump (66 ± 7 cm) than professional rugby union players (49). Testing completed using a linear position transducer one month prior to rugby sevens tournaments (one international and one provincial), found international level players were ~29% more powerful than provincial level players and forwards were ~11% more powerful than backs (in both absolute and relative measures) (78). Players possessing greater peak power in countermovement jumps were shown to be more effective in both attacking and defensive rucks during game play (77). Power training in the form of jump squats is one modality likely to increase muscle stiffness providing benefits for sports requiring change of direction and agility movements such as rugby sevens (53, 62). Further research is required into power output variables and the time course, direction and magnitude of changes that may occur over a full season of rugby sevens. This information is useful in determining any player positional differences that may occur as a result of specific training requirements and game demands associated with scrummaging, line outs and restarts.

It is apparent that concurrent strength, power, rugby sevens skills practice and energy system training across the rugby sevens season needs to be considered carefully when developing the annual periodised plan to optimise the physical requirements of players. To date there has been limited research into the strength and power requirements of rugby sevens players and how they are affected by the demands of an international rugby sevens season.

Monitoring fatigue

The benefits of monitoring training loads and fatigue levels in athletes is well documented (33, 42). The primary aim of this process is to avoid overtraining and optimise performance gains (23). Monitoring player internal (qualitative variables) and external (quantitative variables) training loads also assists coaches and support staff in evaluating the effects of the training programme (16) and the physical demands of competing in international rugby sevens tournaments (91). In rugby league, training harder was likely to result in a higher incidence of injuries, additionally high strength and power training loads indirectly contributed to field based injuries. Consistent monitoring of training loads and thoughtful scheduling of field and gymnasium sessions facilitates reducing residual fatigue and minimising the effect of training related injuries (41).

To highlight the increased intensity and resultant fatigue of rugby sevens following a review of the 2008/09 Sevens World Series and 2009 Sevens World Cup, the risk of injury for international rugby sevens was reported to be two times higher than the rugby union 2007 World Cup (36). Both qualitative and quantitative assessment of player fatigue appear to be of importance in maintaining training quality and intensity (66). Qualitative assessment involves players recording a range of subjective measures linked to their perceived wellness and recovery on a daily basis, and are commonly referred to as internal measures. Players will typically enter personal data relating to perceived fatigue, stress, recovery, willingness to train, quality and length of sleep and sickness (32, 66). In addition heart rate data has been widely used, however this may have limitations when dealing with weight, interval, intermittent and plyometric training (33). Rate of perceived exertion (RPE) has become a popular method of recording internal or subjective stress, whereby the athlete rates the intensity of a session using the Borg Scale (1 nothing at all – 10 being extreme), this number is then multiplied by the session duration to give a workload figure (16). This training load figure provides a method by which coaching and support staff can monitor daily variations in session intensity over one week (acute load) and in comparison to the four weekly average load (chronic load). Weekly loads exceeding 150% of the four week average load are then flagged for potential injury and/or illness risk (33). Alternatively a short questionnaire consisting of eight-items focuses on the perception of training, sleep, leg pain, infection, concentration, efficacy, anxiety, irritability, and general stress has been used in rugby sevens to evaluate player internal fatigue (1 - Not at all to 7 - Very much) (32), however the variation of results from a questionnaire during intense training were not reported in swimmers (8). This questionnaire was found to provide practical and sensitive information for monitoring changes in training load and strain in rugby sevens (32).

Rugby sevens players are subject to reduced neuromuscular function over the course of an international rugby sevens tournament (90). This impairment is due to high intensity running (stretch-shortening based movements) and collisions that result in increased intramuscular proteins/enzymes in the blood (85, 91). Increase in the enzyme creatine kinase in the blood is indicative of skeletal muscle damage which is likely to impair neuromuscular function (91). Creatine kinase levels after one game of rugby sevens have been reported as being up to 18% higher increasing to 42% after two games (48, 85). Highlighting the level of high intensity running, total distance covered during a game has been reported to be ~1400m with ~250m at speeds distance above 5 $m \cdot s^{-1}$ (for players completing ≥70% of game time) (75, 76). Multiple games over consecutive days has shown small (4.6–8.4%) differences in low to moderate running velocities (<5 $m \cdot s^{-1}$) with unclear differences at higher velocities (distance above 5 $m \cdot s^{-1}$) having an overall cumulative effect over a rugby sevens tournament from the first to last match (48).

Neuromuscular fatigue in elite sport has been monitored using countermovement jumps in addition to assessing lower body power (21, 91). A countermovement jump monitoring protocol was used in rugby sevens involving the use of a force platform where players were required to complete 3 maximum jumps with a 90 s rest in between efforts. Results after jumps performed 12 h post-tournament showed a 26% reduction in power with this figure improving to an 8% reduction after five days (89). Due to the reported muscle damage and subsequent neuromuscular fatigue it would appear to be good practice to assess countermovement jumps across the international rugby sevens season. A linear position transducer is a portable and reliable power monitoring tool that may be beneficial in assessing training loads and the impact of travel undertaken by rugby sevens players participating in international tournaments (26).

Effects of long-haul travel

Travel fatigue and jet lag have been documented in elite athletes as the adverse effects of long-haul travel (35, 37). These adverse effects include impaired neuromuscular and cognitive function (57, 90). Travel fatigue is linked with the discomfort caused through immobility in a confined space, with inadequate sleep and experiencing mild hypoxia for extended periods of time (35). Jet lag is caused through the disturbance in an individual's circadian rhythm as a result of crossing numerous time zones resulting in altered sleep patterns (35, 79). Travel fatigue is reported to resolve within 24 h, whereas jetlag requires 12–24 h of recovery time for each time zone crossed (37, 79). Additionally, travel fatigue may continue to accumulate across the season characterised by persistent fatigue, recurrent illness, changes in behaviour and mood, and loss of motivation (79). The impact of travel fatigue and jet lag will vary for teams depending on the associated travel time to each tournament venue, with teams undertaking extensive travel possibly remaining fatigued and jet lagged throughout the duration of the tournament (37).

Competing in the Sevens World Series requires teams to undertake substantial travel varying from as little as one hour through to >24 h of accumulated flight time to participate in tournaments. Travel has been categorised as either domestic or international, where domestic travel may require up to 5 hours of travel to away games for athletes in North America and Australia (35). Domestic air travel within a single time zone has shown no change in grip strength or squat jump performance (64). Travel has been further classified into eastward and westward travel where grip strength has consistently shown reductions in both directions, with conflicting results being reported for a jump squat after eastward travel, with a decrease reported in one study and no change in another (18, 35). There are a number of physiological parameters associated with circadian rhythms such as heart rate, ventilation and blood lactate that have had inconsistent results (28). Additionally, more direct measures such as peak muscle force, anaerobic power output, grip strength and vertical jump have been used to assess the effects of air travel (35, 57).

A number of risk factors have been identified that may result in increased jet lag symptoms in individuals when undertaking long-haul travel. These risk factors include: people with rigid sleeping habits, chronotype differences – early risers have trouble travelling westward whereas late risers struggle with eastward travel with eastward travel direction being more problematic (57). Conversely, high levels of physical fitness allows a quicker adjustment, men have less trouble after 10 time zone travel in an eastward direction, older individuals may be less prone to jet lag, arrival time at midday in eastward travel over 10 time zones has shown less jet lag symptoms (57). There are several recommended practices that athletes may undertake to minimise the effects of jet lag and travel fatigue. Prior to travel start adjusting sleep and meal patterns to minimise the time zone difference between departure city and destination city. During travel, it is recommended to wear compression garments to counter oedema and deep vein thrombosis, minimise sleep disruption and adjust to destination time zone, optimising meals and hydration in line with the destination city (35, 66). Post travel adjust to the destination time zone (by seeking daylight or not) and complying with the destination time zone (either sleeping or waking) (57). Regardless, prolonged travel has been shown to place a physical and emotional burden on athletes (57). To date the impact of travel and tournament play on neuromuscular function and ability to perform athletic movements has not been investigated in rugby sevens players.

Conclusions

The game of rugby sevens delivers a complex training environment where rugby sevens skills, physiological demands, strength and power must be considered carefully across the full-season to optimise the physical requirements of players. To date there has been limited research into the strength and power requirements of rugby sevens forwards and backs. Therefore, understanding the strength and power characteristics of rugby sevens playing positions, and how they change across an international Sevens World Series season, becomes increasingly important when formulating the training programme.

The physical monitoring of rugby sevens players encompasses both qualitative and quantitative formats to report on player fatigue levels and adaptations in response to training and tournament demands. The Sevens World Series requires both short- and long-haul travel, and to date the effects on the neuromuscular system and tournament running demands have not been investigated. To determine if travel has a substantial impact on physical performance an investigation into pre-travel, post-travel and post-tournament neuromuscular function in conjunction with assessment of tournament running volume and intensity is indicated. Presently there are no reported longitudinal data presented examining international tournament running demands and neuromuscular fatigue. This knowledge will be valuable in planning travel and recovery modalities to ensure rugby sevens players minimise neuromuscular fatigue.

Declaration for Thesis Chapter 3: Variable changes in body composition, strength and lower body power during an international rugby sevens season

Declaration by candidate

In the case of Chapter 3 the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
John Mitchell	80%

The following co-authors contributed to the work:

Name	Nature of contribution	Extent of contribution (%)	Contributor is also a student at UC Y/N
Kate Pumpa	Manuscript review	7.5%	N
David Pyne	Data interpretation and manuscript review	7.5%	N
Kym Williams	Data interpretation and manuscript review	5%	Y

Candidate's Signature: 04/03/16

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s) **Australian Institute of Sport – Strength and Conditioning department**

[Please note that the location(s) must be institutional in nature, and should be indicated here as a department, centre or institute, with specific campus identification where relevant.]

Signature 1 **04/03/16**

Signature 2 **04/03/16**

Signature 3 **04/03/16**

Chapter 3: Variable changes in body composition, strength and lower body power during an international rugby sevens season

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Abstract

This study determined whether body composition, strength and power changes that occur during pre-season can be maintained during an international rugby sevens season. Fourteen male international rugby sevens players (age 21.4 ± 2.2 y; mean ± SD) were categorized as a forward (n=7) or back (n=7), and assessed for height, mass (M), skinfolds (S) (∑7), upper body (UB) strength, lower body (LB) strength and LB power. Bench press, back squat and a countermovement jump were used to measure strength and power at three time points: initial, early season and late season. Forwards were taller (185 ± 4cm), heavier (95 ± 6kg) and possessed a greater lean body mass (55.5 ± 4.0 $M \cdot S^{-0.14}$) than backs (181 ± 8cm, 88.5 ± 5.5kg, 51.9 ± 3.4 $M\ S^{-0.14}$). Over the full season, small (~5% ± 5%; mean ± 90% confidence limits) positive changes occurred in body composition. LB strength gained during the pre-season decayed in-season, whereas UB strength increased moderately (~10% ± 3%) across the season. Power showed inconsistencies between measured variables with a moderate positive change across the season in mean velocity and relative peak power. Forwards showed a small decrease in peak power (relative and absolute). Moderate changes were observed in mean power over the season, forwards decreasing (~6% ± 6%) and backs increasing (~8% ± 6%). Rugby sevens forwards in this study found it difficult to maintain and improve power qualities in-season. Training loads of forwards and backs should be differentiated to maximize strength and power in-season.

Key Words

Pre-season, in-season, back squat, bench press, countermovement jump

Introduction

Rugby sevens is a collision-based, high intensity modified version of 15-a-side rugby union. The Sevens World Series (SWS) is regarded as the highest level of competition in which 15 core nations compete in nine tournaments played in nine different countries over a period of eight months. International rugby sevens players require highly-developed speed, mobility, power and endurance to tolerate the physical demands of competition (48, 72). Players demonstrate acceleration, speed, muscular power, and endurance qualities that are similar to, if not better than, professional rugby union players (49). Rugby sevens players are categorized into 2 distinct playing positions, i.e. forward or back and typically commence their playing career in rugby union as a loose forward or back (75). Rugby sevens players cover on average 113 m per min, 45% greater distance per min than rugby union with a higher proportion of that distance at high velocity (>6 m s^{-1}) highlighting the high running demands required (48). Game analyses indicate rugby sevens forwards spend 19% more time jogging and backs spend 8% more time running (73, 75), although other studies reported no clear delineation between playing positions in rugby sevens (49, 76). However, rugby sevens forwards perform exclusive skill sets such as scrummaging, line outs and restarts in training and competition. These exclusive skills require careful consideration when planning the strength and conditioning program to maximize the expression of lower body strength and power.

To meet the demands of rugby sevens, players possess similar body mass and height to professional backs in rugby union, while being substantially leaner (49). Forwards in rugby sevens are typically taller and heavier than backs, although the magnitude of difference is less than in rugby union (78), while international players are taller and heavier than provincial level players (78). The anthropometric characteristics of international rugby sevens, players correlate with estimates of work-rate such as work-to-rest ratios, distance, intensity and time (72). As such, an investigation into the effect body mass has on relative strength and power characteristics would be valuable to assist in determining appropriate training variables and in the selection of rugby sevens players.

