Quantification of training load in junior provincial rugby union players.

MSc. (Med) Exercise Science

Ruan Rust RSTRUA001

Dissertation presented for the degree of Master of Science (Exercise Science) in the Department of Human Biology, University of Cape Town,
September 2019

Division of Exercise Science and Sports Medicine,

Department of Human Biology, Faculty of Health Sciences

UNIVERSITY OF CAPE TOWN

DECLARATION

I, Ruan Rust, hereby declare that the work on which this dissertation is based is my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

I empower the university to reproduce for the purpose of research either the whole or any portion of the contents in any manner whatsoever.

Signature: Signed by candidate

Date: 15/10/19

Table of Contents

Abstract

Study purpose:

The objectives of the study were to measure external and internal load and recovery status of junior semi-professional rugby union players (n = 36) during the u/19 Currie Cup campaign.

Methods:

The monitoring period covered 280 days (July – October) and included phases divided into off-season, pre-season and competition. Twelve league matches were played during the competition phase. The variables associated with external and internal load and recovery status were summarised for each player and also compared to each other to establish relationships between these variables. Data were collected either daily (training load, subjective fatigue and recovery) or weekly (recovery heart rate) or during matches (mechanical load, physiological load and training load). Injuries were also recorded throughout the season.

Results:

The primary finding of this study was that the players' loads (arbitrary units; AU) (605±293 AU), fatigue (4.5±1.3 AU) and recovery (14.1±2.3 AU) did not change significantly throughout the different phases of the season. Also, recovery heart remained similar throughout the different phases of the season supporting the pattern of the subjective data. There was no clear predictive relationship between training load, subjective fatigue and recovery prior to sustaining an injury (both soft tissue and musculoskeletal).

Conclusion:

This study questions the usefulness of a wearable device to measure training load

(internal/external), particularly since the session rating of perceived effort(sRPE) is cost effective, quick and easy to implement and provides accurate information. Subjective training load and subjective fatigue did not predict injury in this cohort of players. However, these variables can be used as markers to guide training to ensure the conditioning status of the players remains similar throughout the season. In particular they enable individualised decisions to be made about each player, ensuring that load and fatigue in response to the load remain steady.

Chapter 1

Background to the study

Background to the study

Rugby Union (henceforth rugby) is a contact sport played between two teams, each consisting of 15 players. The match is divided into two halves, each lasting of 40 minutes. Despite rugby being one of the most popular contact sports internationally (http://www.irb.com), it also has among the highest reported injury rates for contact sports.[1,2] With the increase in popularity and professionalism of rugby union, provincial unions and national institutions have started investing in junior academies. The goal of these junior academies is to create a smooth transition for the players from junior non-professional rugby to senior professional rugby. Academies in South Africa such as the Western Province Rugby Institute, Blue Bulls Tuks Rugby Academy and Sharks Academy contract junior rugby players on a one-year or two-year contract. They provide opportunities for these players to learn rugby skills and acquire physical qualities that are required at a professional level.

One of the greatest challenges that support staff of the academies face when working with the junior semi-professional players is to increase their capacity, so they are able to tolerate the technical, tactical and physical demands of senior rugby. The physical discrepancies may be qualities such as upper body strength and maximal aerobic speed and athletic robustness.[3] Robustness refers to a player's ability to withstand high training and competitive loads without succumbing to injury.[4]

Senior professional rugby players demonstrate increased robustness as they undergo increased training loads and are exposed to multiple training sessions per day. In contrast, junior rugby players come from training backgrounds where the week-to-week training loads may vary up to 35%.[5] This is far greater than the 10% "threshold" as recommended by Gabbett.[6] Junior rugby players therefore not only have higher week-to-week variations in their training loads, they also have lower weekly training loads than senior professionals.[7] This results in junior players experiencing phases of extreme loading, without the necessary physical capacity to endure these extreme periods.[3,5] Although the above-mentioned data are from English school and academies, anecdotal observations in South Africa suggest a similar pattern occurs in junior rugby in South Africa.

Training loads need to be carefully manipulated for players to improve performance. This can take the form of modifying frequency, duration and intensity of training and the rest and recovery periods in between sessions. The total 'load' describes the external stressors the player encounters including the physiological stress of the training load.[8] The response to a load stimulus applied to a player can either be positive, in which the player adapts with an increased physical capacity, or negative, where there is a decrement in performance.[9] Excessive training loads or excessive training spikes are considered a major risk factor for injury in rugby union, football, rugby league, Australian Rules Football, cricket and long-distance running.[8] An excessive training load with insufficient recovery between training sessions leads to symptoms of overreaching.[10]

In the context of professional rugby players, 'load' comprises rugby-related and non-rugby related inputs. While the physical components of training for rugby can be characterized and measured, the non-rugby related stressors, such as travelling, dealing with the competition within the team and fulfilling contractual and media obligations are more difficult to quantify.[8] Since players will deal with the training[11] and other stressors differently,[12] it is important to be able to track players to determine who is adapting, and who is not. It follows that load can be adjusted when players show signs of mal-adaptation.[13] This introduces the concept of monitoring the health and fitness status of players so their management (training load and recovery) can be individualized.

In a junior South African rugby academy this is of particular importance, as in the South African school rugby system there are secondary schools that have access to an abundance of resources and facilities. These schools effectively offer a semi-professional junior rugby program. In contrast the majority of secondary schools' struggle to maintain adequate training facilities. As a result of this disparity, when junior players enter the academies, there are variances in training history, exposure to adequate training loads and markers of performance. This places even more importance on monitoring the well-being of players to ensure they adapt appropriately.

There are several options of measurement for monitoring the well-being of players.[14] These can be broadly classified into external loads, internal loads, symptoms of fatigue, risk of injury and markers of performance. The decision about which tests to incorporate in a monitoring protocol depends on the sport, the age of participants and their level of performance.[13] Therefore, there are many unanswered questions about preparing young rugby players for the physical demands of high-level senior rugby and which tests should be used to monitor fitness and fatigue and performance.

The next section (Chapter 2) will review the literature on the multitude of factors that contribute to the stress imposed on adolescent rugby union players. The symptoms of fatigue and how can these symptoms can be measured will also be discussed. This will be followed by the risk factors and markers of performance associated with success in rugby. The last section will examine the demands of adolescent rugby union and how these demands differs from senior professional rugby union. This section will conclude with the aims and objectives of this dissertation.

Chapter 2

Review of the literature

Review of the literature

As background, the different types of professional rugby union competitions referred to in this review are:

- Super Rugby – Provincial men's rugby union tournament involving teams from Argentina, Australia, New Zealand, South Africa and Japan.
- Six Nations - International rugby union competition between the teams of England, France, Ireland, Italy, Scotland, and Wales
- Aviva premiership – Provincial English men's rugby union competition. French Top 14 – Provincial French men's rugby union competition.

Demands of adolescent rugby union

Field training should replicate the intensity and demands that players are exposed to on match day. However, it is unreasonable to replicate match day demands in every training session, especially in rugby union, particularly considering the negative affect that a collision-based sport has on fatigue and injury risk.[2] In senior rugby it has been argued that not one single training modality can prepare the player for the rigours of the sport, while a combination of different training modalities might improve match preparedness.[3] It may be argued the same logic applies to junior rugby players. Understanding the demands of the sport, which may differ between senior and junior players offers sport scientists and coaches insight into the movement and physical demands, to ensure that the optimum training dose is prescribed. The prescription of load may be either positive (if appropriate load is prescribed) resulting in athletic and skill development, or negative (if inappropriate load is prescribed) which may result in illness , injury or overtraining.[15] Lombard et al (2015) has shown under 20 players have got bigger and stronger over a 13-year period, suggesting the demands of the game on the players have also increased over this period.[16] Therefore, the demands of adolescent rugby union need to be continually reassessed.

Phibbs et al (2017) found that training demands of adolescent academy and scholars differed, with academy players being exposed to position specific training simulating match demands or greater. While the scholars, trained less frequently at match demands, and were exposed to minimal position specific demands.[17] Phibbs also found that the physical demands demonstrated in his study were higher than reported in other similar studies.[17] It has also been reported that sub-elite English adolescent rugby union players, completed on average a weekly sRPE load of 1014 AU,[18] while Australian adolescent rugby union players complete between 2372±1009 - 3645±1588 AU, depending on playing standard.[19]

Phibbs et al (2018) found that sub-elite adolescent rugby union players overall and weekly training loads were low (1217± 364 AU), and that inter-week variability range greatly with sRPE loads ranging from 195-4888 AU.[15] It has been established that high training load alone does not cause injury , but rather regular spikes and troughs in training load contribute to increased injury risk.[6] Therefore adolescent rugby union players that are not regularly exposed to chronic high training loads, while experiencing regular large changes in their training, are at substantial risk of injury.[4]

Defining training load and measuring athlete response

Training load, stress and workload have been used interchangeable in rugby and other sports. Quarrie et al. (2016) stated that load relates to the measurement of "external stressors" applied to an athlete, or monitoring the response the athlete has to the stress[8]. This response can be either psychological or physiological[20]. The athletes response to the stimulus is specific to the nature , duration , intensity of the load[21].Training load is therefore the variable that is used to elicit the desired training response.[21]This training response in turn results in improved speed , power and endurance , benefiting sporting performance[22]. For the purpose of this thesis training load with be further categorized into external load and internal load.

External loads

External load explains the physical work which quantifies training and competition and is usually defined by variables that can be measured during training or competition.[13,23] External load is specific to the measures being taken[21]. For example, weight lifted in the gym, distance covered, speed, number of collisions, number of accelerations/decelerations.[9]Vanrenterghem et.al. (2017) explains further that biochemical and biomechanical stress contribute to external load[22]. The biomechanical component of training loads is largely dependent on the propulsion and braking forces achieved through training, while the biochemical loads are derived from the energy systems. External loads which rugby players are exposed to are either rugby related or non-rugby related.[8]

Rugby related

These are physical loads such as matches, rugby training, resistance training, and conditioning. Each form of rugby related load can be defined by specific variables.

Matches/Rugby Training

- Total distance (meters) - In Super Rugby (2011), the distance covered during a match by players differed depending in the playing position.[15] For example, front row forwards covered 4662 m, back row forwards covered 5262 m, the inside backs covered 6095 m, and outside backs covered 4774 m.[24] Forwards at U/20 International rugby level, covered a similar distance (5370 m) whereas the backs covered slightly more distance (6230 m).[25] A review conducted by Ziv and Lindoor (2016), found that distanced covered varied from 4000m to 7900m , depending on playing level. [26]
- Total duration (minutes) – The average match time for different groups of players in Super Rugby was: front row, (84 min), back row forwards, (92 min), inside backs (89 min) and outside backs (72 min).[24]
- Running intensity ($m.min^{-1}$) - In Super Rugby, inside backs, tend to cover the greatest distance per minute of game time (86 $m.min^{-1}$) which is likely a result of the greater ball-carrying events and positional play on offence and defence.[27] While in the Six Nations "B" division, backs playing intensity was 78 $m.min^{-1}$, and the forwards averaged 71 $m.min^{-1}$,[26] which is lower compared to Super Rugby.

- Number of sprints - In the Aviva Premiership, sprinting occurred on average 16 times per match for forwards and 23 times per match for backs. Each sprint lasted about 1.2 ± 0.2 seconds. Sprinting contributed 10–15% of total game time.[24]
- Speed zones (meters and $km.h^{-1}$)- Backs in the French Top 14 covered greater high speed (>14.4 $km.h^{-1}$) running distance (537 m) than the forwards (397 m). In the moderate speed zone (10.0-14.4 $km.h^{-1}$), the forwards covered greater distances (623 m) than the backs (491 m).[28]
- Impacts – An impact as classified as contact with an opponent , this can be a ball carry , a ruck or a tackle[27]. The total number of impacts recorded in Super Rugby was higher in forwards (0.56 impacts per minute) than backs (0.36 impacts per minute). When the type of impact was analysed, forwards were involved in more tackles, tackle assists and rucks, but backs tended to carry the ball into contact more regularly.[27] Ziv and Lindor (2016) found that forwards were involved in more contacts , however inside backs where involved in more severe impacts (>10g).[26]

Resistance training

- Total duration (minutes) - Gym training of players in Super Rugby formed 23% of the total training time, and contributed to 35%, 19% and 21% of the off-, pre- and in-season phases, respectively.[29] Jones et al. (2017) found that in professional rugby union , frequency of strength training varied by season , with an average of three resistance training sessions occurring in-season , compared to an average of four resistance training sessions in the off-season.[30] This was similar across both the Northern Hemisphere and the Southern Hemisphere.

Conditioning

- Total duration (minutes) - Super Rugby conditioning or fitness training contributed to 8% of the total training time and formed 23%, 12% and 2% of the off-, pre- and in-season phases, respectively. Conditioning played a larger role in the off- and pre-season than during the in-season.[29] Conditioning consisted of any form of field fitness training , not limited to anaerobic interval training , aerobic training , cross-training & speed and agility training.

Non-rugby related

These are loads that although are not associated to rugby, play an important role in player's current state of readiness to sustain further training.[4] These are factors such as, but not limited to;

- Travel related performance - Playing more rugby matches at home in the Super Rugby competition increased a team's chance of doing well in the competition.[31]
- Travel related illness – There is an increase in the incidence of illness in Super Rugby teams travelling from home to foreign locations that were >5 h time zone difference away.[32]
- Travel related fatigue - Jet lag and subsequent recovery is a function of the number of time zones crossed and the direction of travel. The body readjusts and acclimatizes faster for travel in a westbound direction.[31]

Internal loads

Measurements of internal loads represent the player's response to the external loads. Therefore this concept incorporates all psychophysiological responses occurring during the execution of the external load[21].The internal load determines the training outcome , this is due to biochemical ,biomechanical or psychological responses to the external load, [21,22]. Fixed external loads can result in differing internal loads and adaptive responses amongst athletes, this may be due to modifiable and non-modifiable factors such as; age, genetics, training status, health and psychological status[21]. The importance of measuring internal load is of the utmost importance , ensuring that correct psychophysiological responses are achieved.

These measurements are either psychological, such as the rating of perceived effort (RPE) during exercise, biomechanical stress to the musculoskeletal system, such as joint-contact force and muscle-tendon forces , and biochemical stress to the cardiorespiratory system , such as the heart rate, blood lactate concentration or oxygen consumption during exercise.[13,22,35] Examples of the measurements often used in rugby monitoring/research follow.

Hear rate - During an u/19 professional rugby match the forwards had higher heart rates than the backs.[36] The forwards spent approximately 72% of the match at a heart rate greater than 85% of their maximal competition heart rate.[36] The backs spent the majority of time in moderate activities (37% of total time) and low intensity (18% of total time). In this study there was no difference between forwards and backs for the time spent at maximal heart rate.[36] Sparks (2013) found that university rugby union players spent more time in high-intensity than previous studies on elite/professional rugby union players (59% vs 44%).[37] This study also showed there was no significant difference in time spent between intensity zones during the first halves on the game, but that there were significant differences in time spent between the high and low intensity zones in the second half , with an increase in time spent in moderate to low intensity zones.[37]

Blood Lactate - Studies have shown that the mean blood lactate concentrations in u/19 professional rugby players during a match were higher in the forwards (6. 6mmol.L^{-1}) compared to the backs (5.1 mmol. L^{-1}). Semi-professional rugby league forwards and backs had intra-match mean blood lactate concentrations of 8.5 and 6.5 mmol.L^{-1} respectively.[36,38] This measurement is invasive and relatively expensive and therefore has not been used much to monitor rugby players in an applied setting.

RPE (Rating of perceived effort) - Individual responses to training and competition loads can be attributed to personal characteristics such as age, position, training and injury history and current physiological attributes.[6] Subjective ratings of perceived effort with measures of duration (minutes) are considered to be a simple, inexpensive and easily implemented system, that is valid and reliable in terms of monitoring physical loads.[8,39] sRPE is an additional internal load tool , that uses RPE and session duration, to provide a more comprehensive monitoring tool.[40] A study conducted by O'Keeffe et al. (2019) in adolescent Gaelic footballers, found that sRPE may be useful in identifying loading trends that are not beneficial for the players.[40] In particular, they identified that weekly load, monotony, and absolute change in load greater than the team average were significant risk factors for injury. Univariate analysis identified weekly load (OR = 2.75; 95%CI = 1.00–7.59), monotony (OR = 4.17; 95%CI = 1.48–11.72) and absolute change in load (OR=3.27; 95%CI=1.15–9.32) greater than the team average were significant injury risk factors, suggesting that athletes are better able to sustain small changes to weekly load, as opposed to large fluctuations in training load.[4]

Emotional stress placed on the body has been shown to alter and influence the immune system , much like overtraining syndrome.[33] A study by Stults-Kolehmainen et al. (2017) found that athletes who reported to have higher levels of stress took longer to recover from strenuous training bouts, compared to athletes with lower reported stress levels.[34] For example, commercial or sponsorship obligations, along with media coverage and community work, are source of stress for the player, that is received and processed much the same way as physical stress. This highlights the demands that cognitive loads play on athletes and their recovery status.