Field-based contact team sports, such as rugby union and rugby league, are characterized by frequent high-intensity sprints and a high degree of physical contact (80). In rugby league, high levels of strength and power are required to effectively perform tackling, lifting, pushing and pulling tasks, and to tolerate the heavy tackles and collisions that occur during a match (40). High levels of muscular strength and power are thought to be critical to success in collision-based sports (75). Given the high collision nature of rugby sevens it follows that assessment of strength and power qualities would be advantageous in determining player readiness to participate in high collision activities.

Several authors have highlighted the importance of strength and power in rugby sevens (49, 75, 81). Other collision-based sports such as rugby union and rugby league have reported comparable ranges of lower and upper body strength in players (1, 5, 14). Forwards in rugby union are generally stronger than backs in the lower and upper body, likely due to requirements of strength in scrums and a higher frequency of tackles and rucks (70, 80, 81). More recently, rugby union players were physically assessed in the pre-season and then differentiated at the end of the season by the coach into high and low playing ability groups. Backs identified as having high playing ability by the coach demonstrated higher absolute lower body strength as measured by a 1RM back squat suggesting a relationship between lower body strength and playing performance (1). In rugby sevens, international players appear to be stronger in the upper body than provincial level players and forwards are stronger than backs (78). Although cross-sectional comparisons are useful, practitioners need more information on the patterns of within-and-between athlete changes, and differences in lower body and upper body strength that may occur across a full international rugby sevens season.

Power in rugby sevens, expressed through the skills of sprinting, jumping and tackling, is typically assessed in a countermovement jump using a linear position transducer to measure speed of movement and distance (75, 78). Peak power and relative peak power are the primary variables of interest when analyzing neuromuscular fatigue and performance in rugby sevens (78, 90). In testing completed one month prior to rugby sevens tournaments (one international and one provincial), international level players and forwards were more powerful (than backs) in both absolute and relative measures (78). Players reported as possessing greater peak power in countermovement jumps were more effective in both attacking and defensive rucks during game play (77). Further research is required in characterizing power output variables and the time course, direction and magnitude of changes that may occur over a full season of rugby sevens. This information is useful in determining any player positional differences that may occur as a result of specific training requirements and game demands associated with scrummaging, line outs and restarts.

It is apparent that concurrent strength, rugby sevens skills practice and energy system training (or endurance) across the rugby sevens season needs to be considered carefully to optimize the physical requirements of players. To date there has been limited research into the strength and power requirements of rugby sevens players. With the inclusion of rugby sevens as an Olympic sport, the strength and power characteristics of rugby sevens playing positions and how they change across an international SWS season becomes increasingly important when formulating a periodized annual plan.

Methods

Experimental approach to the problem

To establish whether changes occurred across the season, initial upper body and lower body strength and lower body power measurements were collected in bench press, back squat and an instrumented countermovement jump at the start of the pre-season (initial), start of the competition season (early season) and end of the competition season (late season). Changes within-subjects and differences between forwards and backs were assessed for pre-season (initial to early season), in-season (early to late season) and full season (initial to late season). Effects were quantified to establish whether there had been substantial changes between phases and/or the full season as a result of the training and game demands of playing international Rugby sevens.

Subjects

Fourteen male international rugby sevens squad players (seven backs and seven forwards) participated in this study (age 21.4 ± 2.2 y; mean ± SD). These players had ~1.7 years of specific international rugby sevens training and playing experience (range 1–4 years). Each player was informed of the benefits and risks of this investigation prior to signing a University of Canberra informed consent document to participate in this study. This study was approved by the University of Canberra Committee for Ethics in Human Research (Project 12-68).

Procedures

The SWS season consisted of 40 weeks that were divided into the pre-season and in-season training periods. The pre-season training period consisted 12 weeks, one regional international tournament, and ~3 lifting sessions per week (n=13 upper body, n=12 lower body and n=11 combined upper/lower sessions) with an average weekly running volume of ~12km. The in-season training period consisted of 28 weeks, 9 SWS tournaments, ~2.5 lifting sessions per week (n=40 upper body, n=33 lower body sessions) with an average weekly running volume of ~15km. Players completed lifting programs that were tailored to the individual's training experience, musculo-skeletal concerns and rugby sevens requirements. Testing was conducted as part of regular strength and conditioning lifting sessions (see Table 3.1) in line with the rugby sevens periodized plan. Tables 3.2 and 3.3 provide examples of pre-season, in-season and tournament training weekly schedules. Tests were selected using recommendations for the assessment of rugby union players as previously documented (45). Players were instructed to consume their regular pre-training diet, and where possible, refrain from intense exercise at least 48 hours prior to any scheduled testing. Only data collected on players free of injury and illness at the time of testing are reported.

Table 3.1. Key exercises performed during strength and conditioning lifting sessions

Upper body Lift	Lower body Lift	Combined Lift	In-tournament Lift 1 – Strength	In-tournament Lift 2 – Power
Jump Squats	Olympic Lift**	Olympic Lift**	Olympic Lift**	Jump Squats
Bench Press	Squat or Box Squat	Deadlift	Squats	Bench Press*
Chin Ups	Romanian Deadlift	Bench Pull	Bench Press	Push Press
Military Press			Chin Ups	

*Explosive with bands for accommodative resistance. ** Power Clean or Snatch variations.

Table 3.2. ***Pre-season and in-season standard weekly training plans***

Phase	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
Pre-Season	Combined Lift Conditioning Field skills training	Upper Lift Speed Skills	Conditioning	Speed Lower Lift	Field skills training	Recovery	Off
In Season	Lift* Speed Field skills training	Lift* Conditioning Field skills training	Recovery	Speed Field skills training	Lift* Conditioning Field skills training	Field skills training	Off

*Lift is alternate day upper the lower body focus.

Table 3.3. Example of a Sevens World Series tournament week

Game + 1*	Game + 2	Game -3**	Game -2	Game -1	Game Day 1	Game Day 2
Recovery Field skills training	Mixed Lift 1 Game simulation	Recovery Field skills training	Mixed lift 2	Field skills training	3 games Recovery	2/3 games Recovery

* +1 representing one day post games/travel. ** -3 representing three days prior to game day 1

Body composition was assessed by measurement of body mass, height and skinfold thickness using standard laboratory techniques (45). The sum of seven sites (mm): biceps, triceps, subscapular, suprailiac, abdomen, front thigh and medial calf skinfolds, is reported. The typical error of measurement for sum of seven skinfolds is 1.3 mm and <1% for body mass and height. A lean mass index (LMI) was calculated for each subject as $M \cdot S^{-0.14}$, where M is body mass (kg) and S is sum of skinfolds (mm) (45).

Upper body and lower strength was assessed using an estimated one repetition maximum (1RM) for the bench press and back squat exercises respectively (1, 45). The bench press required the player to lay in a supine position, and using a self-selected grip width to lower a free weight barbell to their chest and then return the barbell to full arm extension. Players were not permitted to bounce the bar off the chest, and the feet and hips had to remain in contact with the ground and bench respectively. The grip width was self-selected by the subject in accordance with previous protocols. The back squat required the subject to support a free weight barbell on his upper back, and through movements of the lower body, descend to a depth whereby the anatomical hip crease had moved below the apex of the patella. Players were instructed to have a comfortable foot placement approximately shoulder width apart with feet abducted. No supportive equipment of any kind was permitted during the back squat. Testing loads were based on previous training loads as determined by the strength and conditioning coach (1). Subjects then completed the following preliminary loads 5 x 65%, 5 x 75% and 3 x 85% of their predicted 1RM. Players were required to lift 95% of their prescribed 1RM load to failure. An estimated 1RM was determined from the final number of completed repetitions at the 95% load using an established 1RM prediction equation (17). Data for the bench press and back squat is presented in absolute and relative terms, and scaled allometrically to the power of 0.62 as recommended in previous studies (25, 75).

Lower body muscular power assessment was assessed using a linear position transducer given acceptable validity, reliability and portability to estimate power similar to a force plate when measuring jump performance (26). Prior to the lower body muscular power assessment all players completed a 10 minute standardized warm-up using a space approximately 20m long x 3m wide consisting of a series of dynamic exercises (e.g. 60–70% jogging, lateral/carioca, low to high skipping, jumping/hopping, dynamic hamstring/quadriceps/low back movements) (90). The linear position transducer was anchored to the ground on the right side of the player and attached to the right hand side of a broomstick (45g). In the start position the subject was required to support the broomstick on his upper back [with their hands], and through movements of the lower body perform a countermovement jump. The foot position and depth of the countermovement jump was self-selected by the player with the instruction to jump as high as possible (6). Players completed six countermovement jumps with allowance to reset the feet to the start position between repetitions, with the mean value of all six jumps being reported. A displacement-time curve for each jump was obtained by attaching a digital optical encoder via a cable (GYMAWARE Power Tool. Kinetic Performance Technologies, Canberra, Australia) to one side of the broomstick. This data was uploaded to the GYMAWARE website then exported to Excel for analysis. This system recorded displacement-time data for reported measures (see Table 3.6) with a mean coefficient of variation of 13% and intraclass correlation of 0.815.

Statistical Analyses

Descriptive data are reported as mean and standard deviation (SD). Inferences on changes in a body composition or strength/power test score from phase to phase of the rugby sevens season were made using a student's t-test for dependent samples. Precision of estimation was indicated with 90% confidence limits. Effect sizes were reported in standardized (Cohen) units as the change in the mean with 90% confidence limits (51). Criteria to assess the magnitude of observed changes were: 0.0 to 0.2 trivial; 0.20 to 0.60 small; 0.60 to 1.20 moderate; and > 1.20 Large. An effect was deemed unclear if its confidence interval spanned both substantial positive and substantial negative values (± 0.20 x between-subject SD) (51).

Results

Rugby sevens forwards were substantially taller, heavier and possessed greater lean muscle mass than backs (see Table 3.4). The combined cohort of backs and forwards showed little change in body mass, skinfolds and lean muscle mass across the overall course of the season. The backs showed small (~5% ± 5%; mean ± 90% CL) decreases in skinfolds over the full season, with a small increase in lean mass in-season.

Both forwards and backs showed small (~7% ± 4%) increases in lower body strength in the pre-season (see Table 3.5). Backs had a moderate (~10% ± 3%) increase in lower body strength (back squat) in the pre-season when expressed relative to body weight and allometrically scaled, whereas changes in the forwards were unclear and trivial respectively. The increases in lower body strength gained during the pre-season were lost in-season with the backs having the same levels by the end of the season and the forwards decreasing (~4% ± 3%) below initial levels. Conversely, upper body strength (bench press) showed small (forwards) to moderate (backs) improvements over the full season. Backs exhibited the biggest increases in the pre-season (~9% ± 4%) plateauing in-season to show a moderate increase by the end of the season, while the forwards continued to have small increases in upper body strength throughout the season (~5% ± 3%).

Lower body power scores in the countermovement jump are presented in Table 3.6. The combined cohort showed moderate positive changes (~6% ± 4%) across the season in mean velocity. Backs had a small increase in peak velocity with moderate increases in mean velocity, mean power and mean power $w.kg^{-1}$ (~8% ± 6%). Forwards showed small increases (~3% ± 3%) in peak velocity in the pre-season with moderate (~18% ± 7%) decreases in peak power both absolute and relative with no change in jump height. All power variables for forwards showed a marked decrease over the full season. In both backs and forwards moderate changes (positive and negative) were observed in mean power both relative and absolute for the full season.

Table 3.4. Changes in anthropometric measures from the initial to early season (Pre-Season), early season to late season (In-Season), Initial to late season (Full-Season) phases. Mean change ± 90% confidence limits (CL)

	Time point			Standardized mean change (Cohen's)		
	Initial	Early Season	Late Season	Pre-season	In-season	Full-season
Body Composition	x ± *SD*	x ± *SD*	x ± *SD*	Δx ± 90%CL	Δx ± 90%CL	Δx ± 90%CL
Players Combined n=14						
Height (cm)	183.2 ± 6.4	183.2 ± 6.4	183.1 ± 6.3			
Mass (kg)	92.1 ± 7.1	91.5 ± 6.3	92.2 ± 6.5	-0.07 ± 0.11	0.09 ± 0.09	0.02 ± 0.15
Skinfolds - ∑ 7 sites (mm)	54.5 ± 11.6	53.59 ± 10.9	51.65 ± 12.5	-0.07 ± 0.25	-0.16 ± 0.18	-0.23 ± 0.34 *
LMI (M $S^{-0.14}$)	53.6 ± 3.9	53.4 ± 3.8	54.09 ± 4.0	-0.06 ± 0.09	0.17 ± 0.07	0.11 ± 0.13
Backs n=7						
Height (cm)	181.1 ± 7.8	181.1 ± 7.8	181.1 ± 7.8			
Mass (kg)	89.1 ± 6.3	88.0 ± 5.6	88.6 ± 5.0	-0.14 ± 0.14	0.08 ± 0.12	-0.06 ± 0.20
Skinfolds - ∑ 7 sites (mm)	50.8 ± 7.6	49.2 ± 9.4	46.7 ± 10.0	-0.18 ± 0.38	-0.29 ± 0.27 *	-0.47 ± 0.55 *
LMI (M $S^{-0.14}$)	51.8 ± 3.6	51.5 ± 3.3	52.3 ± 3.40	-0.08 ± 0.10	0.21 ± 0.11 *	0.13 ± 0.17
Forwards n=7						
Height (cm)	185.2 ± 4.2	185.3 ± 4.1	185.1 ± 4.2			
Mass (kg)	95.1 ± 6.7	95.0 ± 5.2	95.8 ± 6.1	-0.01 ± 0.20	0.11 ± 0.15	0.10 ± 0.25
Skinfolds - ∑ 7 sites (mm)	58.2 ± 14.2	57.94 ± 11.0	56.6 ± 13.5	-0.01 ± 0.39	-0.08 ± 0.28	-0.10 ± .50
LMI (M $S^{-0.14}$)	55.5 ± 3.6	55.3 ± 3.5	55.8 ± 3.9	-0.03 ± 0.19	0.12 ± 0.12	0.09 ± 0.25

*0.2 -0.6 -Small ** 0.6-1.2 - Moderate

Table 3.5. Changes in lower and upper body strength measures from the initial to early season (Pre-Season), early season to late season (In-Season), Initial to late season (Full-Season) phases. Mean change ± 90% confidence limits (CL)

	Time point			Standardized mean change (Cohen's)		
Strength	Initial x ± *SD*	Early Season x ± *SD*	Late Season x ± *SD*	Pre-season Δx ± 90%CL	In-season Δx ± 90%CL	Full-season Δx ± 90%CL
Players Combined n=14						
Lower Body Strength						
Squat Absolute (kg)	143.4 ± 23.3	152.10 ± 22.3	142.4 ± 17.9	0.35 ± 0.24 *	-0.39 ± 0.23 *	-0.04 ± 0.17
Squat Relative ($w.kg^{-1}$)	1.6 ± 0.2	1.7 ± 0.2	1.6 ± 0.2	0.43 ± 0.30 *	-0.48 ± 0.27 *	-0.05 ± 0.22
Squat ($w.kg^{0.62}$))	8.6 ± 1.0	9.2 ± 1.1	8.6 ± 1.0	0.59 ± 0.34 **	-0.59 ± 0.34 **	0 ± 0
Upper Body Strength						
Bench Absolute (kg)	114.2 ± 12.5	120 ± 11.2	124.4 ± 12.3	0.44 ± 0.25 *	0.33 ± 0.17 *	0.77 ± 0.30 **
Bench Relative ($w.kg^{-1}$)	1.2 ± 0.1	1.3 ± 0.2	1.4 ± 0.2	0.45 ± 0.26 *	0.24 ± 0.15 *	0.70 ± 0.27 **
Bench ($w.kg^{0.62}$)	6.9 ± 0.8	7.3 ± 0.7	7.5 ± 0.8	0.29 ± 0.17 *	0.29 ± 0.17 *	0.76 ± 0.29 **
Backs n=7						
Lower Body Strength						
Squat Absolute (kg)	133.7 ± 22.0	145.6 ± 20.7	138.3 ± 18.7	0.47 ± 0.34 *	-0.29 ± 0.34 *	0.18 ± 0.19
Squat Relative ($w.kg^{-1}$)	1.5 ± 0.2	1.7 ± 0.2	1.6 ± 0.2	0.75 ± 0.52 **	-0.46 ± 0.46 *	0.29 ± 0.22 *
Squat ($w.kg^{0.62}$)	8.3 ± 1.1	9.1 ± 1.0	8. 6 ± 0.9	0.64 ± 0.45 **	-0.39 ± 0.41 *	0.25 ± 0.21 *
Upper Body Strength						
Bench Absolute (kg)	114.8 ± 9.8	122.3 ± 10.9	124.5 ± 12.0	0.66 ± 0.39 **	0.20 ± 0.34 *	0.86 ± 0.47 **
Bench Relative ($w.kg^{-1}$)	1.3 ± 0.1	1.4 ± 0.2	1.4 ± 0.2	0.69 ± 0.39 **	0.12 ± 0.26	0.80 ± 0.34 **
Bench ($w.kg^{0.62}$)	7.1 ± 0.6	7.6 ± 0.7	7.7 ± 0.8	0.72 ± 0.41 **	0.16 ± 0.30	0.88 ± 0.41 **
Forwards n=7						
Lower Body Strength						
Squat Absolute (kg)	153.2 ± 21.6	158.6 ± 23.4	146.6 ± 17.5	0.22 ± 0.39 *	-0.48 ± 0.39 *	-0.26 ± 0.22 *
Squat Relative ($w.kg^{-1}$)	1.6 ± 0.3	1.7 ± 0.2	1.5 ± 0.2	0.16 ± 0.37	-0.44 ± 0.37 *	-0.28 ± 0.26
Squat ($w.kg^{0.62}$)	9.1 ± 1.4	9.4 ± 1.3	8.7 ± 1.1	0.19 ± 0.38	-0.46 ± 0.39 *	-0.28 ± 0.24
Upper Body Strength						
Bench Absolute (kg)	113.7 ± 15.5	117.8 ± 11.7	124.4 ± 13.7	0.23 ± 0.33 *	0.37 ± 0.15 *	0.60 ± 0.41 **
Bench Relative ($w.kg^{-1}$)	1.2 ± 0.2	1.2 ± 0.1	1.3 ± 0.1	0.23 ± 0.37 *	0.32 ± 0.18 *	0.55 ± 0.45 *
Bench ($w.kg^{0.62}$)	6.8 ± 0.88	7.0 ± 0.6	7.4 ± 0.7	0.24 ± 0.36 *	0.35 ± 0.17 *	0.58 ± 0.44 *

*0.2 -0.6 -Small ** 0.6-1.2 - Moderate

Table 3.6. Changes in lower body power measures from the initial to early season (Pre-Season), early season to late season (In-Season), Initial to late season (Full-Season) phases. Mean change ± 90% confidence limits (CL)

	Time point			Standardized mean change (Cohen's)		
	Initial	Early Season	Late Season	Pre-season	In-season	Full-season
Power	x ± *SD*	x ± *SD*	x ± *SD*	Δx ± 90%CL	Δx ± 90%CL	Δx ± 90%CL
Players Combined n=14						
Jump Height (m)	0.49 ± 0.07	0.50 ± 0.06	0.50 ± 0.07	0.21 ± 0.41	-0.01 ± 0.23	0.20 ± 0.38 *
Peak Velocity (m/sec))	3.8 ± 0.3	3.9 ± 0.3	3.8 ± 0.4	0.30 ± 0.29 *	-0.17 ± 0.24	0.14 ± 0.34
Mean Velocity (m/sec)	2.4 ± 0.2	2.5 ± 0.2	2.5 ± 0.2	0.45 ± 0.52 *	0.23 ± 0.44	0.69 ± 0.56 **
Peak Power (W)	7764 ± 1443	7643 ± 1177	7194 ± 1526	-0.08 ± 0.22	-0.29 ± 0.31	-0.37 ± .38
Mean Power (W)	4402 ± 558	4502 ± 442	4453 ± 615	0.17 ± 0.40	-0.08 ± 0.32	0.09 ± 0.41
Peak Power ($w.kg^{-1}$)	84.7 ± 15.2	83.7 ± 13.6	78.1 ± 17.4	-0.07 ± 0.20	-0.34 ± 0.34 *	-0.41 ± 0.39 *
Mean Power ($w.kg^{-1}$)	48.0 ± 5.7	49.2 ± 5.3	48.4 ± 7.5	0.20 ± 0.39*	-0.14 ± 0.34	0.06 ± 0.43
Backs n=7						
Jump Height (m)	0.52 ± 0.88	0.54 ± 0.06	0.55 ± 0.07	0.30 ± 0.62	0.03 ± 0.36	0.33 ± 0.57
Peak Velocity (m/sec))	3.9 ± 0.3	4.0 ± 0.3	4.0 ± 0.3	0.28 ± 0.50	0.08 ± 0.32	0.36 ± 0.54 *
Mean Velocity (m/sec)	2.4 ± 0.2	2.5 ± 0.2	2.6 ± 0.1	0.49 ± 0.75	0.46 ± 0.61*	0.96 ± 0.56 **
Peak Power (W)	7752 ± 1236	7755 ± 1119	7991 ± 1507	0.00 ± 0.39	0.17 ± 0.45	0.17 ± 0.44
Mean Power (W)	4451 ± 445	4640 ± 492	4821 ± 467	0.37 ± 0.79 *	0.35 ± 0.59 *	0.72 ± 0.51 **
Peak Power ($w.kg^{-1}$)	87.7 ± 13.4	87.7 ± 12.4	89.5 ± 16.2	0.00 ± 0.33	0.12 ± 0.51	0.12 ± 0.47
Mean Power ($w.kg^{-1}$)	50.4 ± 4.9	52.4 ± 5.3	54.0 ± 5.3	0.36 ± 0.68	0.30 ± 0.60	0.66 ± 0.53 **
Forwards n=7						
Jump Height (m)	0.46 ± 0.04	0.46 ± 0.03	0.46 ± 0.03	0.03 ± 0.68	-0.09 ± 0.33	-0.06 ± 0.52
Peak Velocity (m/sec))	3.6 ± 0.3	3.7 ± 0.3	3.6 ± 0.3	0.34 ± 0.42 *	-0.50 ± 0.35 *	-0.16 ± 0.43
Mean Velocity (m/sec)	2.4 ± 0.1	2.4 ± 0.1	2.4 ± 0.1	0.29 ± 0.69	-0.18 ± 0.45	0.11 ± 0.90
Peak Power (W)	7777 ± 1726	7531 ± 1312	6397 ± 1137	-0.12 ± 0.26	-0.57 ± 0.22 *	-0.70 ± 0.36 **
Mean Power (W)	4352 ± 686	4364 ± 369	4084 ± 535	0.02 ± 0.45	-0.36 ± 0.22 *	-0.34 ± 0.43 *
Peak Power ($w.kg^{-1}$)	81.8 ± 17.4	79.6 ± 14.6	66.8 ± 9.7	-0.11 ± 0.27	-0.64 ± 0.27 **	-0.75 ± 0.40 **
Mean Power ($w.kg^{-1}$)	45.7 ± 5.9	46.0 ± 3.0	42.7 ± 4.2	0.05 ± 0.56	-0.49 ± 0.25 *	-0.44 ± 0.52 *

*0.2 -0.6 -Small   ** 0.6-1.2 - Moderate

Discussion

This is the first study to quantify the changes in body composition, strength and power as they relate to playing position over a full season of international rugby sevens. During the pre-season, early season and late season phases, upper body strength showed small improvements for the full season, whereas lower body strength increased in the pre-season before falling away in-season. Lower body power increased in the backs and decreased in the forwards over the duration of the season. The upper body and lower body strength scores confirm preliminary reports that rugby sevens players display similar physical qualities to outside backs in rugby union. Given the different time course of changes in strength and power between forwards and backs it is prudent for the strength and conditioning coach to prescribe position-specific training programs account for potential auxiliary lower limb loading on field during specific skill practice.

The rugby sevens players as a combined group were younger and heavier with similar stature to other reports (49, 78, 81). When differentiating between playing position, the backs were ~2% heavier and within the height ranges previously reported, whereas the forwards were ~2% heavier at the same height in one study (73) and ~2% lighter and ~1% shorter than players in two other studies (36, 78). In this study the weight and stature of rugby sevens forwards and backs compared closely to outside backs in rugby union (36). When players were differentiated by playing ability and position, both forwards and backs showed similar body composition to backs of high playing ability in rugby union and to rugby sevens players of international standard (1, 78). The combined player sum of seven skinfolds was consistent with previous rugby sevens research whereas lean mass was 3.3% higher across the full season (49). Rugby sevens skinfolds and lean mass presented over one season is substantially leaner than professional rugby union players reported over a period of two full seasons (29). Forwards had higher total skinfolds than backs, which is consistent with the two other studies that investigated skinfolds and differentiated between playing positions in rugby sevens (73, 78). The higher sum of seven skinfolds in forwards is likely related to the extra collisions in scrums, rucking, mauling and tackling (70, 80, 81). Across the full season the backs showed small decreases in skinfolds with a small increase in lean mass in-season as shown previously (65). Significantly, there was no negative body composition change for the full season suggesting that the training and nutritional program maintained player body composition for a full international rugby sevens season.