Symptoms of fatigue

From a conceptual perspective, training disturbs homeostasis. This causes a biological response and a temporary impairment to a player's performance.[41] Rugby players are subjected to extremely demanding weekly training schedules, resulting in limited time for recovery. The high training loads, in conjunction with impaired recovery, predispose rugby players to injury.[41] The markers of impairment may last from minutes (blood lactate, heart rate), to days (creatine kinase activity in the blood) to weeks (neuromuscular performance).[42] Impairment in the player's ability to perform a required skill or maintain an expected workload is defined as fatigue.[10] Fatigue manifests in two forms; acute or chronic fatigue. The symptoms of acute fatigue are transient whereas the symptoms of chronic fatigue are more persistent.[10]

Acute fatigue as a result of training can be measured after one training session, however the practical time frame for measurement is usually one week.[43] The tools to measure acute fatigue can be objective (heart rate,[44-45] physical performance,[46] RPE during exercise[47]). More specifically, these measures are often reported as heart rate recovery after exercise, distance covered, tackles completed, and total training load.

Heart rate recovery (HRR) has been used to assess the player's readiness to train.[48] This can be defined as the decrease in heart rate after physical activity, and is usually measured for the first minute after stopping exercise.[49] HRR can be characterized by a decrease in sympathetic activity, combined with an increased in parasympathetic reactivation.[49] Heart rate recovery has been shown to be a reliable indicator of an athlete's training status and well-being.[50] Daanen et al. (2012) has shown that HRR is sufficiently sensitive to be used as a tool to predict changes in training status, and also to monitor the accumulative effects of fatigue.[44,48]

The symptoms of chronic fatigue are more persistent than the symptoms of acute fatigue. There is a continuum of severity of symptoms of chronic fatigue. For example, chronic fatigue is associated with overreaching (functional and non-functional) to the more serious overtraining syndrome.[10] Overreaching is an accumulation of training which results in a decline in performance. With functional overreaching a ''supercompensation'' effect may occur.[10] In this case performance improves when the player either reduces training load or gets more rest between sessions. If intensified training continues players can evolve into a state of non-functional overreaching. This leads to stagnation or decrease in performance for several weeks or months.[10] The overtraining syndrome is the next stage representing an accumulation of training and/or non- training stress.[10] This condition results in long-term decrement in performance capacity with or without related physiological and psychological signs and symptoms of maladaptation. Restoration of performance capacity may take several weeks or months.[51]

Chronic fatigue can be measured subjectively and objectively. The subjective measurements include Player self-report measures such as - Daily Analysis of Life Demands (DALDA),[52] Profile of Mood State (POMS),[50] Recovery Stress Questionnaire for Players(RestQ).[53-54] The objective measurement of chronic fatigue can be done using heart rate recovery after exercise.[35] This measurement is based on the assumption that a decrease in a player's heart rate recovery (i.e. less beats in the first minute after stopping exercise), indicates poor autonomic regulation – a symptom of chronic fatigue[49] or a decrease in the player's training status.[44]

In a rugby context, fatigue induced by repeated high-intensity exercise reduces tackling ability in rugby league players.[55] Players with the best tackling ability in a non-fatigued state demonstrated the greatest decrement in tackling ability under fatigued conditions.[55] The reductions in tackling ability under fatigued conditions occur due to limitations in technical, physical and perceptual qualities.[55,56]

Tavares et al. (2017) used a countermovement jump to assess neuromuscular fatigue in Super Rugby players, while a wellness questionnaire was used to assess muscle fatigue, stress, sleep quality and subjective fatigue.[57] This study found the effects of training load were the most pronounced on day 2 (Tuesday) and day 3 (Wednesday) of the week.[57] This illustrates the cumulative effects of training load, in conjunction with incomplete recovery on fatigue.

Collisions between rugby players may cause muscle damage; the fatigue associated with muscle damage may contribute to a reduction in performance.[56,58] Creatine kinase activity in the blood (CK) may remain elevated for up to 120 h after the activity that caused the damage.[59] Alterations in endocrine responses (i.e. testosterone-to-cortisol ratio)[60] and decreases in neuromuscular function (i.e. countermovement performance),[61] have been altered for up to 4 days after a match.

McLellan et al (2011)[59] speculated that the high running volume, running, jumping, cutting and blunt trauma in rugby contributed to the measures of neuromuscular fatigue, such as peak power, peak force and peak rate of force development being blunted in returning to baseline measures after the match.[59]

To further explore the decrements in neuromuscular fatigue post-match, they found that the decrement in peak power remained up until 48 hours post-match. They speculated that the velocity component of power is more sensitive to fatigue compared to the force component of power.[59]

Contact demands of rugby union have also been shown to effect technical efficiency. For example, the increased upper body neuromuscular fatigue associated with contact has been shown to correlate with tackle competence.[56] Thus a reduction in the peak upper body power may be an important variable to measure closer to match day, to ensure that tackling ability is not hampered.[56]

Fatigue during a rugby match (league) can be shown by the decrease in the total distance covered in the final 5-min periods of each halves, in comparison to the initial 5-min period of both halves.[62] There is also a decrement in technical performance as fatigue manifests during a match.[62] For example, there is a reduction in both the quality of skill performance and the number of involvements in the final stages of the match.[62]

During periods of sustained loading, players experience chronic fatigue.[10] Under conditions of chronic fatigue, RPE is increased for a given exercise intensity.[63] Also players with symptoms of chronic fatigue often report elevated perceived fatigue and muscle soreness (i.e. perceptual changes in well-being questionnaires).[61,63]

Risk of injury

There is a high risk of injury associated with playing rugby. For example, a meta-analysis of studies on senior professional rugby matches showed the overall incidence of injuries was 81 injuries /1000 player hours (95 % CI 63–105). This reduced to 3 injuries per 1000 player hours during training.[64] The mean severity for match injuries was 20 days (95 % CI 14–27), and 22 days (95 % CI 19–24) for training injuries. A higher level of play was associated with a greater incidence of injuries in matches, with no clear difference in severity.[64] While at youth level (u/16) in South Africa , the average match injury incidence was reported as 28 injuries /1000 player hours, with a the injury burden of 379days /1000 player hours .[65] The same study showed that the tackle was the leading event in rugby leading to injury , while the ball carrier was more frequently injured than the tackler.[65]A similar study was conducted in elite English youth rugby (u/16-u/19years) , and found that injury incidence increased with playing level , with schoolboy injury incidence rates lower (35/1000 player hours) compared to elite schoolboy (77/1000 player hours).[66]

While in a study conducted by Hartwig et al.(2019) , it was found that high match load may be an injury risk factor.[67] This is of importance to adolescent rugby players, as it is reported in Hartwig's study that 80% of players played rugby union for more than one team per week. This same study found that in weeks prior to an injury, match load was substantially higher.[67]

Several tests have been designed to assess the risk of injury. These are listed below;

(i) Adductor squeeze test -The adductor squeeze test is a test of adductor strength.[68] Adductor muscle strains are the most common cause of match injury in backs. [69] The measurement uses a sphygmomanometer that is placed between the player's knees. The squeeze test was performed in four positions named by the relative degrees of hip flexion; 0° and 60° and then for the latter two tests by the relative degrees of both hip and knee flexion 90°:90° supported and 90°:90° unsupported. Backs generally have lower adductor strength scores than forwards. An increased risk of developing groin pain in players with low squeeze test scores might explain why there are more groin injuries in backs than forwards and not just related to activities performed.[70] While Tiernan et al.(2019) found an association between adductor strength , subjective training load , subjective fatigue and muscle soreness.[71] It was found that increased subjective training load and muscle soreness , resulted in decreased adductor strength scores.[71] Illustrating its usefulness in conjunction with other markers to gauge athlete readiness and training status.

(ii) Functional Movement Screen (FMS) - The FMS is a test of mobility and stability in various movement patterns.[72,73] The FMS consists of 7 movement tests; deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up and rotary stability. Each test is scored on a scale of 0 to 3. A score of three is given if the person performs the movement correctly without any compensation. A score of two is given if the person is able to complete the movement but must compensate in some way to perform the movement. A score of one is given if the person is unable to complete the movement pattern or is unable to assume the position to perform the movement. An individual is given a score of zero if at any time during the testing he/she has pain anywhere in the body.[59]

The active straight-leg raise, and in-line lunge test are the two component tests of the FMS that predict injury in rugby union players (greater risk to sustain severe injuries, particularly contact injuries). The identification of active straight leg raise score <2 as a risk factor for severe injury in professional rugby union players is a valuable step toward reducing injury risk.[74]

(iii) Acute: Chronic training load relationship- Excessive and rapid increases in training loads are responsible for a large proportion of non-contact, soft-tissue injuries.[4,43] However, physically hard (and appropriate) training develops physical qualities, which in turn protects against injuries.[4,13] Gabbett (2016), showed that when the training load is fairly constant (ranging from 5% to 10% more than the previous week), players had <10% risk of injury.[75] However, when training load was increased by ≥15% above the previous week's load, injury risk escalated to between 21% and 49%.[4,6] These findings suggest it is not necessarily the amount of training the player is exposed to, but rather how the player arrives at their training load. Gabbet (2018) states that appropriate increases in training load promotes capacity , which in turn improves the player's ability to tolerate training futher.[4] This is demonstrated in players with greater chronic training loads, as there was a fivefold lower risk of injury compared to players with low chronic training load.[75] Bourden (2017) reinforces this concept as he states that high chronic training loads act to protect the player against injury, comparing training load as a "vehicle" that can either drive an player towards or away from injury.[13] Therefore, it can be concluded that there are protective factors associated with high chronic training loads and that exposure to training load provides the necessary stimulus for adaptation to occur. Also a high training load develops the necessary physical qualities that are associated with reduced injury risks.[76]

Markers of performance

Key performance indicators (KPI) define a performance against some form of outcome and are used in a comparative way. KPI's are used to draw comparison with opponents, other players or peer groups, while often they are used in isolation as a measure of the performance of a team or individual alone.[77]

In rugby KPI's are specific but not limited to sprinting speed, muscle strength, power, and repeat sprint ability. These are components that can be measured and define how the player has performed and also can be used as a marker of fitness or fatigue.

KPI's vary amongst playing positions, and therefore different fitness requirements are evident in different positions. For example, forwards are involved in more static exertions than backs (89 vs. 24 static exertions).[78] The mean duration of these exertions is longer in the forwards (5.2 seconds) compared to the backs (3.6 seconds). Also, the forwards are involved in about 25 scrums per match and perform more rucks (35 vs. 11 rucks), mauls (25 vs. 4 mauls), and tackles (14 vs. 10 tackles) than backs. The backs cover more distance during a game than the forwards.[78] But they are involved in fewer impacts than forwards. It has been suggested that despite the varying demands among positions, the stress exposure of a match is similar for forwards and backs.[27]

A summary of the KPI's used in rugby follows;

Speed - Faster players break the line, break tackles, evade opposing players and score tries more frequently than slower players. Also faster players arrive at the defensive line quicker, potentially forcing the opposition players into poor defensive decisions and positions.[79]

Body Fat - High levels of body fat increase the metabolic demands on the body and reduce a player's ability to repeatedly perform tasks.[79] This manifests as a decreased work rate and poor tackle ability as the match progresses.

Body Mass - The ability to accelerate, in accordance with gains in total body mass, is a better correlate of match-related contacts than sprinting speed or acceleration alone.[80]

Lower Body Strength - Lower-body strength contributes to tackling ability under fatigued conditions. Also well-developed lower-body strength contributes to team selection, greater repeat high intensity exercise (RHIE) ability during matches, and enhanced recovery following matches.[55] Players who demonstrated greater lower body strength and greater repeat sprint-ability, were at a lower risk of injury during spikes in workloads.[4,76]

Upper and lower body power - Upper body power (measured by means of a plyometric push-up) regardless of playing standard, has been associated with tackling ability. While lower body power (measured by means of a counter movement jump) was not significantly related to tackling ability, this may be due lack of movement specificity of the test for lower-body power.[81]

Field tests are associated with performance in a match. For example, there is a strong relationship between performance in the Maximal Aerobic Speed (MAS) and distance covered during competitive rugby union games ($r = 0.75$, $p <$, 0.001).[82]

Team Selection- Players selected for a rugby league team had greater upper-body strength (3RM chin-up) and endurance (body-mass bench press), lower-body strength (3RM squat), power (vertical jump), and prolonged high-intensity intermittent running ability than the players that were not selected.[83]

Gabbett (2018) states that players who demonstrate low levels or poorly developed physiological qualities, such as the above-mentioned factors, are at increased risk of injury where then are rapid increases in training load.[4,76] This may be due to the protective factor that load over time provides, along with the development of physiological qualities that are associated with continued sporting involvement.

Summary

Training demands should expose players to the specific intensity and volume of match play in the training week. Monitoring the training load players are exposed to, and their response to this training enables the training to be titrated for each player. This approach increases the chance of the players peaking at the expected time, while reducing their risk of injury. It also assists in making evidence-based decisions on when a player is ready to return-to-play after being side-lined from injury. The information obtained during a monitoring programme should be used to drive decision-making about managing the players.[4]

The principles of training young players and adult players are the same. However, a complexity is that young players generally have less position-specific training than senior players. The lack of match and position specific training results in players being underprepared for the physical movement demands, which are key components of match performance.[5] Not much is known about the training loads of young players making it difficult for the prescription of training to be evidence-based.

Therefore, this study will aim to investigate the training loads through all phases of the season accumulated by adolescent semi-professional rugby players, while further investigating the relationship between various markers of training load.

Rationale:

There is a lack of literature on training load, and the training strain of junior (u/19) rugby union players throughout a rugby season.

1) An investigation into the relationship between different methods of collecting training load would provide valuable information on how sport scientists and coaches analyse, interpret and react to load monitoring.
2) Subjective measures of fatigue and recovery by means of a player self-report will provide insight into the player's recovery status.

Therefore, in summary the relationship between recovery, fatigue, training load and injuries will be investigated in this study. This will be presented in Chapter 3, and will include a short introduction, description of the methods, analysis of the results followed by a discussion of the results.

Chapter 3

Quantification of training load in junior provincial rugby union players.

Introduction

As rugby academies invest more time and resources into developing junior professional rugby players there are greater demands imposed on these young players to adapt and acclimatize to their new professional surroundings. The challenge of developing these young players is compounded by the sometimes low training load[7] which is variable from week-to-week.[5] This results in regular periods of undertraining, followed by periods of overtraining. These rapid and regular spikes and troughs in training load are associated with an increased risk of injury.[4] Consequently a primary goal of rugby academies is to best prepare the junior rugby players to be sufficiently robust to meet the physical demands of senior rugby[3] by loading the players systematically to build a large chronic base.[6] This approach requires careful monitoring of players' training load and their responses to this load to identify players who are adapting inappropriately.

Therefore, the aim of this study was to describe the physiological demands of playing semi- professional junior rugby union during a rugby season (four months; July-October).

The specific objectives of the study were to measure external and internal load and recovery status during the u/19 Currie Cup campaign, which included 12 league matches. The variables associated with external and internal load and recovery status were compared to establish relationships between these variables.

Methods

Participants:

Thirty-six semi-professional rugby players between the ages of 18-19 years old were recruited to participate in the study. All the players were members of the Western Province Rugby Institute (http://wpri.co.za).

All the players completed an informed consent form. Before signing the players were made aware of the objectives and demands of the study. Players were told they were free to exclude themselves from testing at any point. All the data collected during training and matches were included in a database, which was registered by the Human Research Ethics Committee of the Faculty of Health Science University of Cape Town, the Western Province Rugby Institute (HREC. R013/2015).

Data Collection:

The monitoring period covered 280 days (July – October). Data were collected at varying times using two different systems; (i) Player Monitoring and Assessment System (AMAS). This is a program that has been created and developed by the High-Performance Centre, at the Sport Science Institute of South Africa (https://www.ssisa.com/high-performance-gym/athlete-monitoring/)

in conjunction with Jembi Health System, Cape Town, South Africa, and (ii) Zephyr Team Monitoring system (Zephyr Technology Corporation, Annapolis, USA). This is a multipurpose team monitoring system, including heart rate (chest mounted electrodes-sampling at 250Hz), tri-axial accelerometer (cantilever beam – sampling at 18Hz) and GPS(10hz sampling rate).

The following variables were recorded for player monitoring:

System 1: AMAS

- sRPE Training Load(sRPE-TL): Session intensity x session duration (e.g. sRPE 7 x 40minutes = 210 sRPE-TL) (Appendix A)
- Total Recovery Scores: The data were collected daily on an online platform where the individuals were required to answer 20 questions ranging from training session intensity to sleep quality. The scores were added to provide a maximum score of 20. Data were submitted retrospectively; i.e. data submitted today pertains to yesterday's training and recovery (Appendix B).
- Subjective General Fatigue Rating: 1-10 subjective rating of fatigue (Appendix C).

System 2: Zephyr team monitoring system

- Heart Rate recovery: Heart rate decrease 1-minute post submaximal exercise.
- Mechanical Load (ML): Average Mechanical intensity over time (6 x 40minutes= 240 ML)
- Physiological Load: Average (PL) Physiological intensity over time (7 x 30minutes = 210 PL)
- Total Training load (TTL): Average Training Intensity over time (8 x 30min = 160 TTL)

To clarify the calculations of mechanical intensity and physiological intensity further:

- Physiological intensity, a null value is attributed to a value less than 50% of maximum heart rate. A score of 10 is equal to 100% of maximum, and a value scaled linearly between 50% (1) and 100% (10) e.g. 75% HR Max = intensity of 5(https://www.zephyranywhere.com/benefits/physiological-biomechanical).
- Mechanical intensity, a null value is attributed to a value less than 0.5g peak acceleration. A score of 10 is equal to peak acceleration of 3.0g or higher, and a value scaled linearly between 0.5g (1) and 3.0g (10) e.g. 1.75g = intensity of 5 (https://www.zephyranywhere.com/benefits/physiological-biomechanical).