To date no other study has reported on the assessment of lower body strength in rugby sevens using a back squat. Lower body strength showed a small increase in absolute and relative values during the pre-season, although notably these improvements were not maintained in-season. The early season squat testing showed lower absolute strength when compared to other rugby codes. In contrast, these results were higher or comparable with relative lower body strength scores reported in rugby union (1, 6, 14). When compared to backs in professional rugby union, rugby sevens forwards and backs have similar relative lower body strength values whereas rugby sevens backs are 15% lower in absolute terms (1). Previous research reported an 8.5% increase in lower body strength across a rugby union season (5). The inverse relationship in lower body strength between the pre-season gains and in-season losses may be attributed to a number of factors including changes in lower body stimulus scheduling in-season, international travel requirements, increased tournament scheduling, and the ability to recover from high running loads (~20% higher – unpublished research) in-season and impact collisions that are integral to rugby sevens (48, 76, 81). Although it appears that maximal strength and power can be maintained at pre-season levels for long in-season periods (10, 59). There are two other possible explanations for this decay in lower body strength. First, forwards need superior lower body strength to perform the skills of scrummaging, line outs and restarts of play in both training and games. Measurement of force during an instrumented individual player simulated scrum session showed values ~52% less than a reported box squat measures and ~50% less than back squat (71, 84). This additional lower body load experienced exclusively by forwards would contribute to overall lower body fatigue and should be considered when structuring the training week to optimize lower body strength gains. Secondly, a box squat replaced the back squat exercise in-season (see Table 3.1) as a quality control measure to ensure players were maintaining a minimum squat depth, this action may also account for the decrease in reported back squat strength. Biomechanical differences such as a narrower stance, lower force values and greater anterior displacement of the torso in a back squat when compared to a box squat could result in the reduced ability to perform maximal back squat (due to the absence of back squat specificity) during the training phase (84).

Upper body strength gains in the combined cohort were small through the pre-season and in-season with an overall moderate increase across the full season similar to previous reports in rugby league (10). This outcome is contrary to a decay of 1.2% in rugby union players across the season which was attributed to professional athletes having a greater strength training background and thus reducing the likelihood of further strength improvements in-season (5). In the current study the players were ~3 years younger with a ~9% lower bench press, which may be due to an inherently shorter strength training background. The backs had a moderate increase in bench press strength for the pre-season similar to a previous study in rugby union (3). Compared to professional rugby union and rugby league players the combined cohort had up to 8% lower absolute bench press values; however, in relative terms they were much closer to reported measures of 1.2–1.5 $w.kg^{-1}$ (2, 12, 14). The group was relatively homogenous when upper body strength was differentiated for forwards and backs. A 5% difference between rugby sevens playing positions has been reported (combined international and provincial level players), whereas international rugby sevens players had a 20% greater bench press than provincial level players (combined backs and forwards) (78). While upper body strength continually improved over the duration of the rugby sevens playing season, the combined cohort bench press scores were 2.4% less than previously reported in international level players (78). It is important to note the increase in upper body strength across the season suggesting running and skill training loads had minimal impact on upper body strength development.

It is apparent that no single lower body power measure showed consistent changes in the combined cohort or when differentiating between forwards and backs. The reported variance in power variables may have been magnified by using a linear position transducer (in place of a force plate). Peak power and relative peak power can be useful in assessing rugby sevens players (78, 90). Combined players showed peak power measures 16% higher than provincial and 13% lower than international level rugby sevens players, and peak power measures were 29% higher than a recent report on elite rugby sevens players (78, 90). The backs in the current study showed small to moderate increases over the full season. In a comparison of squatting techniques it was suggested that a box squat (due to the reported reduced forces and higher rate of force development) could be an effective exercise to develop explosive strength (84). The replacement of back squat with a box squat in-season (see Table 3.1) may account for the moderate increases shown by the backs in the absence of scrummaging, line outs and restarts of play. The decrease in power identified in the forwards may be in part relate to the specific training loads associated with scrummaging, line outs and restarts of play possibly compounding neuromuscular fatigue, resulting in a decreased adaptation to power training. Additionally, in-season training schedule changes reduced the ratio of lower to upper body strength training stimulus by ~20% (see Table 3.2). Given the strong relationship between strength and power, the reduction in the strength training stimulus may have facilitated a similar reduction in power output over time (11).

A longitudinal study comprising of multiple seasons would be beneficial to address chronic adaptations to strength and power training. Future investigations could determine the effect of running loads and position-specific skills training on strength and power of positional groups during both the pre-season and in-season. Determining the optimal training week structure whereby strength and power gains in-season are maximized would be advantageous. It appears that neuromuscular function may be significantly reduced for greater than 120 hours post tournaments (91). Given that there were 9 tournaments and 28 in-season training weeks this research effectively excludes 32% of productive training time in-season.

Conclusion

This study systematically quantified the changes in strength and power across an international rugby sevens season. It appears that rugby sevens players have similar physique and physical qualities to professional level backs in rugby union. Upper body strength continually increased throughout an international rugby sevens season, whereas lower body strength gains made in preseason training but proved difficult to maintain in-season. The ability to maintain and improve power for forwards during the season may be affected by the additional set piece requirements of scrummaging, line outs and restarts. Training loads need to be carefully prescribed for forwards and backs to account for the potential decay of strength and power qualities.

Practical Applications

Consideration should be given to the lower body demands of rugby sevens forwards to ensure that lower body improvements made in the pre-season can be maintained throughout the in-season. These outcomes could be achieved by ensuring the ratio of lower body to upper body programming remains consistent through the season managing training time parity and recovery between positions. Use of the box squat in-season may be useful for maintaining and increasing lower body explosive power, however care should be exercised when assessing the back squat if the box squat has been the primary lower body strength modality.

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Chapter 4: Responses of lower body power and match running demands following long-haul travel in international rugby sevens players

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Abstract

This study determined the effect of long-haul (>5 h) travel on lower body power and match running demands in international rugby sevens players. Twenty-two male international rugby sevens players (age 21.7 ± 2.7 y, mass 89.0 ± 6.7 kg, stature 180.5 ± 6.2 cm; mean ± SD) were monitored over 17 rugby sevens tournaments. A countermovement jump was used to monitor lower body power (peak and mean power) over repeated three week travel and competition periods (pre-travel, post-travel, and post-tournament). Small decreases were evident in peak power following both short and long-haul travel (-4.0%, ± 3.2%; mean, ±90% confidence limits) with further reductions in peak and mean power post-tournament (-4.5%, ± 2.3% and -3.8%, ± 1.5%) culminating in a moderate decrease in peak power overall (-7.4%, ±4.0%). In a sub-set of 12 players who each completed a minimum of 8 tournaments, long-haul travel elicited a large decrease in lower body peak (-9.4%, ± 3.5%) and mean power (-5.6%, ± 2.9%) over the monitoring period, with a small decrease (-4.3%, ± 3.0% and -2.2%, ± 1.7%) post-travel and moderate decrease (-5.4%, ± 2.5% and -3.5%, ± 1.9%) post-tournament respectively. Match running demands were monitored via global positioning system. In long-haul tournaments the 12 players covered ~13%, ± 13% greater total distance (m) and ~11%, ± 10% higher average game meters distance above 5 $m \cdot s^{-1}$ when compared with short-haul (<5 h) travel. Effective pre- and post-travel player management strategies are indicated to reduce neuromuscular fatigue and running load demands in rugby sevens tournaments following long-haul travel.

Key Words

Rugby sevens, travel fatigue, monitoring, countermovement jump

Introduction

Rugby sevens is a high intensity, collision-based sport requiring players to be fast, mobile and powerful while enduring high levels of repeated game efforts to meet the physical demands of tournament-style competition (48, 72). The World Rugby International Sevens World Series is regarded as the highest level of competition in which 15 core nations compete in nine tournaments played in nine different countries over a period of eight months. As such teams are required to undertake significant travel to the tournaments varying from as little as one hour through to >24 h of accumulated flight time. To date the impact of travel and tournament play on physical performance measures has not been investigated in rugby sevens players.

The negative effects of air travel on elite athletes as a result of travel fatigue and jet lag have been previously reported (35, 37). Travel fatigue is associated with the discomfort caused through sitting in a confined space, with inadequate sleep and experiencing mild hypoxia for extended periods of time (35). Jet lag is caused through the disturbance in an individuals' circadian rhythm as a result of crossing numerous time zones resulting in altered sleep patterns (35, 79). Travel fatigue is reported to resolve within 24 h, whereas jetlag requires 12–24 h of recovery time for each time zone crossed (37, 79). Additionally, travel fatigue may continue to accumulate across the season characterized by persistent fatigue, recurrent illness, changes in behavior and mood, and loss of motivation (79). The impact of travel fatigue and jet lag will vary for teams depending on the associated travel time to each tournament venue, with teams undertaking extensive travel possibly remaining fatigued and jet lagged throughout the duration of the tournament (37). Impaired neuromuscular function may be a result of travel fatigue and jet lag (90), and more information is needed on whether travel adversely affects a player's neuromuscular function and ability to perform athletic movements.

Countermovement jumps have been used in elite sport to monitor neuromuscular fatigue and assess lower body power (21, 91). In rugby sevens, power is expressed in the skills of sprinting, jumping and tackling, and are typically assessed in a countermovement jump using a linear position transducer to measure speed of movement and distance (67, 75). Peak power and mean power are the primary variables of interest when analyzing neuromuscular fatigue and performance in rugby sevens (78, 90). Therefore the use of a portable and reliable power monitoring tool such as a linear position transducer may be beneficial given the significant short and long-haul travel undertaken by rugby sevens players participating in international tournaments (26).

Rugby sevens players are susceptible to reduced neuromuscular function over the course of an international rugby sevens tournament (90). This impairment is due to higher intensity running (stretch-shortening based movements) and collisions that result in increased intramuscular proteins/ enzymes in the blood, with levels of creatine kinase up to 18% higher after one game of rugby sevens (48, 85). A rugby sevens tournament typically consists of five to six games played over two to three days. International games are more intense than domestic games with 6% higher maximal running velocity covering 16–27% greater distances with up to 39% more accelerations and decelerations (48, 75). Further, the total distance covered during a game for players (completing ≥70% of game time) has been reported to be ~1400m with ~250m at speeds distance above 5 $m \cdot s^{-1}$ (75, 76). The overall cumulative effect of multiple games over consecutive days has shown small (4.6–8.4%) differences in low to moderate running velocities (<5 $m \cdot s^{-1}$) with unclear differences at higher velocities (distance above 5 $m \cdot s^{-1}$) between the first and last matches of a rugby sevens tournament (48). Consequently, 12 h post-tournament rugby sevens players are reported to have a 26% reduction in countermovement jump measures with this figure improving to 8% after five days (89).

To date there has been no research into the effects of short and long-haul travel on the neuromuscular system and tournament running demands in rugby sevens players. Therefore, the aim of this research was to investigate pre-travel, post-travel and post-tournament lower body power in conjunction with assessment of tournament running volume and intensity to determine if travel has a substantial impact on physical performance.

Methods

Experimental approach to the problem

To establish whether short- and long-haul travel have a deleterious effect on physical performance in rugby sevens players (across multiple seasons), neuromuscular fatigue was monitored via a countermovement jump over multiple three week monitoring periods across 2.5 years (pre-travel, post-travel and post-tournament). Global positioning system (GPS) data was collected to assess tournament match running demands and the changes attributable to travel. Changes between and within subjects were used to determine differences in relation to tournaments; domestic versus international and short versus long-haul travel. Effects were quantified to establish substantial changes in lower body power (post-travel and post tournament) and changes in match running demands attributable to the associated travel required when playing international rugby sevens.

Subjects

Twenty-two male international rugby sevens squad players participated in this study (age 21.7 ± 2.7 y, mass 89.0 ± 6.7 kg, stature 180.5 ± 6.2 cm; mean ± SD) over a period of two years and 6 months. These players had ~2.5 years (2012-14) of specific international rugby sevens training and playing experience (range 1–5 years). Each player was informed of the benefits and risks of this investigation prior to providing written informed consent to participate in this study. This study was approved by the University of Canberra Committee for Ethics in Human Research (Project 12-68).

Procedures

Data collection was conducted over ~2.5 years encompassing 17 rugby sevens tournaments (4 domestic and 13 international) across 7 nations, these tournaments were further classified based on flight travel time to the tournament venue as either <5 h (short-haul) or >5 h (long-haul) not including transit or stop over time(where domestic or short-haul travel may require up to 5 h of travel to away games for athletes in North America and Australia (35)).Players were informed about the necessary adjustments they would need to make prior to travel, during travel and on arrival at their final destination. Before travel players were encouraged to start adjusting their sleep and meal patterns to minimize the time zone difference between their home nation and the tournament destination. During travel, players were provided compression garments and information about adjusting their time zone, optimizing meals, hydration and sleep patterns in line with the tournament destination (66). Players were encouraged to move about and maintain mobility during waking times. Upon arrival, players were encouraged to adjust to the destination time zone (by seeking daylight or not) and complying with the destination time zone (either sleeping or waking). Players would participate in a post-travel recovery session of 30-40 minutes comprising of movement patterns and low intensity running. These sessions included light skills and a low intensity small-sided game followed by general flexibility and hydrotherapy (dependent on the facilities available, e.g. pool, ice bath).

Examples of in-season and tournament training weekly schedules are shown in Tables 4.1 and 4.2.