Testing Protocol

Data were collected throughout the week, starting on a Monday.

Subjective data (recovery scores, subjective fatigue, sleep quality, sRPE) were collected through the AMAS platform and was submitted daily. The players were provided with an internet link directly to the AMAS platform. Players' responses to the recovery and fatigue questionnaires were submitted via the AMAS mobile platform using their mobile devices every morning. sRPE was also submitted through the AMAS mobile platform once the relevant session was completed. The players were expected to complete and submit the relevant sRPE's as soon as possible, but due to limited access to mobile devices throughout the day, the majority of players submitted at the end of the training day. All injuries were reported to the head physiotherapist first thing of every training day. Injuries that where classified a time-loss injury where recorded for this study. A time-loss injury is defined as an injury that requires the player to miss more than 24hours of normal activity.[65]injuries where further categorized into soft-tissue injuries – the damage of muscle and its surrounding tendons , and musculoskeletal injuries – damage caused to the joint and not limited to its surrounding ligaments. These categories were chosen as they are the most prevalent types of injuries occurring in South African adolescent rugby.[65]

The structure of the training week followed a set pattern, with Wednesday and Sundays being recovery days. The amount of training conducted in each week was dependant on the training phase. Off-season consisted of nine rugby sessions, four resistance training sessions (occasionally substituted for contact-training) and one cross-training session (consisting of wrestling, aerobic conditioning, small sided games).

Pre-season followed a similar pattern, with friendly match's introduced to replace the cross-training session and a decrease in the amount of rugby sessions from nine to six sessions per week. Resistance training frequency remained unchanged. In-season saw the greatest changed to the training structure, this was due to matches alternating between Saturdays and Fridays. Rugby training was reduced to four training sessions per week, resistance training decreased to three sessions per week.

Monday mornings consisted of a submaximal shuttle run test known as the Heart Rate Internal Monitoring System (HIMS).[84] In brief the HIMS consists of 4 stages with players running back and forth between markers 20 m apart. The test started at 8.4 km.h^{-1} and the players ran for two minutes. Following a one-minute rest players ran for another two minutes at 9.6, 10.8 and 12.0 km.h^{-1}, with a one-minute rest between each stage. Following the final stage, players stopped immediately and stood still while their heart rates were recorded for one minute. Recovery heart rate was defined as the difference in maximum heart rate at the end of the test and the heart rate one minutes later. This is reliable measurement providing the player remained standing and motionless during the one minute recovery.[85] This measurement was used as a proxy for training status.[48,49]

On match days, each player in the playing squad was equipped with a Zephyr bioharness.[3] The bioharness was located on a “smart fabric” belt, similar to a heart rate monitor belt, and was worn around the ribs at sternum level. This measured physiological (heart rate) and mechanical (movement) loads. Due to restrictions with travel, the Zephyr bioharness was only worn during home matches (n = 6).

A summary of when each test was used through the season is shown in Figure 1.

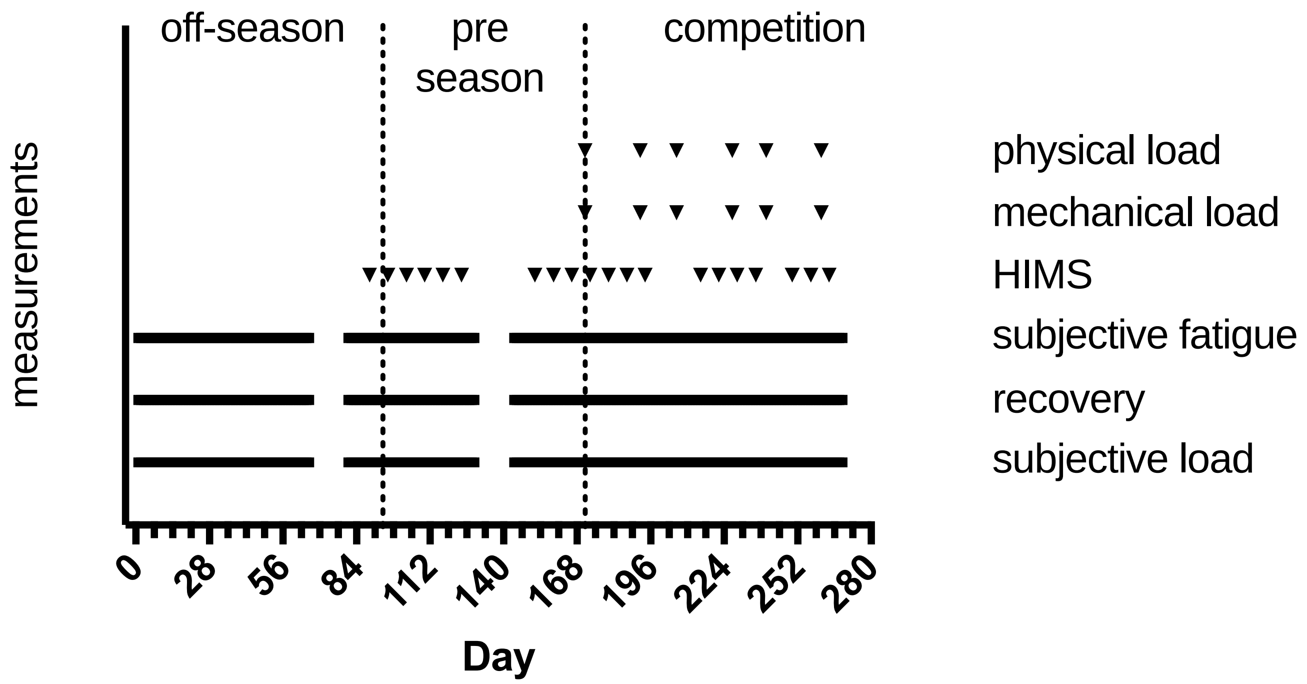


Figure 1: *A summary of when each test was used during the season*

Data analysis:

The individual data points for all the variables of each player are presented. The descriptive statistics of all the variables for each player are presented for each phase (off-season, pre-season and competition) of the season, using GraphPad Prism version 8.0.0 for Windows, GraphPad Software, San Diego, California USA, www.graphpad.com.

1) ANOVA for training loads between phases, subjective fatigue (non-homogeneity of group and time variance was tested using Levene's test, a Scheffes post-hoc was used to identify differences, and the Alpha value was 0,05)
2) Paired t-test for MHR

3) z scores for training load, subjective fatigue and recovery calculated for each injured player (z score = (season average – average for week before injury average)/SD of season.

Results:

All 36 players in the study were born in 1996 and at the time of the study were 18 years. A breakdown of the number of players in the different playing positions is shown in Table 1.

Table 1: *Number of players in each grouped position*

Position grouping	Number
Front Row (props and hooker)	10
Second Row (locks)	5
Back Row (flankers and eighth man)	8
Inside Backs (scrumhalf, flyhalf and centres)	8
Outside Backs (wings and fullbacks)	5
Total	36

The body mass and height of each player measured at the beginning of the season is shown in Table 2. The positional group averages and the team averages are also shown in this table.

Table 2: *Body mass (kg) and height (cm) of each player at the start of the season. Averages for the positional groupings are expressed as mean ±standard deviation.*

Player	**Position**	**Weight (kg)**	**Height (cm)**
1	Front row	114.9	183.3
2	Front row	104.7	186.5
3	Front row	121.9	190.0
4	Front row	127.9	187.7
5	Front row	124.6	185.6
6	Front row	109.9	173.0
7	Front row	106.8	184.3
8	Front row	105.1	183.2
9	Front row	102.9	179.6
10	Front row	104.0	180.8
Average	*Front row*	*112.3 ± 9.4*	*183.4 ± 4.8*
11	Second row	97.3	192.2
12	Second row	114.9	195.7
13	Second row	93.1	197.4
14	Second row	129.7	199.3
15	Second row	118.3	200.7
Average	*Second row*	*110.7 ±15.2*	*197.1 ±3.3*
16	Back row	97.0	183.2
17	Back row	101.2	182.0
18	Back row	90.3	186.6
19	Back row	108.0	188.2
20	Back row	98.9	181.0
21	Back row	86.5	178.3
22	Back row	108.7	186.7
23	Back row	94.3	185.9
Average	*Back row*	*98.1 ±7.9*	*184.0 ±3.4*
24	Inside back	85.7	172.8
25	Inside back	79.7	170.3
26	Inside back	73.7	163.4
27	Inside back	89.9	180.3
28	Inside back	82.7	170.4
29	Inside back	90.4	187.6
30	Inside back	98.4	190.3
31	Inside back	94.5	190.0
Average	*Inside back*	*86.9 ±8.1*	*178.1 ±10.3*
32	Outside back	97.0	184.7
33	Outside back	88.9	187.2
34	Outside back	83.8	175.7
35	Outside back	81.8	179.8
36	Outside back	93.4	177.8
Average	*Outside back*	*89.0 ±6.4*	*181.0 ±4.8*
Team average		**100.0 ± 14.0**	**183.9 ± 8.2**

The average sRPE-TL per training day for the entire team was 682 ± 306 arbitrary units (AU) for the off-season, 582 ± 286 AU for the pre-season and 560 ± 270 AU for the competition phase of the season. There were no differences in subjective training load between the different phases of the season ($F_{2,105} = 1.82$; $p = 0.168$).

The average sRPE-TL per training day for each player during the different phases of the season is shown in Table 3 and displayed graphically in Figure 2. The daily subjective total training load data for each individual is shown in Appendix E.

Table 3: *The sRPE-TL(AU) for all the players during the off-season (84 days), pre-season (77 days), and competition phase of the season (105 days). The data are displayed as the daily mean ±standard deviation (sample size).*

Player	Off-season	Pre-season	Competition	Total
1	660 ± 256 (38)	596 ± 340 (36)	468 ± 269 (36)	564 ± 296 (110)
2	690 ± 308 (42)	532 ± 285 (31)	578 ± 338 (32)	607 ±317 (105)
3	813 ± 342 (35)	633 ± 359 (40)	575 ± 365 (47)	653 ± 368 (122)
4	621 ± 296 (23)	589 ± 232 (37)	541 ± 255 (35)	574 ± 258 (95)
5	782 ± 272 (46)	645 ± 292 (37)	547 ± 351 (40)	657 ± 323 (123)
6	626 ± 307 (22)	556 ± 288 (36)	610 ± 289 (36)	598 ± 291 (94)
7	834 ± 422 (26)	620 ± 321 (37)	562 ± 250 (27)	655 ± 342 (90)
8	578 ± 282 (42)	570 ± 241 (33)	484 ± 164 (29)	543 ± 237 (104)
9	700 ± 438 (33)	519 ± 288 (42)	539 ± 343 (44)	579 ± 364 (119)
10	718 ± 291 (33)	666 ± 353 (35)	628 ± 287 (41)	663 ± 305 (109)
11	587 ± 240 (43)	512 ± 226 (22)	492 ± 254 (33)	535 ± 245 (98)
12	690 ± 347 (46)	539 ± 319 (40)	614 ± 246 (40)	620 ± 307 (126)
13	633 ± 209 (29)	598 ± 278 (34)	522 ± 293 (38)	573 ± 270 (101)
14	697 ± 266 (32)	580 ± 291 (36)	611 ± 221 (36)	626 ± 258 (104)
15	560 ± 283 (28)	499 ± 237 (28)	577 ± 288 (41)	553 ± 274 (97)
16	670 ± 319 (58)	565 ± 235 (38)	541 ± 237 (44)	598 ± 277 (140)
17	610 ± 326 (41)	525 ± 382 (29)	578 ± 297 (39)	577 ± 303 (109)
18	804 ± 397 (44)	629 ± 282 (31)	647 ± 310 (46)	697 ± 343 (121)
19	770 ± 278 (32)	608 ± 296 (36)	660 ± 296 (40)	678 ± 295 (108)
20	630 ± 312 (43)	540 ± 268 (38)	481 ± 226 (34)	550 ± 276 (115)
21	799 ± 358 (48)	663 ± 278 (35)	743 ± 266 (36)	745 ± 310 (119)
22	668 ± 432 (25)	579 ± 283 (32)	561 ± 270 (40)	593 ± 321 (97)
23	715 ± 317 (39)	591 ± 266 (46)	431 ± 246 (36)	566 ± 297 (121)
24	655 ± 285 (32)	580 ± 250 (32)	437 ± 177 (39)	541 ± 250 (103)
25	712 ± 371 (41)	648 ± 300 (40)	535 ± 252 (47)	618 ± 311 (128)
26	586 ± 314 (54)	615 ± 327 (40)	508 ± 282 (41)	564 ± 307 (135)
27	635 ± 338 (40)	579 ± 221 (34)	631 ± 247 (37)	620 ± 275 (111)
28	503 ± 213 (55)	448 ± 228 (41)	480 ± 203 (37)	481 ± 213 (133)
29	729 ± 253 (49)	562 ± 262 (45)	507 ± 320 (47)	595 ± 298 (141)
30	800 ± 305 (36)	635 ± 291 (33)	570 ± 298 (38)	660 ± 312 (107)
31	724 ± 254 (51)	614 ± 379 (39)	559 ± 242 (51)	629 ± 293 (141)
32	NA	617 ± 289 (45)	610 ± 255 (35)	613 ± 269 (80)
33	723 ± 323 (49)	671 ± 329 (34)	579 ± 342 (44)	651 ± 336 (127)
34	617 ± 285 (52)	600 ± 384 (43)	578 ± 225 (43)	597 ± 292 (138)
35	671 ± 242 (54)	532 ± 249 (39)	558 ± 234 (47)	593 ± 246 (140)
36	656 ± 228 (49)	495 ± 262 (38)	604 ± 283 (44)	596 ± 265 (131)
Average	**682 ± 306 (40)**	**582 ± 287 (36)**	**560 ± 271 (39)**	**605 ± 293 (115)**

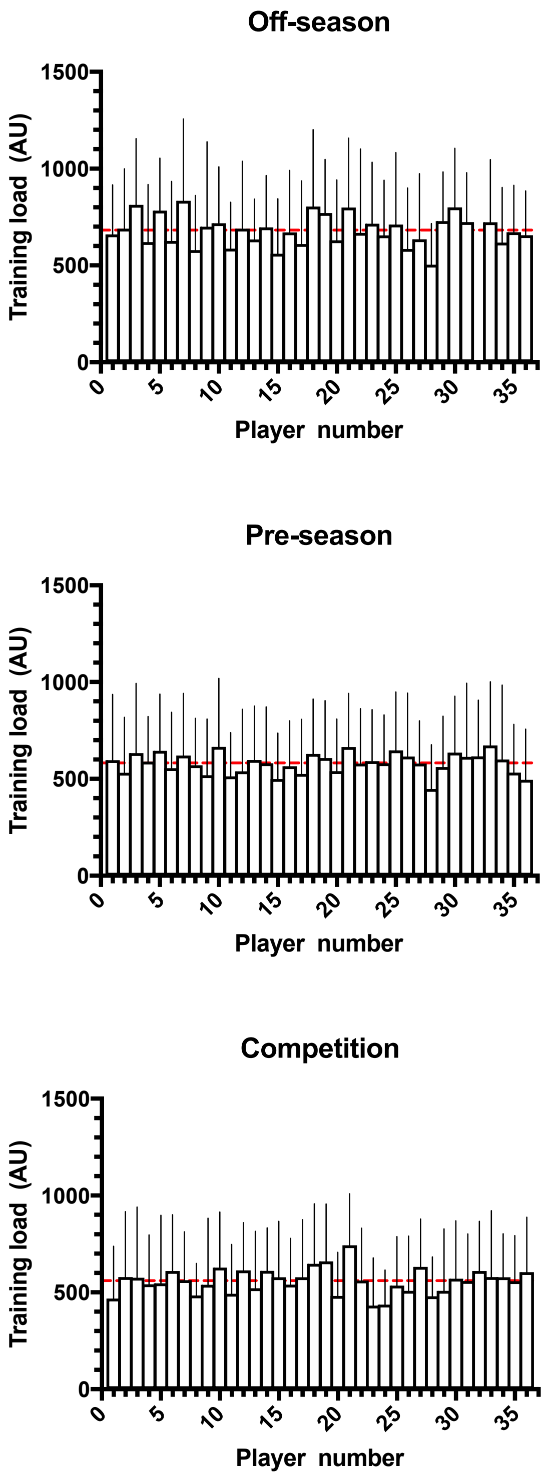


Figure 2: *The sRPE-TL (AU) for all the players during the off-season (84 days), pre-season (77 days), and competition phase of the season (105 days). The data are displayed as the daily mean ± standard deviation. The red dash indicates the season average.*

The average daily subjective fatigue for the entire team for the off-season, pre-season and competition phase of the season was 4.6 ± 1.3 AU; 4.4 ± 1.3 AU and 4.5 ± 1.3 respectively. There were no differences in subjective fatigue between the different phases of the season ($F_{2,105} = 1.82$; $p = 0.168$).

The average daily subjective fatigue for each player during the different phases of the season is shown in Table 4 and displayed graphically in Figure 3. The subjective daily fatigue for each individual is shown in Appendix F.

Table 4: *The subjective fatigue (AU) for all the players during the off-season (84 days), pre-season (77 days), and competition phase of the season (105 days). The data are displayed as the daily mean ± standard deviation (sample size).*

Player	Off-season	Pre-season	Competition	Total
1	5.0 ± 1.5 (51)	5.9 ± 1.9 (43)	3.1 ± 1.7(55)	4.5 ± 2.1 (149)
2	5.2 ± 1.2 (50)	4.3 ± 1.4 (46)	3.9 ± 1.3(53)	4.5 ±1.4 (149)
3	5.9 ± 1.6 (42)	5.9 ± 1.0 (50)	5.5 ± 0.8 (70)	5.7 ± 1.1 (162)
4	5.3 ± 1.7 (30)	4.8 ± 1.5 (42)	4.9 ± 1.4 (55)	4.9 ± 1.5 (127)
5	4.0 ± 1.3 (56)	3.9 ± 1.2 (50)	4.5 ± 0.9 (58)	4.2 ± 1.2 (164)
6	5.6 ± 1.2 (32)	5.6 ± 1.1 (53)	6.2 ± 1.1 (54)	5.8 ± 1.1 (139)
7	4.9 ± 1.0 (32)	3.8 ± 1.0 (49)	3.9 ± 0.7 (48)	4.1 ± 1.0 (129)
8	5.3 ± 1.6 (47)	5.0 ± 1.5 (40)	5.4 ± 0.5 (50)	5.3 ± 1.3 (137)
9	4.8 ± 0.9 (51)	4.5 ± 1.2 (53)	3.8 ± 0.9 (73)	4.3 ± 1.1 (177)
10	4.1 ± 1.2 (41)	3.9 ± 0.9 (44)	4.3 ± 0.9 (66)	4.1 ± 1.0 (151)
11	2.9 ± 0.9 (49)	2.0 ± 1.3 (49)	1.7 ± 0.9 (46)	2.2 ± 1.2 (144)
12	4.6 ± 1.5 (54)	4.6 ± 1.5 (58)	5.0 ± 1.4 (61)	4.8 ± 1.5 (173)
13	5.1 ± 2.2 (38)	4.2 ± 2.4 (45)	5.0 ± 2.4 (56)	4.8 ± 2.4 (139)
14	5.0 ± 0.9 (44)	4.9 ± 0.9 (44)	6.0 ± 1.2 (58)	5.4 ± 1.2 (146)
15	4.3 ± 0.9 (38)	4.2 ± 0.7 (49)	5.4 ± 1.2 (67)	4.8 ± 1.1 (154)
16	3.8 ± 1.3 (72)	3.3 ± 1.3 (61)	3.7± 1.3 (74)	3.6 ± 1.3 (207)
17	5.9 ± 1.7 (51)	4.6 ± 1.7 (51)	4.6 ± 1.6 (72)	4.9 ± 1.8 (174)
18	5.0 ± 1.5 (50)	5.2 ± 1.2 (52)	5.3 ± 0.9 (72)	5.2 ± 1.2 (174)
19	3.8 ± 1.0 (38)	3.8 ± 1.0 (43)	4.1 ± 0.6 (57)	3.9 ± 0.9 (138)
20	5.4 ± 1.1 (54)	4.9 ± 1.3 (51)	4.4 ± 1.2 (53)	4.9 ± 1.3 (158)
21	3.2 ± 1.2 (60)	4.3 ± 1.1 (50)	3.5 ± 1.2 (61)	3.6 ± 1.2 (171)
22	4.0 ± 2.0 (35)	5.4 ± 1.3 (41)	5.8 ± 0.9 (62)	5.3 ± 1.6 (138)
23	6.1 ± 1.4 (46)	5.8 ± 1.0 (53)	4.9 ± 1.4 (56)	5.6 ± 1.4 (155)
24	6.2 ± 1.7 (33)	5.2 ± 1.7 (42)	4.5 ± 1.5 (67)	5.1 ± 1.7 (142)
25	4.9 ± 0.6 (51)	5.2 ± 0.9 (59)	5.3 ± 0.7 (70)	5.2 ± 0.8 (180)
26	4.2 ± 2.0 (66)	2.8 ± 2.2 (58)	3.4 ± 2.6 (62)	3.5 ± 2.3 (186)
27	3.8 ± 1.1 (50)	3.6 ± 1.2 (50)	3.0 ± 1.1 (61)	3.5 ± 1.2 (161)
28	2.6 ± 1.1 (67)	1.7 ± 0.6 (59)	1.8 ± 1.1 (72)	2.0 ± 1.0 (198)
29	4.8 ± 0.8 (52)	4.5 ± 0.9 (50)	4.0 ± 1.4 (71)	4.4 ± 1.2 (173)
30	5.3 ±1.7 (42)	5.7 ± 2.0 (49)	5.1 ± 2.3 (61)	5.3 ±2.1 (152)
31	5.4 ± 1.4 (65)	5.0 ± 1.5 (61)	6.2 ± 1.9 (74)	5.6 ± 1.7 (200)
32	NA ± NA (NA)	6.4 ± 1.0 (29)	6.1 ± 1.4 (59)	6.2 ± 1.3 (88)
33	4.6 ± 1.1 (64)	4.5 ± 1.2 (49)	5.5 ± 1.5 (68)	4.9 ± 1.4 (181)
34	4.8 ± 0.7 (64)	3.9 ± 0.9 (62)	3.9 ± 0.9 (67)	4.2 ± 0.9 (193)
35	2.3 ± 0.9 (68)	2.8 ± 0.8 (62)	3.3 ± 1.2 (72)	2.8 ± 1.0 (202)
36	3.6 ± 1.4 (55)	2.7 ± 1.8 (59)	3.7 ± 1.8 (67)	3.4 ± 1.6 (181)
Average	**4.6 ± 1.3 (50)**	**4.4±1.3 (50)**	**4.5 ± 1.3 (62)**	**4.5 ± 1.3 (160)**

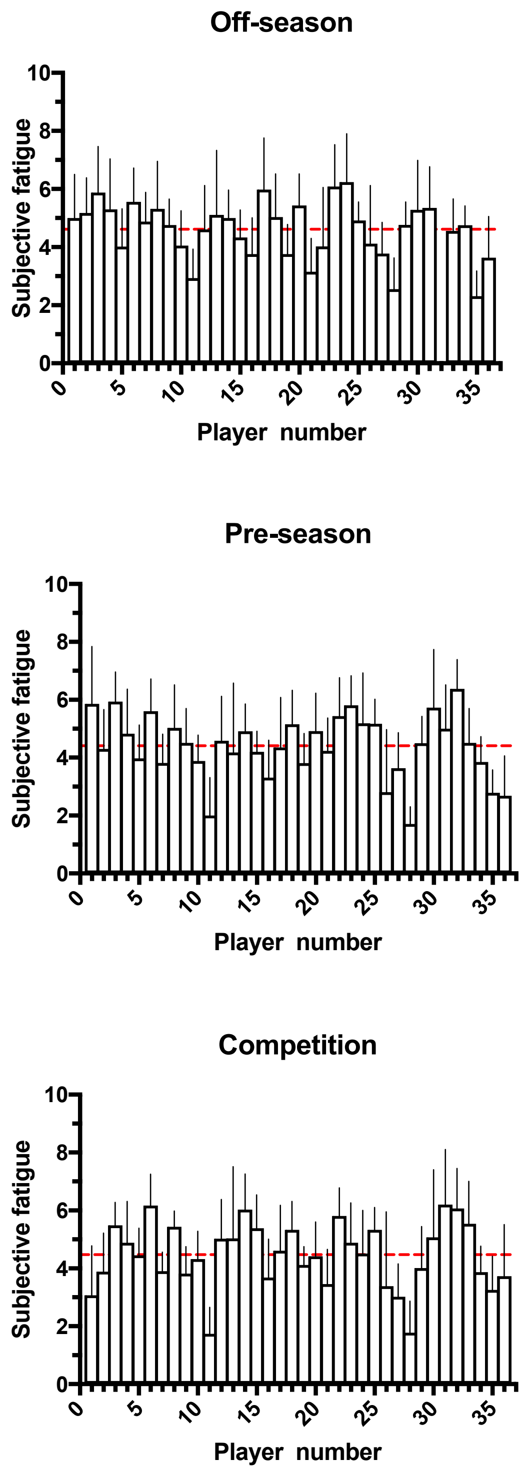


Figure 3: *The subjective fatigue (AU) for all the players during the off-season (84 days), pre-season (77 days), and competition phase of the season (105 days). The data are displayed as the daily mean ± standard deviation. The red dash indicates the season average.*

The average daily composite recovery for the entire team was 13.7 ± 2.4 AU for the off-season, 14.4 ± 2.4 AU for the pre-season and 14.2 ± 2.2 AU for the competition phase of the season. There were no differences in composite recovery between the different phases of the season ($F_{2,105} = 1.82$; $p = 0.168$).

The average daily composite recovery for each player during the different phases of the season is shown in Table 5 and displayed graphically in Figure 4. The daily composite recovery for each individual is shown in Appendix G.

Table 5: *The composite recovery score (AU) for all the players during the off-season (84 days), pre-season (77 days), and competition phase of the season (105 days). The data are displayed as the daily mean ± standard deviation (sample size).*

Player	Off-season	Pre-season	Competition	Total
1	10.9 ± 3.0 (51)	12.2 ± 4.6 (43)	11.3 ± 2.8(55)	11.4 ± 3.5 (149)
2	14.3 ± 2.2 (51)	14.6 ± 1.9 (46)	12.8 ± 1.0 (53)	13.9 ±1.9 (149)
3	14.5 ± 2.1 (42)	13.7 ± 1.0 (50)	16.8 ± 0.8 (70)	15.2 ± 2.6 (162)
4	12.7 ± 1.7 (30)	14.4 ± 1.7 (42)	15.4 ± 1.9 (55)	14.4 ± 2.1 (127)
5	13.0 ± 2.4 (56)	13.8 ± 2.4 (50)	11.2 ± 2.7 (58)	12.6 ± 2.7 (164)
6	11.9 ± 2.7 (32)	12.9 ± 2.3 (53)	13.4 ± 2.3 (54)	12.9 ± 1.1 (139)
7	15.9 ± 1.6 (32)	13.9 ± 2.2 (49)	12.6 ± 2.8 (48)	13.9 ± 2.6 (129)
8	13.7 ± 2.9 (47)	15.5 ± 3.0 (40)	14.1 ± 2.0 (50)	14.4 ± 2.7 (137)
9	11.2 ± 2.9 (51)	11.5 ± 2.7 (53)	12.3 ± 1.4 (73)	11.7 ± 2.4 (177)
10	12.3 ± 2.2 (41)	12.7 ± 1.9 (44)	11.8 ± 2.6 (66)	12.2 ± 2.3 (151)
11	16.9 ± 3.5 (49)	18.1 ± 2.1 (49)	16.9 ± 2.7 (46)	17.3 ± 2.9 (144)
12	13.7 ± 2.5 (54)	14.0 ± 2.1 (58)	14.7 ± 1.9 (61)	14.2 ± 2.2 (173)
13	13.8 ± 1.5 (38)	14.1 ± 2.2 (45)	14.2 ± 1.9 (56)	14.1 ± 1.9 (139)
14	12.0 ± 2.3 (44)	12.7 ± 2.1 (44)	10.4 ± 2.2 (58)	11.6 ± 2.4 (146)
15	14.4 ± 2.5 (38)	15.8 ± 1.9 (49)	15.7 ± 1.2 (67)	15.4 ± 1.9 (154)
16	17.1 ± 2.5 (72)	17.8 ± 2.2 (61)	18.5 ± 1.5 (74)	17.8 ± 2.2 (207)
17	14.4 ± 2.1 (51)	15.3 ± 2.8 (51)	15.7 ± 2.2 (72)	15.2 ± 2.4 (174)
18	13.9 ± 2.7 (50)	16.6 ± 2.6 (52)	16.1 ± 2.6 (72)	15.5 ± 2.8 (174)
19	12.3 ± 1.9 (38)	12.9 ± 2.4 (43)	13.1 ± 1.8 (57)	12.8 ± 2.0 (138)
20	13.7 ± 1.3 (54)	14.2 ± 1.6 (51)	13.7 ± 2.3 (53)	13.9 ± 1.8 (158)
21	17.8 ± 1.9 (60)	17.2 ± 2.3 (50)	17.9 ± 1.9 (61)	17.7 ± 2.1 (171)
22	12.9 ± 3.0 (35)	12.4 ± 2.5 (41)	11.7 ± 2.2 (62)	12.2 ± 2.6 (138)
23	13.1 ± 3.3 (46)	13.8 ± 2.2 (53)	14.9 ± 1.6 (56)	13.9 ± 2.5 (155)
24	11.6 ± 2.7 (33)	11.2 ± 2.4 (42)	11.5 ± 2.9 (67)	11.4 ± 2.7 (142)
25	9.8 ± 3.3 (51)	11.9 ± 1.8 (59)	11.5 ± 2.9 (70)	11.1 ± 2.8 (180)
26	17.6 ± 1.9 (66)	16.8 ± 2.4 (58)	15.7 ± 2.8 (62)	16.7 ± 2.5 (186)
27	13.0 ± 3.4 (50)	14.8 ± 4.0 (50)	18.5 ± 1.8 (61)	15.7 ± 3.9 (161)
28	12.7 ± 2.9 (67)	14.1 ± 1.9 (59)	11.8 ± 2.1 (72)	12.8 ± 2.5 (198)
29	11.9 ± 2.1 (52)	11.7 ± 2.4 (50)	11.3 ± 2.9 (71)	11.6 ± 2.6 (173)
30	14.8 ± 2.0 (42)	14.9 ± 1.9 (49)	13.0 ± 4.4 (61)	14.1 ± 3.3 (152)
31	15.8 ± 2.1 (65)	17.5 ± 1.8 (61)	18.8 ± 1.7 (74)	17.4 ± 2.3 (200)
32	NA ± NA (NA)	17.2 ± 1.9 (29)	17.9 ± 1.4 (59)	17.6 ± 1.6 (88)
33	12.1 ± 2.4 (64)	12.4 ± 3.0 (49)	13.8 ± 2.3 (68)	12.8 ± 2.7 (181)
34	11.9 ± 2.8 (64)	12.2 ± 2.9 (62)	11.3 ± 3.2 (67)	11.8 ± 2.9 (193)
35	17.6 ± 1.7 (68)	17.8 ± 1.8 (62)	17.4 ± 2.4 (72)	17.6 ± 2.0 (202)
36	13.9 ± 1.8 (55)	14.4 ± 2.1 (59)	12.5 ± 2.7 (67)	13.6 ± 2.4 (181)
Average	**13.7 ± 2.4 (50)**	**14.4 ± 2.4 (50)**	**14.2 ± 2.2 (62)**	**14.1 ± 2.3 (162)**

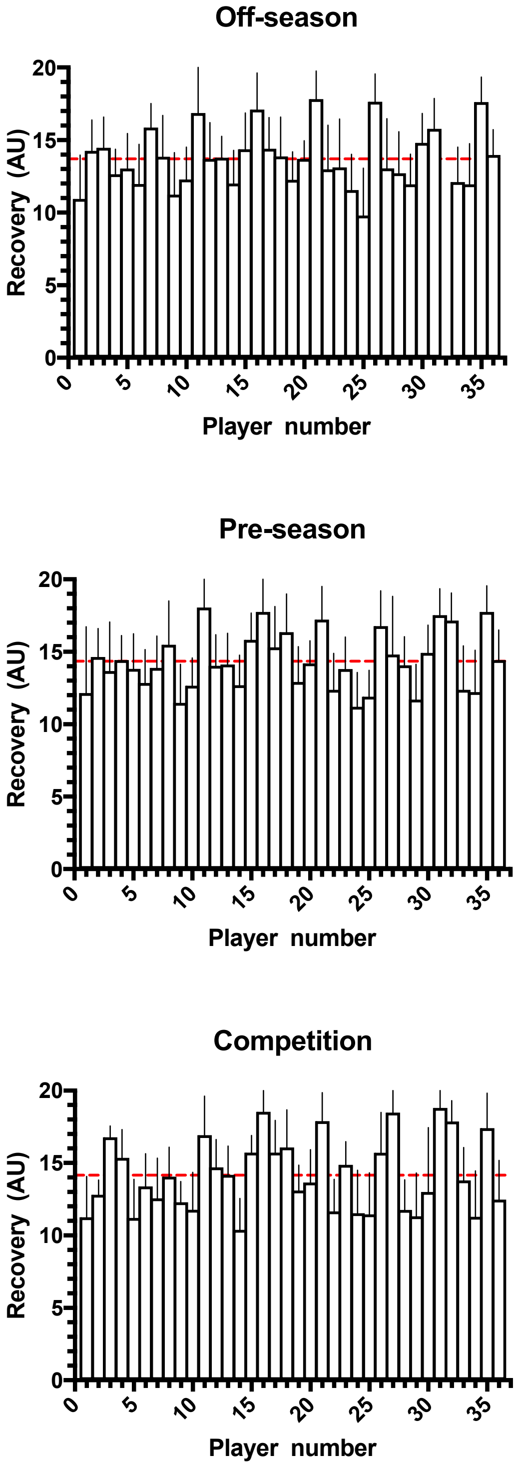


Figure 4: *The composite recovery (AU) for all the players during the off-season (84 days), pre-season (77 days), and competition phase of the season (105 days). The data are displayed as the daily mean ± standard deviation. The red dash indicates the season average.*

The average maximum heart rate measured during the HIMS test for the pre-season was 184.8 ± 4.8 beats.min^{-1} and during the competition phase was 181.6 ± 4.0 beats.min^{-1}. The HIMS test was not conducted during the off season. The maximum heart rate during the pre-season was significantly higher than during the competition phase ($t = 7.1$, $p < 0.0001$).