Table 4.1. Typical in-season pre-departure weekly training plan

Phase	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
In Season	Lift ^ Speed Field skills training	Lift Conditioning Field skills training	Recovery	Speed Field skills training	Lift* Field skills training	Off	Departure to tournament

^ Counter movement jump monitoring.

Table 4.2. Example of a Sevens World Series tournament week

Game +1*	Game +2	Game -3**	Game -2	Game -1	Game Day 1	Game Day 2
Recovery Field skills training	Lift ^ Game simulation	Recovery Field skills training	Lift	Field skills training	3 games Recovery	2/3 games Recovery

* +1 representing one day post travel. ** -3 representing three days prior to game day 1.
^ Counter movement jump monitoring

The countermovement jump monitoring protocol was selected using recommendations for the assessment of rugby union players (45). Players were encouraged to consume their regular pre-training diet. Only data collected on players free of injury and illness at the time of testing are reported. Countermovement jump data collection was conducted in the morning (86) over three time points in relation to a tournament week; pre-travel, post-travel and post-tournament. Pre-travel monitoring was conducted as part of the first planned strength and conditioning lifting session of the week. The scheduling of this session varied from four to five days prior to departure for the upcoming tournament. Post-travel monitoring was conducted on day two after arrival at the tournament venue as part of the first planned strength and conditioning lifting session during the week leading into the tournament. This session occurred three to four days prior to the tournament. Post-tournament monitoring was conducted on either day two or three after the completion of the tournament as part of the first planned strength and conditioning lifting session which was dependent on travel to the next tournament and training schedule, which would vary based on the team staff and senior players perceived player recovery needs. Given travel logistics and team policies (regarding recovery and rest after paired tournaments) monitoring was not conducted after the second tournament of a paired series. Therefore all data presented is only relevant to single tournaments and the first of two paired tournaments in the Sevens World Series (see Table 4.3).

Table 4.3. World Rugby International Sevens World Series Tournament legs

Tournament number	1st Leg	Travel time (h)	2nd Leg	Travel time (h)	Time of year
1	Gold Coast, Australia	1.5	-		October
2-3	Dubai, United Arab Emirates	14	Port Elizabeth, South Africa	11.5	November-December
4-5*	Wellington, New Zealand	3	Las Vegas, USA	16.5	January-February
6-7*	Tokyo, Japan	9.5	Hong Kong, China	3.5	March-April
8-9	Glasgow, Scotland	24+	London, England	1.5	May

*Tournaments completed in reverse order over two consecutive seasons.

Lower body power monitoring (using a countermovement jump) was assessed using a linear position transducer given acceptable validity, reliability and portability to estimate power similar to a force plate when measuring jump performance (4, 26). Prior to the lower body muscular power monitoring all players completed a 10 min standardized warm-up using a space approximately 20m long x 3m wide consisting of a series of dynamic exercises (e.g. 60–70% jogging, lateral/carioca, low to high skipping, jumping/hopping, dynamic hamstring/quadriceps/low back movements) (67, 90). The linear position transducer was anchored to the ground on the right side of the player and attached to the right hand side of a broomstick (45 g). In the start position the subject was required to support the broomstick on their upper back (with their hands), and through movements of the lower body perform a countermovement jump. The foot position and depth of the countermovement jump was self-selected by the player with the instruction to jump as high as possible (6). Players completed six countermovement jumps with allowance to reset the feet to the start position between repetitions, with the mean value of all six jumps being reported. A displacement-time curve for each jump was obtained by attaching a digital optical encoder via a cable (GYMAWARE Power Tool, Kinetic Performance Technologies, Canberra, Australia) to one side of the broomstick. This data was uploaded to the GYMAWARE website then exported for analysis. This system recorded displacement-time data for reported measures (see Table 4.4) with a mean coefficient of variation of 13% and intraclass correlation of 0.82.

GPS game movement data was measured by portable GPS devices (SPI HPU, GPSport Systems, Canberra, Australia) with a raw sampling rate of 5 Hz (38). The portable GPS device was inserted into specially tailored pockets located in the playing jersey, positioned on the upper-back between the shoulder blades. Data was analyzed with a sub-group of 12 players, who competed in a minimum of 8 tournaments across 2.5 years to form a representative within-subject analysis of rugby sevens tournament movement patterns. Data was uploaded to SPI IQ data analysis software (GPSport Systems, Canberra, Australia) for assessment of total distance covered during a tournament (m), mean distance covered per min of game-time played ($m \cdot min^{-1}$), mean total distance covered during a game above 5 m per second ($>5\ m \cdot s^{-1}$) and mean total distance covered during a game above 6.6 m per second ($>6.6\ m\ s^{-1}$).

Statistical analyses

Descriptive data are reported as mean and standard deviation (SD). Inferences on changes in lower body power over the three time points for each rugby sevens tournament (pre-departure, tournament week and recovery) were made using a student's t-test for dependent samples. A two-way analysis was performed for combined player group (between-subject group n=22 across 17 tournaments) and a sub-group of players (within-subject n=12 minimum of 8 tournaments with a range of 8–14 tournaments). Precision of estimation was indicated with 90% confidence limits. Effect sizes were reported in standardized (Cohen) units as the change in the mean with 90% confidence limits (51). Criteria to assess the magnitude of observed changes were: 0.0 to 0.2 trivial; 0.20 to 0.60 small; 0.60 to 1.20 moderate; and >1.20 Large. An effect was deemed unclear if its confidence interval spanned both substantial positive and substantial negative values (± 0.20 x between-subject SD) (51). Covariate analysis was undertaken to assess whether the quality of the opposition or tournament-finishing position impacted substantially on the tournament GPS data. Quality of the opposition was based on the accumulated ranking points of the teams played at each tournament (i.e. team ranked 1 – ascribed 1 point, team ranked 15 – 15 points) with the lower the accumulated points inferring better quality opposition. The adjustment for the finishing position was based on the actual position the study cohort finished the tournament (1st–15th place).

Results

The combined cohort of 22 rugby sevens players in this study demonstrated a substantial decrement in both peak and mean lower body leg power in over the three week monitoring period pre-travel, post-travel and post tournament (see Table 4.4). Small decreases were evident in peak power post-travel (-3.2%, ± 2.9%; mean, ± 90% confidence limits) with an additional small decrease in peak and mean power post-tournament of -4.3%, ± 2.0% and -2.6%, ± 1.4%. Over the three week monitoring period there was a moderate decrease in peak power of-7.4%, ± 4.0% with a small decrease in mean power of -3.6%, ± 2.6%.

International tournaments with the combined player cohort showed a greater decrement in lower body power over the three week monitoring period when compared to domestic tournaments. Domestic tournaments showed trivial to no change across the three monitoring sessions for both mean and peak power, whereas peak power in international tournaments showed a small decrease post-travel (-4.5%, ± 2.7% with a moderate decrease post-tournament (-5.1%, ± 2.2%) that resulted in a moderate decrease overall of -9.3%, ± 3.4%. Mean power in international tournaments was shown to have a small decrease post-travel and post-tournaments (-2.3%, ± 1.3% and -3.1%, ± 1.7%) with a moderate decrease over the 3 week monitoring period of -5.4%, ± 2.3%.

Further investigation into the sub-set of 12 players showed small decreases in peak power post-travel (-4.0%, ± 3.2%) with an additional small decrease in peak and mean power post-tournament (-4.5%, ± 2.3% and -3.8%, ± 1.5%). Peak power showed a moderate decrease (-8.4%, ± 3.4%) accompanied with a small decrease in mean power over the monitoring period of -4.2%, ± 2.0%, showing a similar trend to the combined cohort of players.

Short-haul travel showed the sub-set of 12 players had a small change in peak power over the three monitoring sessions of -5.1%, ± 8.4%. Tournaments with long-haul travel showed a large decrement in both peak and mean power overall (-9.4%, ± 3.5% and -5.6, ± 2.9%), with a small decrease post-travel (-4.3%, ± 3.0% and -2.2%, ± 1.7%) and moderate decrease post- tournament (-5.4%, ± 2.5% and -3.5%, ± 1.9%).

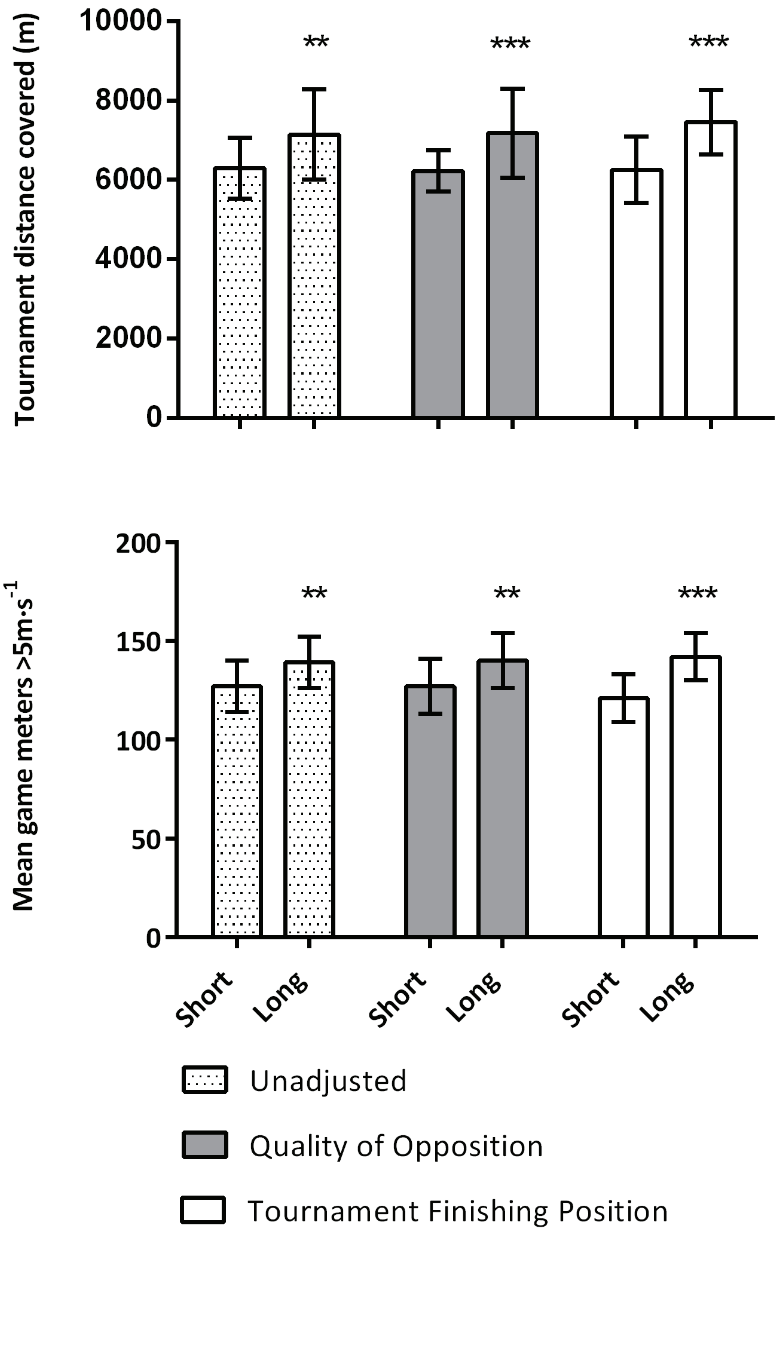
Table 4.4. Differential changes in peak power and mean power over a 3 week tournament period (pre-travel, post-travel and post tournament). Analysis of between (combined players) and with-in (12 player sub-group) rugby sevens players. Mean change, ±90% confidence limits (CL)

	3 Week Tournament Time point			Standardized mean change (Cohen's)		
	–Pre-travel	–Post-Travel	–Post-Tournament	Post-Travel – Pre-Travel	Post-Tournament – Post-Travel	Post-Tournament – Pre-Travel
	X ± *SD*	X ± *SD*	X ± *SD*	ΔX, ±90%CL	ΔX, ±90%CL	ΔX, ±90%CL
Between-Player Group (n=22)						
17 tournaments						
Peak Power (W)	7855 ± 860	7580 ± 600	7246 ± 496	-0.27, ±0.25*	-0.36, ±0.17*	-0.63, ±0.35**
Mean Power (W)	4571 ± 368	4516 ± 294	4398 ± 258	-0.12, ±0.20	-0.29, ±0.16*	-0.41, ±0.30*
Domestic Tournaments n=4						
Peak Power (W)	7359 ± 1431	7357 ± 790	7217 ± 607	0.04, ±0.44	-0.07, ±0.23	-0.03, ±0.66
Mean Power (W)	4280 ± 549	4400 ± 388	4361 ± 283	0.17, ±0.37	-0.04, ±0.20	0.13, ±0.52
International Tournaments n=13						
Peak Power (W)	8008 ± 606	7648 ± 550	7255 ± 486	-0.54, ±0.34*	-0.63, ±0.28**	-1.17, ±0.45**
Mean Power (W)	4660 ± 262	4551 ± 269	4409 ± 261	-0.38, ±0.22*	-0.51, ±0.27*	-0.88, ±0.38**
Within-Player Sub Group (n=12)						
17 tournaments						
Peak Power (W)	7910 ± 936	7627 ± 1204	7263 ± 970	-0.32, ±0.26*	-0.35, ±19*	-0.67, ±28**
Mean Power (W)	4555 ± 444	4549 ± 577	4377 ± 549	-0.04, ±0.16	-0.36, ±0.15*	-0.40, ±0.19*
Tournaments <5 hours travel n=8						
Peak Power (W)	7653 ± 1134	7463 ± 783	7216 ± 634	-0.12, ±0.35	-0.19, ±0.22	-0.30, ±0.51*
Mean Power (W)	4436 ± 482	4436 ± 380	4363 ± 036	0.02, ±0.27	-0.12, ±0.19	-0.10, ±0.39
Tournaments >5+ hours travel n=9						
Peak Power (W)	8035 ± 526	7684 ± 397	7273 ± 373	-0.59, ±0.43*	-0.74, ±0.35**	-1.32, ±0.52***
Mean Power (W)	4691 ± 182	4586 ± 187	4428 ± 220	-0.52, ±0.41*	-0.82, ±45**	-1.43, ±0.70***