The average maximum heart rate measured during the HIMS test for each player in the pre-season and competition phase of the season is shown in Table 6 and Figure 5. The average maximal heart rate measured during the HIMS test for each individual is shown in Appendix H.

Table 6: *The maximal heart rate (beats.min-1) measured during the HIMS test for all the players during the pre-season (77 days), and competition phase of the season (105 days). The data are displayed as the mean ± standard deviation (sample size).*

Player	Pre-season	Competition	Total
1	191.7 ± 5.8 (4)	191.0 ± 1.0 (6)	191.5 ± 4.8 (10)
2	195.5 ± 1.9 (7)	195.0 ± 1.2 (7)	195.4 ±1.7 (14)
3	187.8 ± 7.1 (8)	184.7 ± 2.7 (10)	186.8 ± 6.1 (18)
4	188.5 ± 4.1 (7)	184.0 ± 3.6 (7)	187.5 ± 4.3 (14)
5	184.0 ± 2.7 (1)	178.1 ± 1.7 (11)	180.6 ± 3.6 (12)
6	199.8 ± 3.5 (8)	197.0 ± 4.4 (6)	199.2 ± 3.7 (14)
7	186.9 ± 1.7 (8)	188.0 ± 1.4 (7)	187.2 ± 1.7 (15)
8	188.0 ± 9.2 (6)	189.4 ± 2.3 (9)	188.5 ± 7.5 (15)
9	190.7 ± 4.2 (3)	185.1 ± 3.7 (10)	187.7 ± 4.7 (13)
10	189.2 ± 3.1 (7)	184.9 ± 3.0 (11)	187.5 ± 3.7 (18)
11	178.4 ± 10.3(7)	177.2 ± 3.4 (9)	177.9 ± 8.3 (16)
12	192.7 ± 1.9 (5)	193.2 ± 4.4 (6)	192.9 ± 3.1 (11)
13	171.0 ± 4.0 (8)	168.7 ± 8.2 (10)	170.1 ± 5.9 (18)
14	180.9 ± 4.1 (8)	173.7 ± 1.2 (9)	178.4 ± 4.9 (17)
15	183.5 ± 3.8 (8)	179.4 ± 1.4 (9)	181.8 ± 3.6 (17)
16	173.0 ± 9.5 (7)	167.8 ± 4.9 (9)	171.1 ± 8.3 (16)
17	200.2 ± 3.2 (6)	195.6 ± 4.0 (10)	198.2 ± 4.2 (16)
18	192.4 ± 6.5 (7)	191.2 ± 2.6 (9)	192.0 ± 5.5 (16)
19	185.6 ± 5.4 (6)	180.9 ± 3.7 (11)	183.6 ± 5.2 (17)
20	185.1 ± 3.1 (6)	186.0 ± 5.9 (9)	185.4 ± 4.1 (15)
21	173.2 ± 8.1 (4)	167.9 ± 3.8 (10)	170.1 ± 6.4 (14)
22	186.1 ± 3.1 (4)	179.7 ± 2.9 (10)	183.4 ± 4.4 (14)
23	183.0 ± 7.9 (2)	174.9 ± 5.9 (11)	178.6 ± 7.9 (13)
24	181.5 ± 3.7 (8)	179.0 ± 3.7 (10)	180.6 ± 3.8 (18)
25	190.1 ± 4.3 (8)	180.8 ± 4.7 (11)	186.2 ± 6.4 (19)
26	182.2 ± 3.4 (5)	181.5 ± 9.2 (10)	181.9 ± 6.1 (15)
27	171.8 ± 9.3 (8)	165.8 ± 6.9 (9)	170.1 ± 8.9 (17)
28	198.5 ± 3.0 (8)	197.9 ± 6.1 (10)	198.3 ± 4.4 (18)
29	172.6 ± 3.7 (7)	171.0 ± 3.7 (10)	171.9 ± 3.6 (17)
30	176.7 ± 3.3 (6)	173.8 ± 6.4 (9)	175.5 ± 4.8 (15)
31	194.7 ± 2.4 (6)	192.0 ± 3.1 (10)	193.5 ± 2.9 (16)
32	173.7 ± 7.2 (8)	168.5 ± 1.0 (7)	172.3 ± 6.5 (15)
33	179.9 ± 2.4 (8)	177.9 ± 2.6 (12)	179.1 ± 2.6 (20)
34	189.5 ± 2.5 (7)	184.6 ± 3.0 (11)	187.6 ± 3.6 (18)
35	172.1 ± 8.8 (5)	171.5 ±12.6 (9)	171.9 ± 10.1 (14)
36	180.9 ± 3.2 (7)	179.9 ±5.0 (11)	180.5 ± 3.9 (18)
Average	**184.8 ± 4.8(6.5)**	**181.6 ± 4.0(9.4)**	**183.2± 4.4(15.9)**

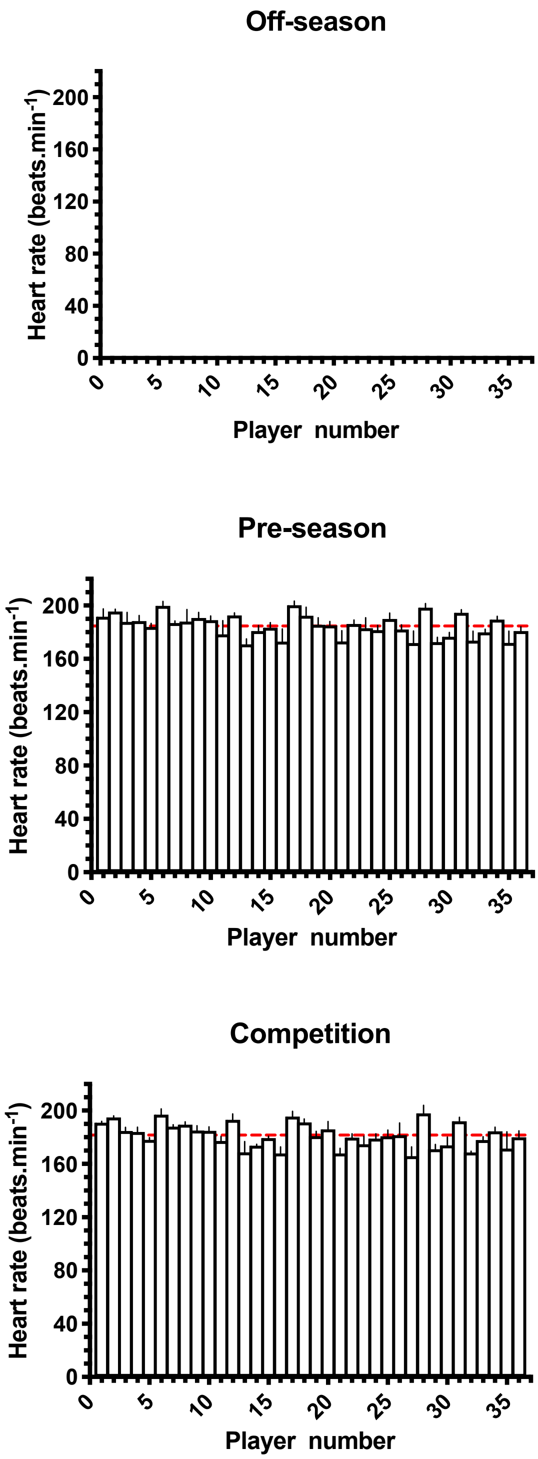


Figure 5: *Maximum heart rate (beats.min-1) measured during the HIMS test during pre-season and competition phase of the season. The test was not conducted to the off-season. The red dash indicates the season average.*

There was a significant relationship between maximum heart during the pre-season and competition phase (r = 0.96) (Figure 6).

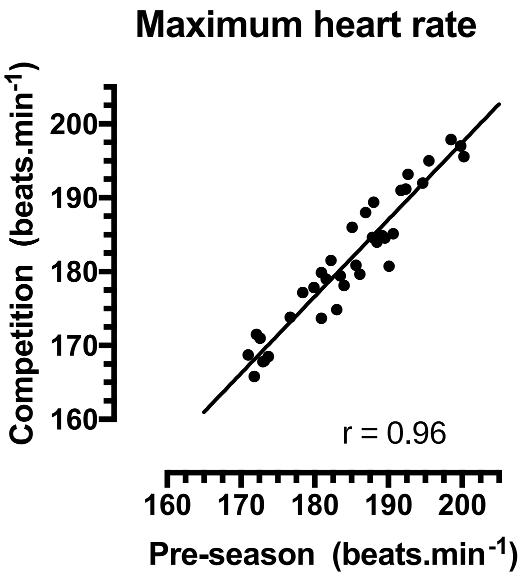


Figure 6: *Relationship between maximum heart during the pre-season and competition phase of the season.*

The average heart rate recovery during the HIMS test for the pre- season was 37.7 ± 5.8 beats.min-1 and during the competition phase was 38.5 ± 5.6 beats.min-1. The HIMS test was not conducted during the off season. There was no difference in recovery heart rate measured the pre-season and competition phase of the season,

The average heart rate recovery for each player in the pre-season and competition phase of the season is shown in Table 7 and Figure 7. The average heart rate recovery measured during the HIMS for each individual is shown in Appendix I.

Table 7: *The heart rate recovery (beats.min-1) for all the players during the pre-season (77 days), and competition phase of the season (105 days). The data are displayed as the mean ± standard deviation (sample size).*

Player	Pre-season	Competition	Total
1	29.2 ± 2.9 (4)	25.7 ± 3.5 (6)	28.0 ± 3.4 (9)
2	26.2 ± 3.0 (7)	28.5 ± 3.7 (7)	26.9 ±3.3 (14)
3	31.0 ± 13.2 (8)	30.0 ± 6.8 (10)	30.7 ± 11.3 (18)
4	29,5 ± 6.4 (7)	29.7 ± 2.1 (7)	29.5 ± 5.7 (14)
5	40.6 ± 8.1 (1)	36.9 ± 7.8 (11)	38.4 ± 7.8 (12)
6	47.2 ± 6.7 (8)	43.3 ± 3.1 (6)	46.4 ± 6.2 (14)
7	36.8 ± 3.1 (8)	37.0 ± 4.3 (7)	36.9 ± 6.2 (14)
8	27.4 ± 5.7 (6)	28.2 ± 4.5 (9)	27.7 ± 5.1 (14)
9	50.8 ± 4.9 (3)	54.6 ± 6.9 (10)	52.9 ± 6.1 (13)
10	30.8 ± 3.1 (7)	29.7 ± 5.5 (11)	30.4 ± 4.0 (18)
11	37.7 ± 4.6(7)	31.7 ± 9.5 (9)	35.3 ± 7.3 (15)
12	39.0 ± 2.8 (5)	38.2 ± 2.5 (6)	38.6 ± 2.5 (11)
13	37.6 ± 6.2 (8)	45.0 ± 13.4 (10)	40.5 ± 9.9 (18)
14	26.1 ± 4.8 (8)	30.3 ± 8.3 (9)	27.7 ± 6.4 (16)
15	28.8 ± 7.3 (8)	33.7 ± 3.9 (9)	30.8 ± 6.5 (17)
16	36.0 ± 9.3 (7)	36.8 ± 3.3 (9)	36.3 ± 7.5 (16)
17	32.4 ± 9.1 (6)	31.0 ± 6.1 (10)	31.8 ± 7.7 (16)
18	40.7 ± 5.1 (7)	47.4 ± 5.6 (9)	43.8 ± 5.9 (16)
19	25.7 ± 5.5 (6)	22.1 ± 4.6 (11)	24.2 ± 5.3 (17)
20	33.9 ± 7.3 (6)	32.8 ± 3.4 (9)	33.5 ± 6.1 (15)
21	40.4 ± 3.6 (4)	40.3 ± 3.2 (10)	40.3 ± 3.3 (15)
22	26.0 ± 3.7 (4)	29.5 ± 4.6 (10)	27.5 ± 4.4 (14)
23	53.2 ± 10.4 (2)	46.9 ± 9.9 (11)	49.8 ± 10.2 (13)
24	37.0 ± 3.6 (8)	40.7 ± 8.9 (10)	38.4 ± 6.3 (18)
25	41.4 ± 6.3 (8)	41.6 ± 4.9 (11)	41.5 ± 5.6 (19)
26	41.9 ± 2.9 (5)	47.5 ± 4.6 (10)	44.1 ± 4.5 (15)
27	37.9 ± 12.1 (8)	39.4 ± 5.4 (9)	38.4 ± 10.4 (17)
28	39.8 ± 4,6 (8)	41.2 ± 5.9 (10)	40.3 ± 4.9 (18)
29	55.1 ± 8.2 (7)	52.3 ± 6.5 (10)	53.9 ± 7.5 (17)
30	26.2 ± 7.2 (6)	35.0 ± 6.3 (9)	29.7 ± 7.9 (15)
31	51.1 ± 4.5 (6)	49.3 ± 4.9 (10)	50.3 ± 4.6 (16)
32	27.5 ± 5.9 (8)	25.5 ± 3.9 (7)	26.9 ± 5.4 (15)
33	41.7 ± 2.7 (8)	43.0 ± 4.3 (12)	42.2 ± 3.4 (20)
34	58.8 ± 4.4 (7)	63.9 ± 7.5 (11)	60.8 ± 6.2 (18)
35	40.5 ± 5.8 (5)	47.0 ±8.2 (9)	43.3 ± 7.4 (14)
36	50.1 ± 4.6 (7)	48.6 ±5.9 (11)	49.5 ± 5.1 (18)
Average	**37.7 ± 5.8 (6.5)**	**38.5 ± 5.6 (9.4)**	**38.1 ± 5.7 (15.9)**

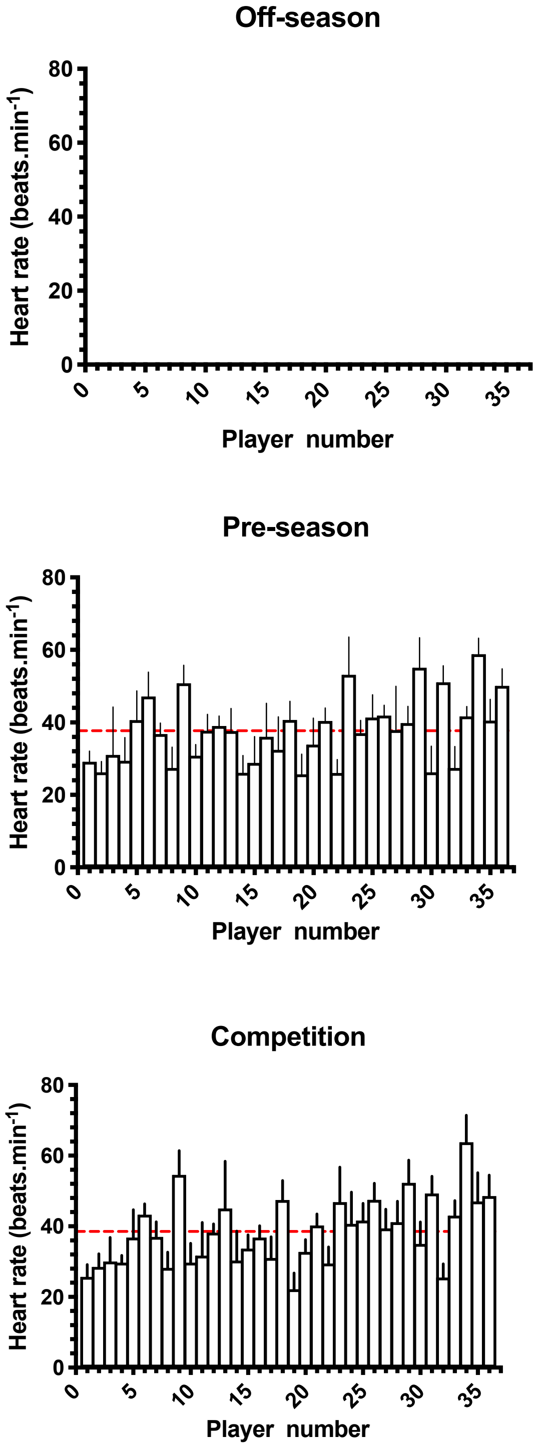


Figure 7: *Heart rate recovery (beats.min-1) measured during the HIMS test during pre-season and competition phase of the season. The test was not conducted to the off-season. The red dash indicates the season average.*

There was a significant relationship between heart rate recovery during the pre-season and competition phase (r = 0.92) (Figure 8).

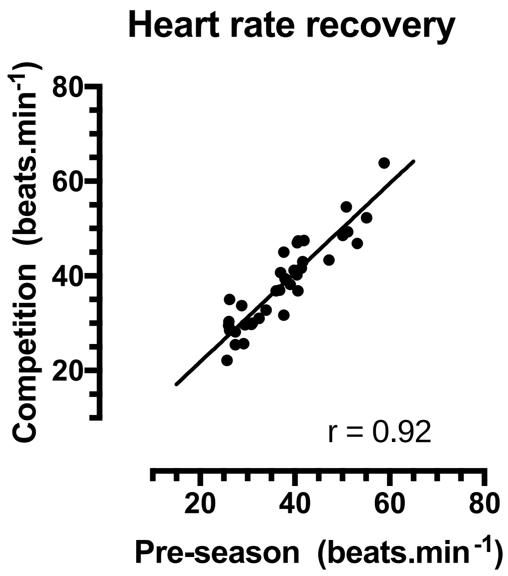


Figure 8: *Relationship between heart rate recovery during the pre-season and competition phase of the season.*

The relationship between sRPE-TL (1-week and 4-weeks) and heart rate recovery was calculated for each player (Figure 9). The number of HIMS tests for the players ranged from 9 to 20 (15 ± 2).

For the 1-week sRPE-TL vs. heart rate recovery the correlation coefficients ranged from r = -0.57 to 0.69. The average correlation coefficient was -0.07 ± 0.26. There was a significant relationship ($p < 0.05$) between 1-week sRPE-TL and heart rate recovery in three players. In two players (#16 and #29) the relationship was negative (i.e. as sRPE-TL increased the heart rate recovery decreased), and the relationship was positive in player 32 (i.e. as sRPE-TL increased the heart rate recovery increased);

Player 16: r = -0.57 (95% CI = -0.10 to -0.83). The participant was a back-row player, weighed 97.0kg, was 183.2cm tall, and had no injuries during the season

Player 29: r = -0.48 (95%CI = -0.78 to -0.00). He was an inside back, weighed 90.0 kg, was 186.6cm tall, and had one injury throughout the season (1 Musculoskeletal injury).

Player 32: r = 0.69 (95% CI 0.23 to 0.90). He was an outside back, weighed 97.0kg, was 184.7cm tall and had no injuries.

For the 4-weeks vs. heart rate recovery the correlation coefficients ranged from r = -0.61 to r = 0.59. The average correlation coefficient for all participants was 0.00 ± 0.27.

There was a significant relationship ($p < 0.05$) between 4-weeks sRPE-TL and heart rate recovery in three participants (#12, #26, #35). All the relationships were positive (i.e. as sRPE-TL increased the heart rate recovery increased);

Player 12: r = 0.59 (95% CI = -0.02 to 0.88). The participant was a second-row player, weighed 114.9kg, was 195.7cm tall and had four injuries throughout the season (1 soft tissue injury and 3 musculoskeletal injuries).

Player 26: r = 0.55 (95%CI = -0.05 to 0.83). He was an inside back, weighed 73.7kg, was 163.3cm tall and had three injuries throughout the season (3 Musculoskeletal injuries).

Player 35: r = 0.54 (95% CI 0.01 to 0.83). He was an outside back, weighed 81.8kg, was 179.8cm tall and had one injury throughout the season (1 Musculoskeletal injury).

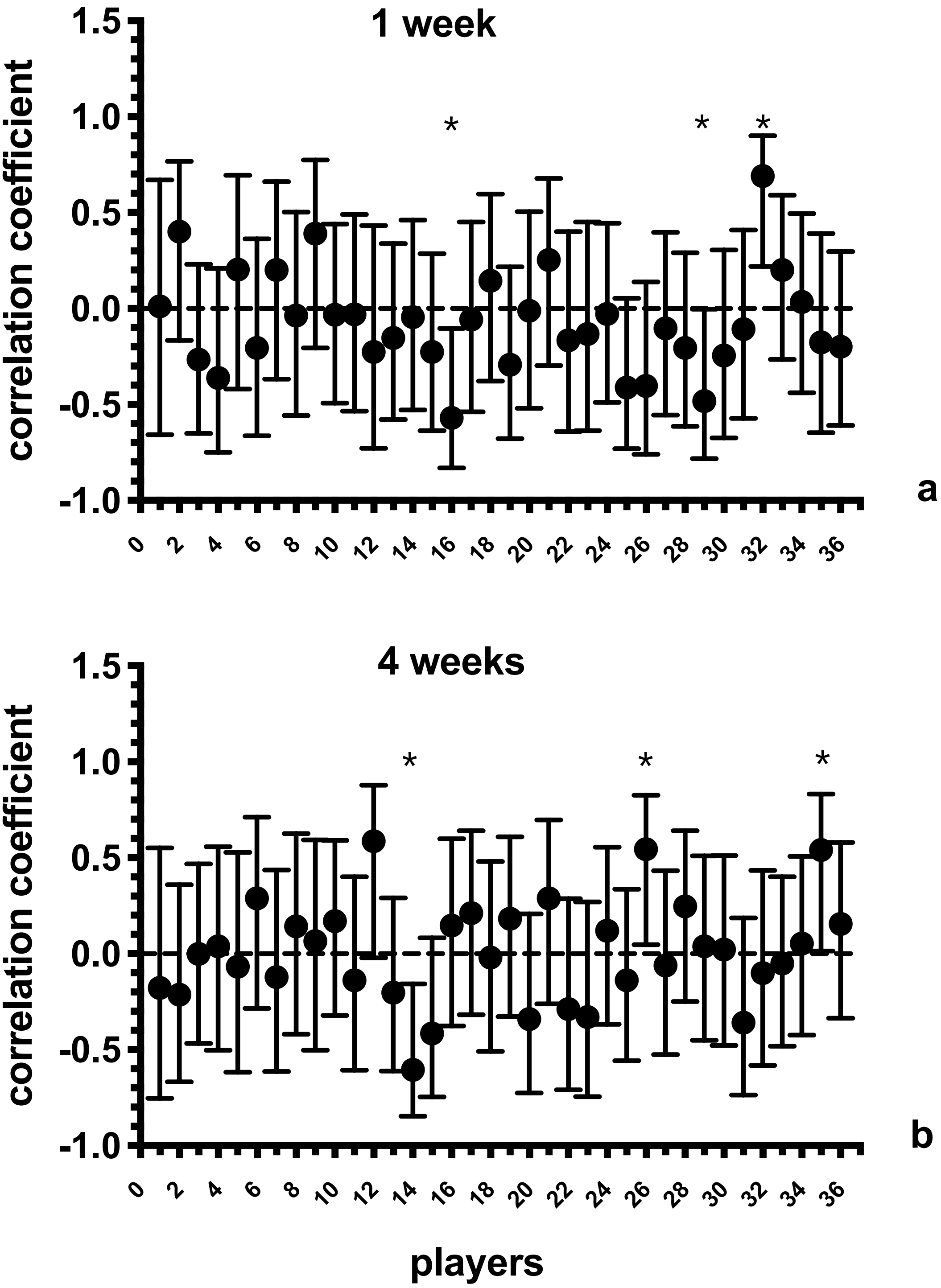


Figure 9: *Relationship between sRPE-TL (1-week and 4-weeks) and heart rate recovery) was calculated for each player.*

The Zephyr mechanical, physiological and total training measurements were recorded on match days (n = 6). The relationship between these measurements and the AMAS sRPE-TL on the same day are shown in figure 10. The relationship between Zephyr mechanical load and AMAS sRPE-TL, and Zephyr physiological load and AMAS sRPE-TL where both R = 0.78. While the relationship between Zephyr total training load and AMAS sRPE-TL was R = 0.73.

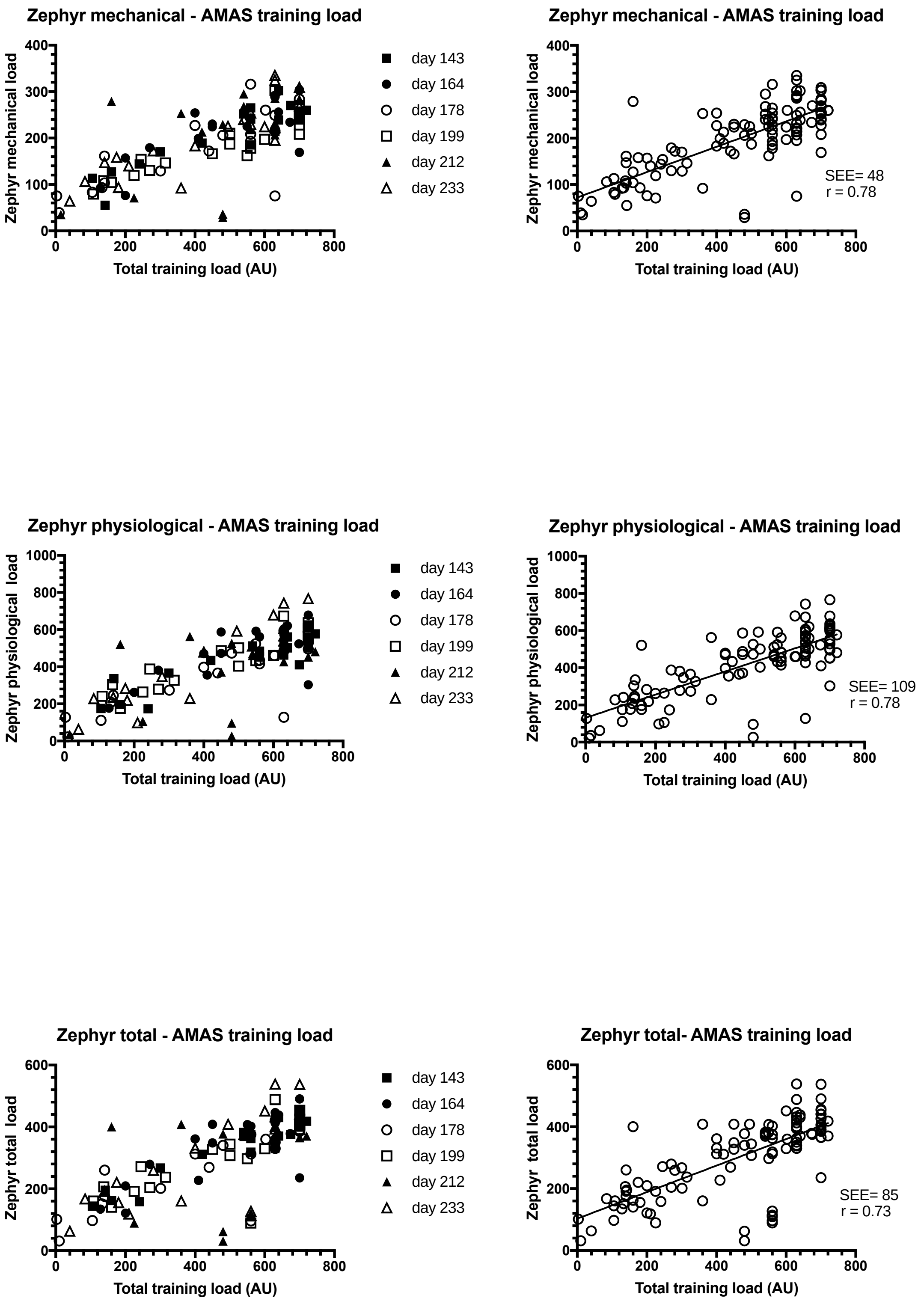


Figure 10: *Relationship between Zephyr mechanical (ML), physiological (PL) and total load (TTL) and sRPE-TL (AU) measured with the AMAS system. The data were recorded on match days (n = 6). The graphs in the left panel have different symbols for each match. The graphs in the right panel show all the data combined.*

There were 15 soft tissue and 23 musculoskeletal injuries in the off-season. In the pre-season there were 3 soft tissue injuries and 11 musculoskeletal injuries. During the competition phase of the season there were 9 soft tissue injuries and 11 musculoskeletal injuries. The days when these injuries occurred during the different phases is shown in Figure 11.

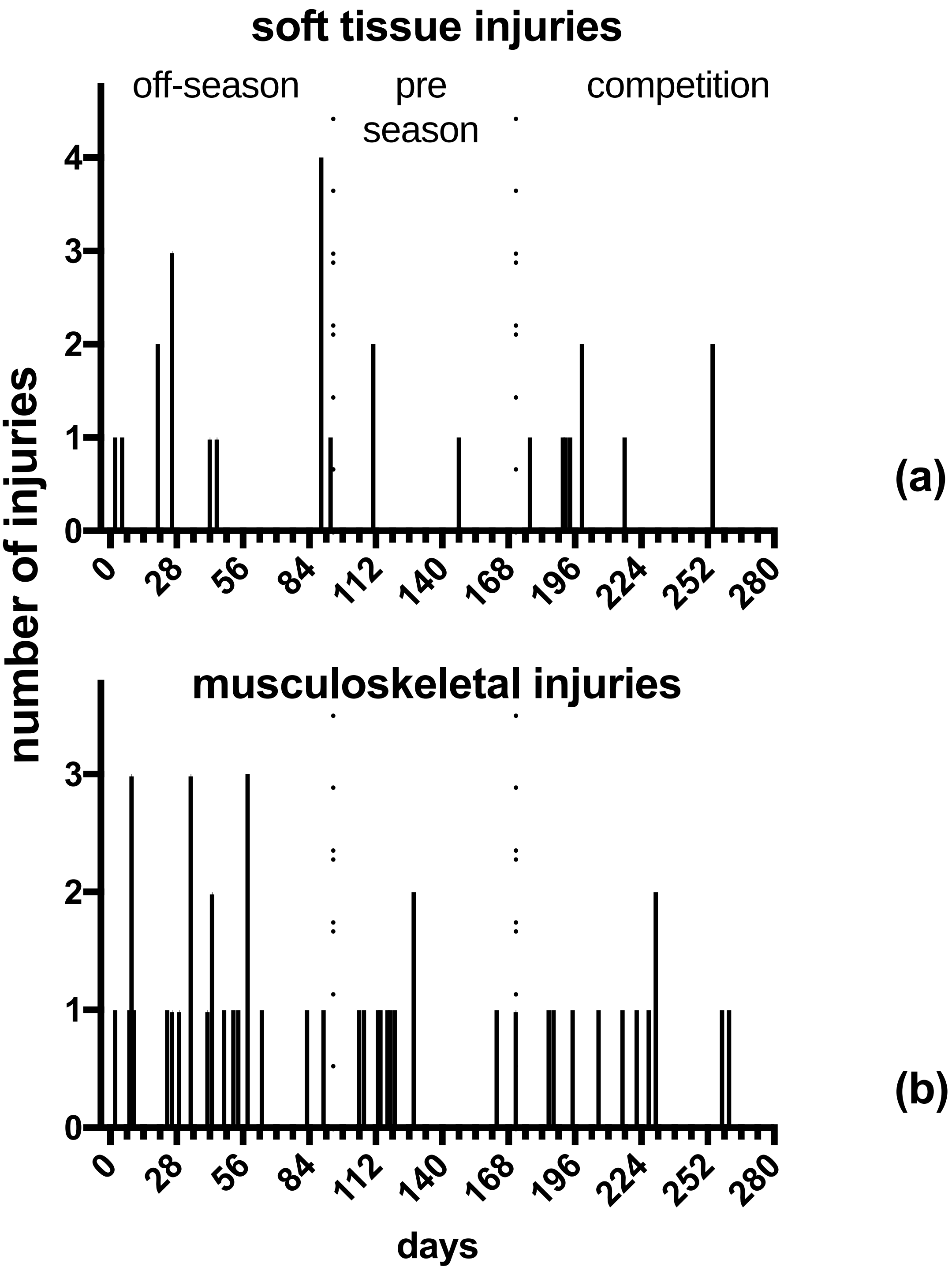


Figure 11: The soft tissue injuries (n = 27) (a) and musculoskeletal injuries (n = 45) (b) during the phases of the season.

The z score representing the average sRPE-TL, subjective fatigue and recovery for each injured player in the week preceding the injury is shown in Table 8 (soft tissue) and Table 9 (musculoskeletal). A negative z score means the weekly average score was higher than the season average score. The average z scores ranged from -0.13 (subjective fatigue) to 0.09 (recovery) for soft tissue injuries. For musculoskeletal injuries the average z score ranged from -0.18 (training load) to 0.10 (recovery). These data are plotted in Figure 12.

Table 8: The z score representing the sRPE-TL, subjective fatigue and recovery scores for the week before each soft tissue injury compared to each player's season average. The data are also expressed as mean ± standard deviation for each variable.

Soft Tissue injuries z score Day	**Player**	**sRPE-TL**	**Subjective fatigue**	**Recovery**
89	1	1.39	0.26	0.50
26	3	-0.54	-0.51	0.31
20	4	-1.39	-0.02	0.67
26	5	-0.85	-0.63	-0.05
194	8	-0.24	0.06	0.87
177	9	0.35	0.15	0.14
111	10	-0.48	0.96	-0.10
45	12	0.24	0.10	-0.30
89	14	0.74	0.34	0.18
93	14	-0.17	0.70	-0.79
192	15	0.59	0.27	-0.23
58	17	-0.10	-0.57	0.21
254	19	-0.49	-0.08	-0.47
199	20	0.51	0.14	0.29
20	21	-1.45	-1.95	-0.16
111	21	0.41	-0.85	2.22
26	22	-0.69	-0.40	0.51
254	22	0.14	-0.06	-0.45
2	24	-0.47	-1.08	-1.16
89	27	0.61	-0.05	-0.02
191	27	-0.65	0.00	0.32
199	31	0.40	-0.12	-0.18
5	33	-0.43	-0.07	-0.26
89	33	0.59	0.32	0.78
42	34	-0.43	-0.38	-0.98
147	34	0.00	0.00	0.00
217	34	-0.39	0.01	0.62
Mean ± SD		**-0.10 ± 0.66**	**-0.13 ± 0.57**	**0.09 ± 0.66**

Soft Tissue: 40% (11/27) of sRPE-TL z-scores were positive, 44% (11/27) of Subjective Fatigue z-scores were positive and 48% (13/27) of composite recovery z-scores were positive.