*0.2 -0.6 -Small   ** 0.6-1.2 - Moderate   *** 1.2+ Large

In addition to the lower body power decrements in tournaments following long-haul travel, changes were evident in match running demands. GPS data collected for the sub-set of 12 players demonstrates players covered an extra 960 ± 520 meters representing ~13% ± 13% greater distance per tournament. Game meters distance above 5 $m \cdot s^{-1}$ also averaged an extra 12 ± 13 meters or ~11% ± 10% than short-haul travel tournaments (see Figure 4.1). Trivial and no changes were shown in tournament $m \cdot min^{-1}$ and game distance >6.6 $m \cdot s^{-1}$. Additionally, when the GPS data was adjusted for the quality of the opposition and the tournament finishing position, the difference in the distance covered during tournaments after long-haul travel remained large (Figure 4.1 upper panel). Similarly, for average game meters distance above 5 $m \cdot s^{-1}$ adjustments for the two covariates had little effect (Figure 4.1 lower panel). Taken together these data support the assertion that increased distance after long-haul travel was not related to quality of the opposition or finishing position.

Figure 4.1. Difference between short-haul (Short) and long-haul travel (Long) total tournament m ± SD and the mean game meters distance above 5 m·s^{-1} ± SD. Three conditions are expressed as: 1. Unadjusted distance, 2. Distance adjusted for the quality of opposition and 3. Distance adjusted for tournament finishing rank. Standardized difference in means ± 90% CL (*0.2 -0.6 - Small ** 0.6-1.2 - Moderate *** 1.2+ - Large).



Discussion

Rugby sevens players following long-haul travel exhibited small reductions in lower-body power after travel and a large reduction after a tournament. Players covered both a greater total distance per tournament (m) and greater average distance >5m·s^{-1} per game in tournaments following long-haul travel. The level of the opposition played and the tournament finishing position were not contributing factors to the increased running volume. The deleterious effects of long-haul travel on player neuromuscular fatigue and performance should be considered when planning training, travel logistics and player recovery protocols.

Overall there were 22 between-subject rugby sevens players that participated in this study with a within-subject sub-set of 12 players that played in a minimum of 8 tournaments. The results show a similar decline in lower body power over the three week monitoring period for both the combined cohort of 22 players and sub-set of 12 players. These two groups showed a small decrease in peak power (~3%) post-travel and post tournament (~4%). The decrease from pre-travel to post-tournament in both groups was small in mean power (~4%) and moderate in peak power (7%). Irrespective of the playing group the peak and mean power values after all tournaments were ~7200W and ~4400W respectively. Similar values were presented in rugby sevens players showing a decrement in lower body power over the course of a rugby sevens season (67). This analysis demonstrates for the first time in rugby sevens an impairment in counter movement jump performance post-travel as well showing a consistent decrement after competing in rugby sevens tournaments (91). This finding is in contrast to a study in which jump tests were questioned as a monitoring tool due to their limited ecological relevance in team sports requiring prolonged bouts of intermittent-sprint activities (24).

International rugby sevens players are stronger and more powerful than domestic-level players, covering greater overall distance in games and distances at high speed in international tournaments (48, 78). Monitoring performance over domestic tournaments showed trivial or unclear changes in both peak and mean power, inferring minimal impairment on neuromuscular function pre and post domestic rugby sevens tournaments. The relative stability in power may be due in part to the decreased travel time (<5h) to attend domestic tournaments and the likely inferior physical levels of domestic rugby sevens players who competed against international players in this study, possibly inflicting less physical demand when playing at the domestic level (75, 78). Conversely, there were small (~5%) and moderate (~9%) decreases in lower body peak power over the three week monitoring period in international tournaments. These reductions may be attributable to the variable flight times (ranging from 1–24 h) and the reported increased intensity associated with competing in international tournaments (48, 75).

It is apparent that flight times are influential when considering neuromuscular fatigue in rugby sevens players (91). There was a small decrease in peak power (~5%) over the three week monitoring period for tournaments requiring short-haul travel. Two previous studies found no change in lower body power post-short-haul travel (35, 64), which is not consistent with the results of this study, suggesting there may be neuromuscular fatigue or travel fatigue in flights <5 h. However the combined effect of travel and tournaments indicate that there is likely a cumulative affect associated with short-haul travel and competing in tournaments. The most substantial decreases in lower body power were evident in tournaments requiring long-haul travel. Small changes in peak (~4%) and mean power (~3%) were shown post-travel that are likely the result of travel fatigue (35, 79). In simulated long-haul travel, reduced morning cortisol levels with increased submaximal heart rates post-travel have been implicated in increased physiological fatigue (35). These physiological variables as a result of travel fatigue potentially add to the reduced ability of rugby sevens players to perform a countermovement jump post long-haul travel.

Whilst it is difficult to separate the effects of travel fatigue and jet lag (35), the ability of rugby sevens players to adapt to multiple time zone changes (2–9 time zones) may be a contributing factor to the large decreases (~10% peak and ~6% mean power) in lower body power shown post-tournament. Given that changes shown post-long-haul tournaments were moderate and post-short-haul travel were small, we infer that the associated travel fatigue two days post-travel may have decreased countermovement jump power. In contrast, jet lag and cumulative fatigue may be responsible for the large decreases in power that occurred over the three week monitoring period (79). However, the reported ~10% decreases in lower body power is considerably less than ~26% decrement previously reported 12 h post-tournament that included a pool recovery session (91). Players in the current study may have had less decay in lower body power post-tournament by participating in planned post-tournament recovery practices including nutritional interventions promoting hydration and replenishing macronutrients, hydrotherapy and cryotherapy practices, the wearing of compression garments and maximizing sleep (31, 88). It is important for rugby sevens players to maximize recovery practices on arrival at the tournament destination after long-haul travel and maintain them throughout the tournament and post-tournament (31, 88).

GPS data provides further insight into the role of neuromuscular fatigue monitoring associated with long-haul flights and the running demands of international rugby sevens tournaments. When compared to short-haul travel, players after long-haul travel covered ~13% more total distance (m) and~11% more mean distance covered per game distance above 5 $m \cdot s^{-1}$. A decrease in countermovement jump performance associated with increased low speed running <15 $km \cdot hr^{-1}$ (4.2 $m \cdot s^{-1}$) was shown in Australian Rules Football, whereby a change in running mechanics (as a result of neuromuscular fatigue) could result in running at a steady pace, accumulating lower-end high speed meters (>15 $km \cdot hr^{-1}$ or 4.2 $m \cdot s^{-1}$) (20). This outcome is consistent with the current study highlighted by increased game average meters distance above 5 $m \cdot s^{-1}$ (lower-end high speed meters) with trivial or no change in game average meters >6.6 $m \cdot s^{-1}$. It would be prudent for strength and conditioning practitioners to provide recovery modalities focusing on returning to or maintaining optimal running mechanics post-travel.

Two co-variates were used to assess whether opposition quality or tournament finishing position had an effect on distance covered in short and long-haul flights. Given both co-variants were not shown to influence tournament running metrics, the effects of travel fatigue and jet lag are likely to contribute to the increased total distance covered in a tournament as well as the increased meters distance above 5 $m \cdot s^{-1}$ (79, 91). The increased distances attributed to neuromuscular fatigue (highlighted by the ~5% decrease in peak power and ~3% decrease in mean power) and the symptoms of jet lag characterized by sleep disruption appear to result in reduced cognitive performance (35). Decision making ability under tournament playing conditions may be impaired by loss of sleep with slower reactions to team plays and counter moves to opposition plays resulting in further distance being covered. In Australian Rules Football, teams finishing higher on the table covered less distance than teams lower on the table which was in part attributed to higher ranked teams making better decisions (92). Other factors may also contribute, for example in soccer, short-haul travel indicated players cover greater distance in away games conceding more goals and having less shots on goal, this was attributed to situational variables, territoriality, tactics and player psychological state (34). Further research into changes in rugby sevens game statistics (in short versus long-haul travel) would be valuable in determining further the effects of neuromuscular fatigue.

Several limitations exist in this current study and should be considered with the data presented. Player compliance in reporting rate of perceived exertion (RPE) was inconsistent when compared to the collection of counter movement jumps and game running metrics, as such this self-reported data was not included in the study. Matching player RPE data would be valuable in determining intrinsic tournament intensities in line with GPS data when considering the effect of short and long-haul travel. Additionally, due to the collision nature of rugby sevens the assessment and/or monitoring of upper body power would be beneficial in providing an additional variable to monitor fatigue post-travel and post-tournament.

Conclusion

This is the first study to demonstrate rugby sevens players incur lower body neuromuscular fatigue (as measured via a countermovement jump) post long-haul travel. Consequently, players were shown to cover greater distances in tournaments accumulating more meters above 5 $m \cdot s^{-1}$ following long-haul travel. The combined decrease in lower body power with increased running demands results in player neuromuscular fatigue levels that may impair game performance. It is imperative coaching staff minimize neuromuscular fatigue pre travel, educate players in minimizing travel fatigue and jet lag, and employ the most appropriate recovery modalities post-travel and post-tournaments.

Practical applications

Periodization and training load planning need to be carefully considered in the week preceding long-haul travel to minimize neuromuscular fatigue, which can be further exacerbated by travel fatigue and jet lag. Rugby sevens players should be educated and strongly encouraged to embrace strategies designed to minimize travel fatigue and prioritize sleep as a recovery modality. Pre-travel, players should start to adjust their sleep and meal patterns. During travel players should wear compression garments, adjust their time zone, meals, hydration and sleep patterns in line with the tournament destination (66). Players should move about and maintain mobility during waking times. Upon arrival players need to adjust to the destination time zone (by seeking daylight or not) and complying with the destination time zone [either sleeping or waking]. Players would benefit from post-travel recovery session of 30–40 min comprising of movement patterns and low intensity running to enhance maintenance of optimal running mechanics. These sessions would include some light skills and a low intensity small-sided game followed by general flexibility and a hydrotherapy format (dependent on the facilities available, e.g. pool, ice bath). Team management and tournament organizers should be cognisant of the impact on players crossing multiple time zones and allow appropriate time for player circadian rhythms to adjust at a rate of 12–24 h per time zone crossed (37, 79).

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Chapter 5: Discussion

Superior levels of strength and power with minimal levels of neuromuscular fatigue are thought to be beneficial when competing in international rugby sevens tournaments. The challenge of meeting the demands of training, traveling and competing in international tournaments has been the focus of coaching and support staff seeking to develop optimal training, travel and recovery schedules. Through a series of systematic studies, changes in body composition, strength and power over a full season of international rugby sevens were quantified, along with the effects of long-haul travel (>5 h) on neuromuscular function and tournament running demands (distance and intensity). It is apparent that forwards find it difficult to maintain strength and power qualities in-season, and minimising travel induced neuromuscular fatigue may lead to a decrease in tournament running demands.

This is the first study to quantify the changes in body composition, strength and power as they relate to playing position over a full season of international rugby sevens. During the pre-season, early season and late season phases, upper body strength showed small improvements over the course of the season, whereas lower body strength increased during the pre-season, before decaying during the in-season. Lower body power increased among backs and decreased in forwards over the duration of the season. The upper body and lower body strength scores confirm preliminary reports that rugby sevens players display similar physical qualities to outside backs in rugby union. Given the different time course of changes in strength and power between forwards and backs, it is prudent for coaching staff to prescribe position-specific training programmes. These programmes would take into account the potential auxiliary lower limb loading, during specific skill drilling practice as part of on-field training sessions.

Body composition

Anthropometric measures such as mass, height and body composition are used in rugby sevens to discriminate between players at different levels, positional groups and evaluate player physical and training programme progress (29, 49). Anthropometric measures are also important when rugby union players are making the transition into rugby sevens (46). The rugby sevens players in this study were younger and heavier with similar stature to previously reported literature in rugby sevens (49, 78, 81). When players were differentiated as either a forward or back, backs were found to be ~2% heavier and with similar heights as previously reported in rugby sevens players, whereas the forwards were ~2% heavier at the same height in one study (73) and ~2% lighter and ~1% shorter than players in two other studies (36, 78). In terms of body mass and stature, rugby sevens forwards and backs in this study compared closely to outside backs in rugby union (36), as well as contemporary rugby sevens players (49, 78).