Table 9: The z score representing the sRPE-TL, subjective fatigue and recovery scores for the week before each musculoskeletal injury compared to each player's season averages. The data are also expressed as mean ± standard deviation for each variable.

Musculoskeletal injuries z score				
Day	**Player**	**sRPE-TL**	**Subjective fatigue**	**Recovery**
41	1	-0.15	-1.04	0.07
227	1	-0.05	0.67	-0.52
222	2	0.03	0.79	0.98
48	3	-0.10	-0.02	1.62
185	3	0.33	0.48	0.08
29	5	-0.54	-0.31	0.39
52	5	-0.96	0.55	-0.60
58	6	0.20	0.28	0.57
196	6	-0.14	-0.57	-0.73
207	6	0.38	0.28	-0.07
34	7	-0.69	-0.95	-1.08
258	8	0.78	0.02	0.35
2	9	0.00	0.00	0.00
26	9	-1.19	-0.67	0.31
58	9	-0.32	-0.42	0.32
34	11	0.15	-0.53	0.72
128	11	2.18	-0.36	-0.16
64	12	-0.57	-0.18	0.87
120	12	0.86	-0.09	0.85
163	12	0.34	0.18	-0.51
34	13	-0.35	0.00	-0.37
9	14	-1.24	-0.81	-0.11
230	14	0.04	-0.93	0.13

Continued

Continued

Day	**Player**	**sRPE-TL**	**Subjective fatigue**	**Recovery**
230	15	-0.10	-0.17	-0.09
54	19	-0.29	0.78	0.42
118	19	-0.35	0.91	-0.27
9	20	-0.63	-0.58	0.11
128	20	0.18	-0.32	-0.48
113	22	-0.02	0.15	-0.61
111	23	-0.39	-0.08	0.27
10	25	-3.21	0.21	1.29
9	26	0.12	0.20	0.75
105	26	-1.28	0.48	-0.61
216	26	0.34	0.33	0.12
43	29	-1.17	0.61	-0.14
171	30	0.07	-0.12	-0.43
187	30	-0.08	0.02	-0.53
43	31	-1.14	0.47	0.88
83	31	1.25	0.94	0.18
107	31	-0.11	0.04	1.25
117	33	0.02	-0.21	0.34
8	34	-0.02	-0.57	0.30
261	34	0.12	0.94	0.23
114	35	-0.21	0.54	-0.86
24	36	0.01	-0.61	-0.61
Mean ± SD		**-0.18 ± 0.79**	**0.01 ± 0.53**	**0.10 ± 0.61**

Musculoskeletal: 40% (18/45) of sRPE-TL z-scores were positive, 49% (22/45) of subjective fatigue z scores where positive and 55% (25/45) of composite recovery scores where positive.

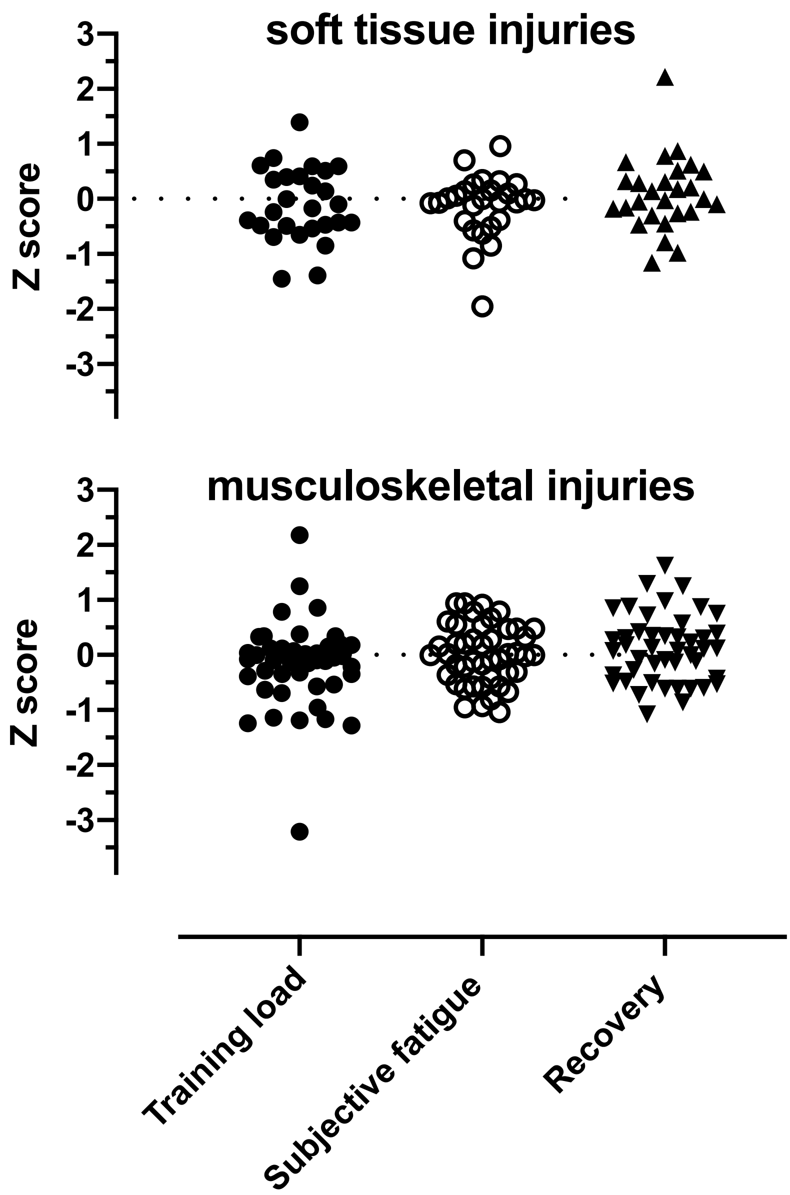


Figure 12: The z scores for sRPE-TL, subjective fatigue and recovery for each player who sustained a soft tissue injury (n = 27) (a) or a musculoskeletal injury (n = 45) (b)

The relationship between sRPE-TL z score and subjective fatigue z score and recovery z score in the week before a soft tissue injury or a musculoskeletal injury is shown in table 10.

Table 10: *The correlation coefficient (and 95% CI) for the relationship between sRPE-TL z score and subjective fatigue z score and recovery z score in the week before a soft tissue injury (n = 27) or a musculoskeletal injury (n = 45).*

	sRPE-TL vs.	
	Subjective fatigue	**Recovery**
Soft tissue injuries	0.46 (0.09 to 0.71) *	0.17 (-0.23 to 0.52)
Musculoskeletal injuries	0.03 (-0.26 to 0.32)	-0.10 (-0.38 to 0.20)

* $p = 0.02$

Discussion

The main finding of the study was that there was little variance in the daily sRPE-TL that the players sustained throughout the different phases of the season (Table 3). The players' response to this load also lacked major variance. For example, mean daily subjective fatigue (Table 4), mean daily composite recovery score (Table 5) and average heart rate recovery (Table 6), all had minimal variance from phase-to-phase during the season, suggesting the players' state of training remained fairly constant. These findings indicate that the players where well-managed throughout the different phases of the season, as no significant loading fluctuations or troughs occurred between the different phases of the season. This lack of variance is in accordance with the recommendations of Gabbett et al (2018), who stated that major fluctuations in load increases the risk of injury.[4] When prescribing workloads, it is important to ensure that load is administered in an incremental and planned fashion, as either too much loading can result in negative training adaptations and fatigue, while under loaded athletes will not have had the loading stress to develop the necessary physiological adaptations.[15] Heisman et al further emphasises the negative effects of inconsistent fluctuations in load , stating that increased load resulted in decreased performance.[86]

It is noteworthy that the load completed by the players was substantially higher (42%) than the reported load for elite English adolescent rugby union players(1,217 ± 364AU),[15] and 35% higher than the average in-season load for senior professional rugby union players(1,425 ± 545AU).[7] Both of these studies only conducted load monitoring in-season. It would have been interesting to have had access to the loading parameters during the off-season and pre-season to determine whether they also had consistent loads through the season.

Phibbs et al. (2017) quantified the demands of academy players and scholars in the UK using GPS to assess the running demands completed during matches and practises. They found that academy players trained at or above match demands, while scholars trained less specifically and below match demands and were therefore underprepared for the demands of competitive adolescent rugby.[5] Gabbett (2018) states that training load serves as a protective mechanism against injury,[4] and the ability of an athlete to withstand large load is seen as robustness.[75] This robustness along with the development of other physical and skill characteristics are the primary desired outcomes of these rugby academies.

The subjective variables illustrated in Table 4 and 5, further emphasise a well-managed squad, with small but not significant reductions in sRPE-TL as the competition nears, and greater but once again unremarkable increases in average daily composite recovery. The maintenance of the relatively high sRPE-TL throughout the different phases of the season, and the similar responses to these loads was an interesting finding. This response suggests the players were well managed. Whether this finding is unique to junior players remains to be determined. A study conducted in 2009 on professional adult players showed that training load decreased as the season progressed,[19] possibly to ensure that the players' responses to load remain positive. Another interpretation is that 10 years ago when the study was conducted the strength and conditioning trainer had less refined knowledge about prescribing training compared to the trainers who prescribed the training in this study.

The second main finding of this study was that there was a strong association (r=0.92) between heart rate recovery scores when compared between the pre-season (37.7±5.8 beats.min^{-1}) and the competition phase (38.5±5.6 beats.min^{-1}). There are two interpretations of this finding. Either there was no change in the players' training status, even though they were exposed to varying demands associated with competitive rugby. This is unexpected, as it can be assumed that as the players were exposed to steady chronic load, they would have adapted to the load, and had a more favourable response to the load (i.e. increased heart rate recovery at a similar training load.). This is what Aubry et el. (2015) found after athletes in their study were exposed to a 3-week overload.[87] The other interpretation is that recovery heart rate lacks the sensitivity to detect changes in training status. Noon et al (2018) debates the sensitivity of heart rate recovery, stating that it been shown to be sensitive to change , however on other occasions lacking sensitivity.[88] However, a study conducted by Buchheit (2015) argues that heart rate recovery is a reliable indicator of athletes' well-being , and their ability to cope with load.[50] This lack of clarity from multiple sources exposes the inconsistencies associated with using heart rate recovery as a tool for athlete monitoring. The inconsistencies in the research suggests that an athlete's recovery status should not be made from heart rate recovery alone. Instead other variables such as subjective fatigue and athlete performance should be considered in conjunction with heart rate recovery.[87] When these variables are considered in context in this study it may be concluded that the players' recovery status (initially illustrated by subjective fatigue scores and composite recovery) remained fairly constant throughout the pre-season and the competition phases.

The third finding of the study was that there was no relationship between 1-week sRPE-TL and heart rate recovery for the whole group (r=0.07) (Table 10). However, three players had a moderately significant relationship, of which two were negative associations (r = -0.57 and r =-0.48) and one positive association (r=0.69). A negative association refers to a situation where sRPE-TL increases and heart rate recovery decreases, and a positive association indicates both sRPE-TL increases and heart rate recovery increases. The latter indicates the player is adapting in the presence of increasing training loads. There are no clear explanations why the above-mentioned players had a moderate relationship between average 1-week sRPE-TL and heart rate recovery, in contrast to the other players who did not show this relationship. Although the sample size is small, the differences cannot be explained by injury rate. For example, one of the players (player 29) who showed a negative relationship between training load and recovery heart (i.e. undesirable relationship) sustained an injury whereas the other player (player 16) did not. The player who had a desirable relationship between training load and recovery heart rate (player 32) did not get injured during the season.

There was no relationship between the average 4-week sRPE-TL and heart rate recovery for the whole group (r=0.0). However, within the group three different players had a moderate significant positive relationship between 4-week sRPE-TL and heart rate recovery (r = 0.59, r =0.55 and r =0.54). These relationships can be interpreted as positive because they show the increase in training load were accompanied by an increase in recovery heart rate. The above mentioned three athletes sustained a combined 8 injuries (2.7 injuries per player vs. squad 1.9 injuries per player) throughout the season. This leads us to speculate as to why these three players sustained injuries at a greater rate that the squad, while showing positive adaptations to training (increased heart rate recovery, combined with increased training load).

What needs to be considered is that an increase in 1-week sRPE-TL can be described as causing acute fatigue, whereas an increase in 4-week sRPE-TL is associated with chronic fatigue. Therefore, when assessing the relationship between 4 weeks sRPE-TL and heart rate recovery, the effects of constant chronic loading may result in an increase in the ability of the player to tolerate load, hence improve capacity.[89] This improved capacity results in training imposing less stress on the players, the outcome being an improved recovery status. The lack of variance in the load, coupled with sustained chronic loading over the season, may have resulted in the players improving their physical performance capacity, and therefore not exhibiting overtraining symptoms. This explanation fits the responses of all but three of the players (Figure 9b). The reasons for this are not clear and can be attributed to individual variation in response[11].

The fourth finding of this study pertains to the relationship between the three different measures of training load acquired from the Zephyr bioharness (Mechanical load, Physiological load and Training load) and sRPE-TL. It was not possible to use the Zephyr bioharness for away matches in the competition, therefore only data from the home matches (n = 6) were collected.

This analysis showed that the relationships between sRPE-TL and mechanical load, physiological load and training load ranged between (r=0.73 to r =0.78). Physical loads (i.e. training load derived from heart rate data) and mechanical load (training load derived from accelerometery) had the highest correlation with sRPE-TL (r=0.78; i.e. 61% of the variance in sRPE-TL was accounted for by changes in either physical or mechanical load), while total training load had the lowest (r=0.73; i.e. 53% of the variance in sRPE-TL was accounted for by changes training load.). These findings mitigate against using expensive loading monitoring tools in preference to subjective assessments of training load which include subjective measures of training load such as rate of perceived exertion multiplied by training duration. This supports the findings of researchers in other sports such as running[23], football,[90] basketball[91] and fencing.[92] Quarrie et al. (2016) also recommends using sRPE to monitor training load in rugby because it is reliable, easy to administer and valid.[8]

The final finding of this study concerns the relationship between injuries sustained throughout the season (45 musculoskeletal injuries and 27 soft tissue injuries) and sRPE-TL. In the week leading up to when a soft tissue injury occurred, there was no change in sRPE-TL (z-score = -0.10 ± 0.66), mean daily subjective fatigue (z-score = -0.13 ± 0.57) or mean daily composite recovery (z-score = 0.09 ± 0.66). Similar outcomes were obtained from the weeks leading up to a musculoskeletal injury where there were no changes in sRPE-TL (z-score = -0.18 ± 0.79), decreased mean daily recovery (z-score = 0.10 ± 0.61) or mean daily fatigue (z-score = 0.01 ± 0.53). This further reinforces the idea , that although the management and monitoring of athletes was important in trying to minimize injury risk , it by no means predicts injury risk.[89] Fanchini et al. strengthens this finding , showing that although training load markers are associated with non-contact injuries , they showed poor predictive capabilities.[93]

In the week before a soft tissue injury there was a moderate relationship (r = 0.46; 21% variance explained) between subjective variable z-scores and sRPE-TL z-scores. Although there was a moderate relationship between the two variables, 79% of the variance was unexplained. This puts into context the usefulness of using subjective fatigue as a consequence of training load, particularly if the main outcome is to prevent injury.

Chapter 4

Conclusion

Conclusion

The primary finding of this study was that the players' loads, fatigue and recovery did not change significantly throughout the different phases of the season. This suggests the players were well managed during the season because spikes in these variables were avoided. It may be concluded that the feedback loop that exists between the high-performance staff who conducted the monitoring and the coaching staff was well calibrated. This enabled the feedback from the subjective and objective data to titrate the training load and recovery effectively, ensuring that there were no major changes between phases of the season.

The magnitude of the training load through the season was relatively high. This can be attributed to the fact that the players in the academy are full time rugby players and have more time for training compared to scholars, who have to attend to school activities. The academy players often had multiple training sessions per day which contributed to the high total training load.

This study also questions the usefulness of using expensive measures of training load (internal/external) in isolation. In a high-performance environment, if a device or apparatus does not provide a substantial benefit to the player or the team it soon becomes obsolete[94]. A method such as sRPE is cost effective, quicker and easier to implement than a wearable device. It stands to reason that this should then be the preferred method for assessing training load, allowing resources to be invested into other areas to contribute to the teams' wellbeing.

This study has shown no clear predictive relationship between training load prior to sustaining an injury (both soft tissue and musculoskeletal). Therefore, we can conclude that subjective training load and subjective fatigue may not predict injury but can be used as a marker to guide training. Important individualised decisions should be made about each player, ensuring that load and fatigue in response to the load remain steady.

In conclusion, monitoring the loading parameters of players over different phases of the season, is important for tracking the stress the players are exposed to. This provides the coach and strength and conditioning trainers with information they can use to manage the wellbeing of the players. This is particularly important for academy players who are making the transition from school into adult rugby. These players are in the process of developing athlete robustness and the physical qualities that are needed to play high level adult rugby.

Limitations

Possible limitations associated with this study are the fact that there were no physical testing data, additional external load measures (such as GPS) and Off-season heart rate data. These data sources may have confirmed that the loading experience by the rugby players was sufficient to induce the required physiological adaptations (improved strength, running capacity etc.) sought after by the coaching staff, assisting in improving rugby performance.