It is evident that high lean mass and low fat mass is advantageous for the mobility and high intensity running demands of rugby sevens. The skinfold data derived from players over one season of rugby sevens, appears to be substantially different (higher lean mass and lower fat mass) to that reported of professional rugby union backs over two full seasons (29). Rugby sevens forwards and backs showed similar body composition traits to backs classified as having high playing ability in rugby union, and other reported international rugby sevens players (1, 78). The combined player sum of seven skinfolds was consistent with previous rugby sevens research (49), whereas lean mass was on average ~3% greater across the full season (49). Forwards in this cohort had higher total skinfolds when compared to backs, which is consistent with other studies that have investigated skinfolds and playing positions in rugby sevens (73, 78). The associated higher sum of seven skinfolds in forwards is likely a protective mechanism related to the extra collisions associated with scrums, rucking, mauling and tackling (70, 80, 81). Over the duration of the season the backs showed small decreases in skinfolds with a small increase in lean mass in-season in accordance with earlier reports (65). Importantly, there was no negative body composition change (increase in body fat mass or decrease in lean muscle mass) for the full season suggesting that the training and nutritional programme maintained player body composition for a full international rugby sevens season.

Changes in strength and power

Maintaining strength and power gains achieved in the pre-season over the duration of an international rugby sevens season, is a key training goal to prevent declines in physical performance. In rugby sevens, strength and power are essential in applying high forces rapidly in contact situations such as tackling, rucks, mauls and scrummaging (71, 76). In this study, lower body strength improvements made during the pre-season decayed in-season, whereas upper body strength increased moderately (~10% ± 3%) across the season. Difficulties were shown in maintaining and improving strength and power qualities in-season possibly due to a number of factors such as increased running demands during training and tournaments, decreased frequency and intensity of lower body strength training and the rigors of international travel. With this in mind the prescription of training loads in-season should consider position-specific training to optimise strength and power gains.

To date this is the first reported assessment of lower body strength in rugby sevens using a back squat. The squat is widely regarded as one of the most effective resistance exercises for improving strength and athletic ability in the lower body – hence it is regularly used to assess lower body strength (19, 84). Rugby sevens forwards in this study had greater absolute lower body strength measures (6–14% higher) than backs across the international season. When lower body strength is expressed relative to body mass, the forwards had a higher relative strength measure at the start of the season when compared to backs with this trend reversing at season end representing a range of ~ ± 6.5% across the season. Body mass is a variable that is generally believed to affect the outcome of physical performance tests. As such, the reporting of data normalised for body mass has been employed in the literature (7, 61). When squat data was allometrically scaled to the power of 0.62, forwards were ~9% stronger at the start of the season, narrowing to ~1% stronger than backs at the end of the season (7). Therefore while forwards were stronger than backs in this study, they display an inability to maintain strength levels relative to backs over the course of an international rugby sevens season.

During the pre-season training period, small increases in lower body strength (absolute and relative) were identified, though these improvements were not maintained in-season. The early season squat testing results of players showed ~6–20% lower absolute strength scores compared to other rugby codes (1, 6, 19). In contrast these results were higher or comparable with relative lower body strength scores reported in rugby union (1, 6, 14). When compared to backs in professional rugby union, rugby sevens forwards and backs have similar relative lower body strength values, however rugby sevens backs were 15% lower in absolute terms (1). The difference in absolute strength levels may be due to the higher mass and skinfold measures in rugby union players as opposed to backs in rugby sevens (4, 5, 19).

The ability to maintain lower body strength levels across a competitive season has produced mixed outcomes across the rugby codes (5, 10, 39). Studies in rugby union show an 8.5% increase in lower body strength across a competitive season (5), whereas in rugby league strength levels have been maintained in one study (10), with a 0.7% reduction in another (39). The inverse relationship in rugby sevens lower body strength between pre-season gains and in-season losses may be attributed to a number of factors including changes in lower body stimulus scheduling in-season, international travel requirements, increased tournament scheduling, and the ability to recover from high running loads (~20% higher – unpublished research, John Mitchell, Australian Rugby Union) in-season and impact collisions that are integral to rugby sevens (48, 76, 81). Although it appears that maximal strength and power can be maintained at pre-season levels for extended periods in-season (10, 59). It may be hypothesised that there are other possible explanations for this decay in lower body strength. First, forwards need superior lower body strength to perform the skills of scrummaging, line outs and restarts of play in both training and games. Measurement of force during an instrumented individual player simulated scrum session showed values ~52% less than a reported box squat measures and ~50% less than back squat (71, 84). This additional lower body load experienced exclusively by forwards [although less than gym based exercises] would contribute to overall lower body fatigue and should be considered when structuring the training week to optimise lower body strength gains. Secondly, a box squat replaced the back squat exercise in-season (see Table 3.1, p.27) as a quality control measure to ensure players were maintaining a minimum squat depth, this action may also account for the decrease in reported back squat strength. Biomechanical differences such as a narrower stance, lower force values and greater anterior displacement of the torso in a back squat when compared to a box squat could reduce the ability to perform maximal back squat given the absence of back squat specificity during the training phase (84).

When upper body strength was differentiated for forwards and backs the group was relatively homogenous in absolute strength measures with backs being slightly stronger ~3% than forwards across the international season. However, in relative terms the backs were ~15% stronger than forwards and when the bench press was allometrically scaled to the power of 0.62, backs were ~8% stronger than forwards across the season (7). This outcome is in contrast to a previous upper body strength study reporting rugby sevens forwards to be stronger than backs in both relative (~8%) and absolute terms (~5%), however players were not differentiated between domestic and international levels (78). Positional differences could relate to accumulated fatigue as a result of concurrent training whereby forwards complete upper body strength training as well as being involved in rucks, mauls, scrummaging and more collisions during training and games (77).

Upper body strength gains in the combined cohort were small through the pre-season and in-season with an overall moderate increase across the full season similar to previous reports in rugby league (10). This outcome is contrary to a 1.2% decrease in upper body strength identified in rugby union players across the competitive season (5). This difference was attributed to professional athletes having a greater strength training background and thus reducing the likelihood of further strength improvements in-season (5). In the current study, players were ~3 years younger and had a bench press ~9% lower than previously reported data, possibly due to an inherently shorter strength training background. Backs in this study had a moderate increase in bench press strength for the pre-season similar to a previous study in rugby union players (3). Compared to professional rugby union and rugby league players, the combined cohort had up to 8% lower absolute bench press values; however, in relative terms they were much closer to reported measures of 1.2–1.5 x BW (2, 12, 14). In this study, upper body strength continually improved over the duration of the rugby sevens competition season, the combined cohort bench press scores were 2.4% less than previously reported in international level rugby sevens players and 18% greater than provincial level players (combined backs and forwards) (78). It is important to note the increase in upper body strength in both forwards and backs across the season, suggesting running and skill training loads did not limit upper body strength development.

It is apparent that no single lower body power measure showed consistent changes in the combined cohort or when differentiating between forwards and backs. The variance in power variables may have been magnified by using a linear position transducer (in place of a force platform). Therefore discussion surrounding lower body power in this current study will focus on peak power and relative peak power as the preferred variables when assessing power in rugby sevens players (78, 90). The lower body power measures in this study showed when players are combined (forwards and backs) their peak power measures are 16% higher than provincial and 13% lower than international level rugby sevens players (78). In addition these peak power measures were 29% higher than a recent report on elite rugby sevens players (90). Forwards (combined provincial and international level) were 11% more powerful than backs in both relative and absolute terms (78), conversely backs were ~7–~24% more powerful than forwards in relative terms across the season in this current study.

Notably backs increased lower body power (peak power ~3% and relative peak power ~2%) across the season, whereas forwards have a marked decline (peak power ~17% and relative peak power ~18%).

There are several possible reasons for this disparity observed in power measures between forwards and backs. A box squat (as a function of reduced forces and higher rate of force development) could be an effective exercise to develop explosive strength (84). The replacement of back squat with a box squat in-season (see Table 3.1, p.27) may account for the moderate increases shown by the backs in the absence of scrummaging, line outs and restarts of play. The decrease in power identified in the forwards may in part relate to the specific training loads associated with scrummaging, line outs and restarts of play possibly compounding neuromuscular fatigue. Additionally, in-season training schedule changes reduced the ratio of lower to upper body strength training stimulus by ~20% (see Table 3.2, p.27) (5). Given the strong relationship between strength and power, the reduction in the strength training stimulus may have facilitated a similar reduction in power output over time (11).

In summary, it appears that rugby sevens players have similar physique and physical qualities to professional level backs in rugby union. Upper body strength continually increased throughout the international rugby sevens season, whereas lower body strength gains made in pre-season training proved difficult to maintain in-season. The ability to maintain and improve power for forwards during the season may be affected by the additional set piece requirements of scrummaging, line outs and restarts. Therefore, training loads need to be carefully prescribed for forwards and backs to account for the potential decay of strength and power qualities.

Effects of long-haul travel

The combined effect of international travel and tournaments on neuromuscular fatigue has not been examined in rugby sevens. The Sevens World Series has 15 core nations competing in nine tournaments played in nine different countries over a period of eight months. Teams undertake extensive travel to compete in tournaments varying from as little as one hour through to >24 h of accumulated flight time. Rugby sevens players following long-haul (>5 h) travel exhibited small reductions in lower-body power after travel and a large reduction after a tournament. Additionally, players covered both a greater total distance per tournament (m) and greater average distance >5m·s^{-1} per game in tournaments following long-haul travel. The level of the opposition played and the tournament finishing position were not contributing factors to the increased running volume. The deleterious effects of long-haul travel on player neuromuscular fatigue and tournament running demands should be considered when planning training, travel logistics and player recovery protocols.

Overall there were 22 between-subject rugby sevens players that participated in this study, and a within-subject sub-set of 12 players who competed in a minimum of 8 tournaments. A similar decline in lower body power over the three week monitoring period was evident for both the combined cohort of 22 players and sub-set of 12 players. These two groups showed a small decrease in peak power (~3%) post-travel and post tournament (~4%). The decrease from pre-travel to post-tournament in both groups was small in mean power (~4%) and moderate in peak power (7%). Irrespective of the playing group the peak and mean power values after all tournaments were ~7200W and ~4400W respectively. Similar values were presented in rugby sevens players showing a decrement in lower body power over the course of a rugby sevens season (67). This analysis demonstrates for the first time in rugby sevens an impairment in counter movement jump performance post-travel as well showing a consistent decrement after competing in rugby sevens tournaments (91). This outcome is in contrast to previous research where jump tests were questioned as a monitoring tool due to their limited ecological relevance in team sports requiring prolonged bouts of intermittent-sprint activities (35). The current study effectively shows that there is a real change in jump test performance in rugby sevens players over three week study period and consistently over multiple tournaments over multiple years.

International rugby sevens players are stronger and more powerful than domestic-level players, covering greater overall distance in games and distances at high speed in international tournaments (48, 78). Monitoring performance over domestic tournaments showed trivial or unclear changes in both peak and mean power, inferring minimal impairment on neuromuscular function pre and post domestic rugby sevens tournaments. The relative stability in power may be due in part to the decreased travel time (<5 h) to attend domestic tournaments and the likely inferior physical levels of domestic rugby sevens players who competed against international players in this study, possibly inflicting less physical demand when playing at the domestic level (75, 78). Conversely, there were small (~5%) and moderate (~9%) decreases in lower body peak power over the three week monitoring period in international tournaments. These reductions may be attributable to the variable flight times (ranging from 1–24 h) and the increased intensity associated with competing in international tournaments (48, 75).

It is apparent that flight times are influential when considering neuromuscular fatigue in rugby sevens players (91). There was a small decrease in peak power (~5%) over the three week monitoring period for tournaments requiring short-haul travel. Two previous studies found no substantial change in lower body power post-short-haul travel (35, 64), contrasting the results of this study showing neuromuscular fatigue or travel fatigue in flights <5 h. However the combined effect of travel and tournaments indicate that there is likely a cumulative affect associated with short-haul travel and competing in tournaments. The most substantial decreases in lower body power were evident in tournaments requiring long-haul travel. Small changes in peak (~4%) and mean power (~3%) were shown post-travel, likely the result of travel fatigue (35, 79). In simulated long-haul travel, reduced morning cortisol levels with increased submaximal heart rates post-travel have been implicated in increased physiological fatigue (35). These physiological variables as a result of travel fatigue potentially add to the reduced ability of rugby sevens players to perform a countermovement jump post long-haul travel.

While it is difficult to separate the effects of travel fatigue and jet lag (35), the ability of rugby sevens players to adapt to multiple time zone changes (2–9 time zones) may be a contributing factor to the large decreases in lower body power shown post-tournament (~10% peak power and ~6% mean power). Given that changes shown post-long-haul tournaments were moderate and post-short-haul travel were small, it appears that the associated travel fatigue two days post-travel may have decreased countermovement jump power. In contrast, jet lag and cumulative fatigue may be responsible for the large decreases in power that occurred over the three week monitoring period (79). However, the reported ~10% decreases in lower body power is considerably less than ~26% decrement previously reported 12 h post-tournament that included a pool recovery session (91). Players in the current study may have had less decay in lower body power post-tournament by participating in planned post-tournament recovery practices including nutritional interventions promoting hydration and replenishing macronutrients, hydrotherapy and cryotherapy practices, the wearing of compression garments and maximising sleep (31, 88). It is important for rugby sevens players to optimise recovery practices on arrival at the tournament destination after long-haul travel and maintain them throughout the tournament and post-tournament (31, 88).

GPS data provides further insight into the role of neuromuscular fatigue monitoring associated with long-haul flights and the running demands of international rugby sevens tournaments. In assessing the GPS tournament data the research group was narrowed down to a sub-set of 12 players based on the inclusion criteria of competing in a minimum of 8 tournaments. This within-subject data set provides a deeper understanding of changes that occur in tournament running demands as a result of either short- or long-travel.

When compared to short-haul travel, players after long-haul travel covered ~13% more total distance (m) and ~11% greater mean distance per game distance above 5 $m \cdot s^{-1}$. A decrease in countermovement jump performance associated with increased low speed running <15 $km \cdot hr^{-1}$ (4.2 $m \cdot s^{-1}$) was shown in Australian Rules Football, whereby a change in running mechanics (as a result of neuromuscular fatigue) could result in accumulating lower-end high speed meters (>15 $km \cdot hr^{-1}$ or 4.2 $m \cdot s^{-1}$) (20). This outcome is consistent with the current study highlighted by increased game average meters distance above 5 $m \cdot s^{-1}$ (lower-end high speed metres) with trivial or no change in game average metres >6.6 $m \cdot s^{-1}$. It would be prudent for coaching staff to provide recovery modalities focusing on returning to or maintaining optimal running mechanics post-travel.

Two covariates were used to assess whether opposition quality or tournament finishing position had an effect on distance covered after short and long-haul flights. Both covariants were shown to not influence tournament running demands (see Figure 4.1, p.51). Therefore the effects of travel fatigue and jet lag are likely to contribute to the increased total distance covered in a tournament as well as the increased meters distance above 5 $m \cdot s^{-1}$ (79, 91). The increased distances may be attributed to neuromuscular fatigue and symptoms of jet lag characterised by sleep disruption that reduce cognitive performance (35). Decision making ability under tournament playing conditions may be impaired by loss of sleep with slower reactions to team plays and counter moves to opposition plays resulting in further distance being covered. In Australian Rules Football, teams finishing higher on the competition table covered less distance than teams lower on the competition table which was in part attributed to higher ranked teams making better decisions (92). Other factors may also contribute, for example in soccer, following short-haul travel players covered greater distance in away games conceding more goals and having less shots on goal, which was attributed to situational variables, territoriality, tactics and player psychological state (34). Further research into changes in rugby sevens game statistics (in short versus long-haul travel) would be valuable in characterising all the effects of neuromuscular fatigue.

This research clearly demonstrates rugby sevens players incur lower body neuromuscular fatigue post long-haul travel. Consequently, players covered greater distances in tournaments accumulating more metres above 5 $m \cdot s^{-1}$ following long-haul travel. The combined decrease in lower body power with increased running demands resulted in player neuromuscular fatigue levels that may impair game performance. It is imperative coaching staff minimise neuromuscular fatigue pre-travel, educate players in limiting travel fatigue and jet lag, and employ the most appropriate recovery modalities post-travel and post-tournaments.

Conclusion

The depth of research on rugby sevens has continued to grow dramatically, providing valuable knowledge of game, tournament and player demands. This thesis contributes new and valuable knowledge into the physical demands and effects of travel on international rugby sevens players across a competition season. Rugby sevens players are able to increase upper body strength across the season which is in contrast to a decay in lower body strength in-season. Forwards find it difficult to maintain lower body power in-season which may be attributable to the additional demands of exclusive skills such as scrummaging, line outs and restarts. Awareness of the changes that occur in strength and power, and differences between forwards and backs over the duration of season, can inform annual training plan development. Moreover coaches and support staff should attend to the demands associated with travelling and competing in international tournaments. In particular, long-haul travel has detrimental effects on neuromuscular function resulting in an increase in tournament running demands. The practical outcomes of this thesis can be readily implemented by the coaching staff to optimise player strength and power for positional groups over the season, and by incorporating an appropriate well-considered post-travel and post-tournament recovery plan.

Chapter 6: Research Outcomes

The research presented in this thesis provides major findings that contribute to, and provide evidenced-based outcomes on the physical preparation of rugby sevens players. It is important that coaching and support staff, players and administrators are aware of physical changes that occur in strength and power over the duration of an international rugby sevens season, and the likely effects of long-haul travel on lower body power and tournament running demands.

Changes in strength and power during a season of rugby sevens

1. ***Quantify changes in body composition, upper body strength, lower body strength and lower body power over a season of international rugby sevens.***

Rugby sevens players show variable small to moderate changes in physical qualities across an international season. Strength and power qualities increase during the pre-season training period. In-season, players body composition remained stable, and they experienced a ~10% increase in upper body strength. However players were unable to maintain the pre-season gains made in lower body strength, with the backs reverting to initial levels by the end of the season and the forwards decreasing by up to ~4% below initial levels. Lower body power was more sensitive to the different training and game demands of positional players with moderate changes observed in mean power over the season, forwards decreasing by ~6% and backs increasing by ~8%.

2. ***Profile lower body strength in international rugby sevens players, identify the differences between playing positions (i.e. forwards and backs) and compare these results with previously published values in collision-based sports.***

Forwards are up to ~14% stronger in the lower body than backs in absolute terms, whereas relatively backs are shown to be ~6% stronger across the season. Both forwards and backs in rugby sevens have comparable relative lower body strength measures to research assessing lower body power in rugby union backs.

3. ***Identify differences in strength and power qualities between playing positions in international rugby sevens players and the magnitude of changes across the season in forwards and backs.***

Both forwards and backs are able to increase upper body strength substantially over an international rugby sevens season, conversely lower body strength appears to decay in-season after gains shown during the pre-season. Backs demonstrate an ability to continually increase power, whereas forwards show up to an 18% decrement during the in-season period.

Long-haul travel effects in rugby sevens

4. ***Establish the effects of short- and long-haul travel combined with the demands of competing in a rugby sevens tournaments on lower body power.***

Following short haul travel (<5 hours) there was a small decrease in lower body power (~5%), with trivial or no apparent changes following competing in domestic-level rugby sevens tournaments. However, small decreases in lower body power (~4%) were observed following international tournaments. Following long-haul travel (>5 hours) there is a small decrease in lower body power (~4%) which appears to be further exacerbated by up to ~10% if long-haul travel is followed by competing in an international tournament.

5. ***Quantify and compare the differences in tournament running demands following short- and long-haul travel, in addition consider whether any differences were related to opposition quality and/or tournament finishing position.***

Rugby sevens players competing in international rugby sevens tournaments following long-haul travel cover ~13% greater total distance which is comprised of ~11% higher total distance at high speed (distance above 5 $m{\cdot}s^{-1}$). This effect is evident irrespective of the quality of the opposition encountered or the finishing position of the team in the tournament.

Limitations

Although the findings of this thesis have important implications for managing player strength and power qualities across an international rugby sevens seasons, the following limitations are acknowledged.

Participants in this study were limited to international male rugby sevens players from one country. As there are only a limited number of players in each national squad, the sample size available for investigation was restricted to the number of players available free from injury or illness. Therefore this study may not be representative of all international rugby sevens players competing around the world, however this is representative of elite level rugby sevens players in Australia. Future research should examine whether rugby sevens players in other nations have similar physiological characteristics and responses.

It appears that neuromuscular function as assessed by the counter movement jump may be significantly reduced for greater than 120 hours post tournaments (91). Given that there were nine tournaments and 28 in-season training weeks, tournament and post-tournament fatigue could affect ~30% of productive training time in-season.

Player compliance in reporting rate of perceived exertion (RPE) was inconsistent when compared to the collection of counter movement jumps and game running demands, as such the self-reported data was not included in the study. Matching player RPE data would be valuable in determining intrinsic tournament intensities in line with GPS data when considering the effect of both short- and long-haul travel.

Practical applications

The findings of this thesis can be applied by coaches and support staff, players and rugby sevens administrators to maximise the physical performance of players in training, following travel and in competition throughout the duration of an international rugby sevens season.

Coaching and support staff

Lower body demands of rugby sevens forwards should be a priority to ensure that lower body improvements in strength and power made in the pre-season can be maintained throughout the in-season period. These outcomes could be achieved by:

- Ensuring the ratio of lower body to upper body programming remains consistent through the season managing training time parity and recovery between playing positions.
- Using a box squat in-season may be useful in maintaining and increasing lower body explosive power.

- Exercising care when assessing the back squat if the box squat has been the primary lower body strength modality.
- The careful consideration of periodisation and training load planning in the week preceding long-haul travel to minimise neuromuscular fatigue, which can be further exacerbated by travel fatigue and jet lag.

Rugby sevens players

Rugby sevens players should be educated and embrace strategies designed to minimise travel fatigue and prioritise sleep as a recovery modality. Based on research in the area of travel and performance (35, 66), the following strategies are recommended:

- Pre-travel, players should start to adjust their sleep and meal patterns.
- During travel players should wear compression garments, adjust their time zone, meals, hydration and sleep patterns in line with the tournament destination. Players should move about and maintain mobility during waking times.
- Upon arrival players need to adjust to the destination time zone (by seeking daylight or not) and complying with the destination time zone [either sleeping or waking].
- Players would benefit from a post-travel recovery session of 30-40 min comprising of movement patterns and low intensity running to enhance maintenance of optimal running mechanics. These sessions would include some light skills and a low intensity small-sided game followed by general flexibility and a hydrotherapy format (dependent on the facilities available, e.g. pool or ice bath).

Administrators

Team management and tournament organisers should be cognisant of the physical impact on players embarking on long-haul travel, crossing multiple time zones. This can be achieved by:

- Where appropriate, select and schedule flights that minimise total travel time to tournament venues.

- Allowing sufficient time after arrival at the tournament destination to enable players circadian rhythms to return to normal before competition commences. Current recommendations are to allow 12–24 hours per time zones crossed (37, 79).

Directions for future research

The continued growth in the maturity of rugby sevens as an international sport provides researchers with opportunities to further increase the depth of knowledge relating to strength and power and ways to optimise these traits through training and the effects on performance. This research could provide the catalyst for increased research across multiple areas in rugby sevens.

- A longitudinal study comprising of multiple seasons would be beneficial to address chronic adaptations to strength and power training. This experimental approach would enable tracking of players over consecutive seasons, assessing any loss in strength and power in the off-season, and measuring the changes in strength in individual players over time.
- Determining the effect of running loads and position-specific skills training on strength and power for positional groups during both the pre-season and in-season will provide insights into strategies that may help to optimise lower body power. Specifically, quantifying the force load placed on forwards during a three-man rugby sevens scrum, lineouts and restarts of play would be useful.
- The collision nature of rugby sevens demands both lower and upper body strength. The assessment and/or monitoring of upper body power would be beneficial to more effectively monitor fatigue post-travel and post-tournament. The monitoring of upper body power across the season in conjunction with the reported increases in upper body strength may provide further insight into the role of the upper body in rugby sevens.
- Determining the ideal training week structure whereby strength and power gains in-season are maximised would be advantageous. This investigation would need to consider the intensities of different training modalities focusing on measures of both internal and external loads.
- Matching player RPE data would be valuable in determining intrinsic tournament intensities in line with GPS data when considering the effect of short and long-haul travel. This way

training loads prior to travel, post-travel and post-tournament could be correlated with neuromuscular function and game running demands.

- Research investigating the recovery time course of neuromuscular fatigue after consecutive tournaments would inform coaching staff on the reintegration of physical training attributes for players returning to full training.

Conclusion

This thesis documents the physical changes that occur in strength and power over the duration of an international rugby sevens season, and the effects on lower body power and tournament running demands following long-haul travel. Both forwards and backs are able to increase upper body strength across the competitive season; conversely lower body strength decreased. Forwards appear to have difficulty in maintaining lower body power over an international rugby season likely due to position-specific skill demands. In addition, lower body power in rugby sevens players declined following long-haul travel and after competing in rugby sevens tournaments. This decline in lower body power may be linked to a subsequent increase in running demands experienced by players during tournaments following long-haul travel. Together the outcomes of these investigations allow coaches and support staff, players and rugby sevens administrators to develop effective training, travel and competition plans. Greater knowledge of the demands of rugby sevens allows for the optimal expression of strength and power characteristics, enabling players the opportunity to perform to their potential.

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