References

1. Rafferty J, Ranson C, Oatley G, et al. On average, a professional rugby union player is more likely than not to sustain a concussion after 25 matches. *Br J Sports Med*. 2018:1-5.
2. Brown JC, Lambert MI, Verhagen E, Readhead C, van Mechelen W, Viljoen W. The incidence of rugby-related catastrophic injuries (including cardiac events) in South Africa from 2008 to 2011: a cohort study. *BMJ Open*. 2013;3:1-9.
3. Jones B, Weaving D, Tee J, et al. Bigger, stronger, faster, fitter: the differences in physical qualities of school and academy rugby union players. *J Sports Sci*. 2018:1-6.
4. Gabbett TJ. Debunking the myths about training load, injury and performance : empirical evidence, hot topics and recommendations for practitioners. *Br J Sports Med*. 2018:1-9.
5. Phibbs PJ, Jones B, Read DB, et al. The appropriateness of training exposures for match-play preparation in adolescent schoolboy and academy rugby union players. *J Sports Sci*. 2017:1-6.
6. Gabbett TJ. The training-injury prevention paradox: should athletes be training smarter and harder? *Br J Sports Med*. 2016;50:273-280.
7. Phibbs PJ, Jones B, Roe G, et al. The organised chaos of English adolescent rugby union: Influence of weekly match frequency on the variability of match and training loads. *Eur J Sport Sci*. 2018:1-8.
8. Quarrie KL, Raftery M, Blackie J, et al. Managing player load in professional rugby union: a review of current knowledge and practices. *Br J Sports Med*. 2016;0:1-8.
9. Drew MK, Finch CF. The relationship between training load and injury, illness and soreness: A systematic and literature review. *Sport Med*. 2016;46(6):861-883.
10. Meeusen R, Duclos M, Foster C, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: Joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. *Med Sci Sports Exerc*. 2013;45(1):186-205.
11. Mann TN, Lamberts RP, Lambert MI. High responders and low responders: Factors associated with individual variation in response to standardized training. *Sport Med*. 2014;44(8):1113-1124.
12. Cresswell SL. Possible early signs of athlete burnout: A prospective study. *J Sci Med Sport*. 2009;12(3):393-398.
13. Bourdon PC, Cardinale M, Murray A, et al. Monitoring athlete training loads : Consensus statement. *Int J Sports Physiol Perform*. 2017;12:161-170.
14. Thorpe RT, Atkinson G, Drust B, Gregson W. Monitoring Fatigue Status in Elite Team-Sport Athletes : Implications for Practice. 2017:27-35.
15. Phibbs PJ, Jones B, Roe G, et al. Organized chaos in late specialization team sports: Weekly training loads of elite adolescent rugby union players. *J Strength Cond Res*. 2018;32(5):1316-1323.
16. Lombard W, Durandt JJ, Masimla H, Green M, Lambert MI. Changes in body size and physical characteristics of South African under-20 rugby union players over a 13-year period. *J Strength Cond Res*. 2015;29(7):980-988.

17. Phibbs P, Jones B, Read D, et al. The appropriateness of training exposures for match-play preparation in adolescent schoolboy and academy rugby union players. *J Sports Sci*. 2018;36(6):704-709.
18. Read DB, Jones B, Phibbs PJ, et al. The physical characteristics of match-play in English schoolboy and academy rugby union. *J Sports Sci*. 2018;36(6):645-650. doi:10.1080/02640414.2017.1329546
19. Hartwig TB, Naughton G, Searl J. Defining the volume and intensity of sport participation in adolescent rugby union players. *Int J Sports Physiol Perform*. 2008;3:94-106.
20. Halson SL. Monitoring Training Load to Understand Fatigue in Athletes. *Sport Med*. 2014;44:139-147. doi:10.1007/s40279-014-0253-z
21. Impellizzeri FM, Marcora SM, Coutts AJ. Internal and external training load: 15 years on. *Int J Sports Physiol Perform*. 2019;14(2):270-273.
22. Vanrenterghem J, Nedergaard NJ, Robinson MA, Drust B. Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. *Sport Med*. 2017;47(11):2135-2142.
23. Wallace LK, Slattery KM, Coutts AJ. A comparison of methods for quantifying training load: Relationships between modelled and actual training responses. *Eur J Appl Physiol*. 2014;114(1):11-20.
24. Austin D, Gabbett T, Jenkins D. The physical demands of Super 14 rugby union. *J Sci Med Sport*. 2011;14(3):259-263.
25. Cunningham D, Shearer DA, Drawer S, et al. Movement demands of elite U20 international rugby union players. *PLoS One*. 2016;11(4):4-6.
26. Ziv G, Lindor R. On-field performance of rugby union players - A review. *J Strength Cond Res*. 2016;30(3).
27. Lindsay A, Draper N, Lewis J, Gieseg SP, Gill N. Positional demands of professional rugby. *Eur J Sport Sci*. 2015;15(6):480-487.
28. Dubois R, Paillard T, Lyons M, Mcgrath D, Maurelli O, Prioux J. Running and metabolic demands of elite rugby union assessed using traditional , metabolic power, and heart rate monitoring methods. *J Sport Sci Med*. 2017;16(1):84-92.
29. Viljoen W, Saunders CJ, Hechter GD, Millson HB. Training volume and injury incidence in a professional rugby union team. *South African J Sport Med*. 2009;21(3):97-101.
30. Jones T, Smith A, MacNaughton L, French D. Variances in strength and conditioning practice in elite rugby union between the nothern and southern hemisphere. *J Strength Cond Res*. 2017;31(12):3358-3371.
31. Du Preez M, Lambert MI. Travel fatigue and home ground advantage in South African Super 12 rugby teams. *SAJSM*. 2007;19(1):20-22.
32. Schwellnus MP, Derman WE, Jordaan E, et al. Elite athletes travelling to international destinations > 5 time zone differences from their home country have a 2 – 3-fold increased risk of illness. *Br J Sports Med*. 2012;46:816-821.
33. Korte SM, Koolhaas JM, Wingfield JC, Mcewen BS. The Darwinian concept of stress : benefits of allostasis and costs of allostatic load and the trade-offs in health and disease. *Neurosci Biobehav Rev*. 2005;29:3-38.
34. Stults-Kolehmainen M, Bartholomew J, Sinha R. Chronic pyschological stress impairs recovery of muscular function and somatic sensations over

a 96-hour period. *J Strength Cond Res*. 2017;28(7).
35. Borresen J, Lambert MI. The quantification of training load, effect on performance. *Sport Med*. 2009;39(9):779-795.
36. Deutsch MU, Maw GJ, Jenkins D, Reaburn P. Heart rate, blood lactate and kinematic data of elite colts (under-19) rugby union players during competition. *J Sports Sci*. 1998;16:561-570.
37. Sparks M, Coetzee B. The use of heart rates and graded maximal test values to determine rugby union game intensities. *J Strength Cond Res*. 2013;27(2):507-513.
38. Coutts AJ, Reaburn P, Abt G. Heart rate, blood lactate concentration and estimated energy expediture in a semi-profesional rugby league team during a match: case study. *J Sport Sci Med*. 2003;21(2):97-103.
39. Foster C, Florhaug J a, Franklin J, et al. A new approach to monitoring exercise training. *J Strength Cond Res*. 2001;15:109-115.
40. O'Keeffe S, O'Connor S, Ni Chéilleachair N. Are internal load measures associated with injuries in male adolescent Gaelic football players ? *Eur J Sport Sci*. 2019;0(0):1-12.
41. Tavares F, Smith TB, Driller M. Fatigue and recovery in rugby: A review. *Sport Med*. 2017;47(8):1515-1536.
42. Lambert MI, Mujika I. Physiology of Exercise Training. In: Hausswirth C, Mujika I, eds. *Recovery for Performance in Sport*. 1st ed. Human Kinetics; 2013:3-8.
43. Hulin BT, Gabbett TJ, Caputi P, Lawson DW, Sampson JA. Low chronic workload and the acute:chronic workload ratio are more predictive of injury than between-match recovery time: a two-season prospective cohort study in elite rugby league players. *Br J Sports Med*. 2016;50(6):955-956.
44. Buchheit M. Monitoring training status with HR measures: Do all roads lead to Rome? *Front Physiol*. 2014;5:1-19.
45. Herman L, Foster C, Maher MA, Mikat RP, Porcari JP. Validity and reliability of the session RPE method for monitoring exercise training intensity. *SAJSM*. 2006;18(1):14-17.
46. Waldron M, Highton J. Fatigue and pacing in high-intensity intermittent team sport : An Update. *Sport Med*. 2014;44:1645-1658.
47. Eston R. Use of ratings of perceived exertion in sports. *Int J Sports Physiol Perform*. 2012;7:175-182.
48. Daanen HAM, Lamberts RP, Kallen VL, Jin A, Van Meeteren NLU. A systematic review on heart-rate recovery to monitor changes in training status in athletes. *Int J Sports Physiol Perform*. 2012;7:251-260.
49. Borresen J, Lambert MI. Autonomic control of heart rate during and after exercise training status. *Sport Med*. 2008;38(8):633-646.
50. Buchheit M. Sensitivity of monthly heart rate and psychometric measures for monitoring physical performance in highly trained young handball players. *Int J Sport Med*. 2015;36:351-356.
51. Kreider R, Fry A, O'Toole M. Overtraining in sport: Terms, definitions, and prevalence. In: Kreider R, Fry A, O'Toole M, eds. *Overtraining in Sport*. Human Kinetics; 1998:7-9.
52. Nicholls AR, Backhouse SH, Polman RCJ, Mckenna J. Stressors and affective states among professional rugby union players. *Scand J Med Sci Sports*.

2009:121-128.
53. Coutts AJ, Slattery KM, Wallace LK. Practical tests for monitoring performance, fatigue and recovery in triathletes. *J Sci Med Sport*. 2007;10:372-381.
54. Saw AE, Main LC, Gastin PB. Monitoring athletes through self-report: Factors influencing implementation. *J Sport Sci Med*. 2014;14(1):137-146.
55. Gabbett TJ. Influence of fatigue on tackling ability in rugby league players : Role of muscular strength, endurance, and aerobic qualities. *PLoS One*. 2016;11(10):1-11.
56. Roe G, Darrall-jones J, Till K, et al. The effect of physical contact on changes in fatigue markers following rugby union field-based training. *Eur J Sport Sci*. 2017;17(6):647-655.
57. Tavares F, Healey P, Smith TB, Driller M. The effect of training load on neuromuscular performance , muscle soreness and wellness during an in-season non-competitive week in elite Rugby athletes. *J Sport Med Phys Fit*. 2017;58(11):1565-1571.
58. Tee JC, Bosch AN, Lambert MI. Metabolic consequences of exercise-induced muscle damage. *Sport Med*. 2007;37(10):827-836.
59. McLellan C, Lovell D, Gass G. Markers of postmatch fatigue in professional rugby league players. *J Strength Cond Res*. 2011;25(4):1030-1039.
60. Elloumi M, Maso F, Michaux O, Robert A, Lac G. Behaviour of saliva cortisol [C], testosterone [T] and the T / C ratio during a rugby match and during the post-competition recovery days. *Eur J Appl Physiol*. 2003;90:23-28.
61. McLean BD, Coutts AJ, Kelly V, McGuigan MR, Cormack SJ. Neuromuscular , endocrine , and perceptual fatigue responses during different length between-match microcycles in professional rugby league players. *Int J Sports Physiol Perform*. 2010;5:367-383.
62. Kempton T, Sirotic AC, Cameron M, Coutts AJ. Match-related fatigue reduces physical and technical performance during elite rugby league match-play : a case study. *J Sports Sci*. 2017;31(16):1770-1780.
63. Twist C, Highton J. Monitoring fatigue and recovery in rugby league players. *Int J Sports Physiol Perform*. 2013;8:467-474.
64. Williams S, Trewartha G, Stokes K. A Meta-analysis of injuries in senior men's professional rugby union. *Sport Med*. 2013;43(10):1043-1055.
65. Sewry N, Verhagen E, Lambert M, et al. Seasonal time-loss match injury rates and burden in South African under-16 rugby teams. *J Sci Med Sport*. 2019;22(1):54-58. doi:10.1016/j.jsams.2018.06.007
66. Barden C. Epidemiology of Injury in elite English schoolboy rugby union: A 3-year study comparing different competitions. *J Athl Train*. 2018;53(5):514-520.
67. Hartwig TB, Duncan C, Harries S, Perry N, Gabbett TJ, Naughton G. Training and match volume and injury in adolescents playing multiple contact team sports: A prospective cohort study. *Scand J Med Sci Sports*. 2019;29:469-475.
68. Coughlan GF, Delahunt E, Caul BM, Forde C, Green BS. Normative adductor squeeze test values in elite junior rugby union players. *Clin J Sport Med*. 2014;24(4):10-12.
69. Brooks JHM, Fuller CW, Kemp SPT, Reddin DB. Epidemiology of injuries in English professional rugby : part 1. *Br J Sports Med*. 2005;39:757-767.

70. Hodgson L, Hignett T, Edwards K. Physical therapy in sport normative adductor squeeze tests scores in rugby. *Phys Ther Sport*. 2015;16(2):93-97.
71. Tiernan C, Lyons M, Comyns T, Nevill AM, Warrington G. The relationship between adductor squeeze strength , subjective markers of recovery and training load in elite rugby players. *J Strength Cond Res*. 2019;(2):1-6.
72. Cook G, Burton L, Hoogenboom B. Pre-participation screening: The use of fundamental movements as an assesment of function - Part 1. *North Am J Sport Phys Ther*. 2006;1(2):62-71.
73. Cook G, Burton L, Hoogenboom B. Pre-participation screening: The use of fundamental movements as an assesment of function – Part 2. *North Am J Sport Phys Ther*. 2006;1(3):132-139.
74. Tee JC, Klingbiel JF, Collins R, Lambert MI, Coopoo Y. Preseason functional movement screen component tests predict severe contact injuries in professional rugby union players. *J Strength Cond Res*. 2016;30(11):3194-3203.
75. Gabbett TJ, Hulin BT, Blanch P, Whiteley R. High training workloads alone do not cause sports injuries: how you get there is the real issue. *Br J Sports Med*. 2016;50(8):443-443.
76. Gabbett TJ, Nielsen RO, Bertelsen ML, et al. In pursuit of the ‘ Unbreakable ’ Athlete : what is the role of moderating factors and circular causation ? *Br J Sports Med*. 2018;53(7):1-2.
77. Hughes MD, Bartlett RM. The use of performance indicators in performance analysis. *J Sports Sci*. 2002;20(10):739-754.
78. Roberts SP, Trewartha G, Higgitt R, El-Abd J, Stokes KA. The physical demands of elite English rugby union. *J Sports Sci*. 2008;26(8):825-833.
79. Taylor P, Smart D, Hopkins WG, Quarrie KL, Gill N. The relationship between physical fitness and game behaviours in rugby union players. *Eur J Sport Sci*. 2011:37-41.
80. Waldron M, Worsfold PR, Twist C, Lamb K. The relationship between physical abilities, ball- carrying and tackling among elite youth rugby league players. *J Sports Sci*. 2013:37-41.
81. Speranza J, Gabbett TJ, Johnston RD, Sheppard J. Muscular strength and power correlates of tackling ability in semiprofessional rugby league players. *J Strength Cond Res*. 2015;29(8):2071-2078.
82. Swaby R, Jones PA, Comfort P. Relationship between maximal aerobic speed performance and distance covered in rugby union games. *J Strength Cond Res*. 2016;30(10):2788-2793.
83. Seibold AJ, Gabbett TJ. Relationship between tests of physical qualities, team selection, and physical match performance in semiprofessional rugby league players. *J Strength Cond Res*. 2013;27(12):3259-3265.
84. Lamberts RP, Lemmink K a PM, Durandt JJ, Lambert MI. Variation in heart rate during submaximal exercise: implications for monitoring training. *J Strength Cond Res*. 2004;18(3):641-645.
85. Buchheit M, Haddad H Al, Laursen PB, Ahmaidi S. Effect of body posture on postexercise parasympathetic reactivation in men. *Exp Physiol*. 2009;94(7):795-804.
86. Heishman A, Curtis M, Saliba E, Hornett R, Malin k S, Weltman A. Non-invasive assessment of internal and external player load: Implications for optimizing athletic performance. *J Strength Cond Res*. 2018;32(5):1280-

1287.
87. Aubry A, Hausswirth C, Louis J, Coutts AJ. The development of functional overreaching is associated with a faster heart rate recovery in endurance athletes. *PLoS One*. 2015;10(10):1-16.
88. Noon M, James R, Clarke N, Taylor RJ, Thake Douglas. Next day subjective and objective recovery indices following acute low and high training loads in academy rugby union players. *Sports*. 2018;6(56):1-11.
89. Myers NL, Mexicano G, Aguilar K V. The association between non-contact injuries and the acute:chronic workload ratio in elite level athletes: A criticially appraised topic. *J Sport Rehabil*. 2019:1-13.
90. Impellizzeri FM, Rampinini E, Coutts AJ, Marcora SM. Use of RPE-based training load in soccer. *Med Sci Sports Exerc*. 2004;36(6):1042-1047.
91. Berdejo-del-Fresno D, Gonzalez-Rave J. Validation of an instrument to control and monitor the training load in basketball : The BATLOC Tool. *Am J Sport Sci Med*. 2014;2(4):171-176.
92. Turner A, Buttigieg C, Marshalll G, Noto A, Phillips J, Kilduff L. Ecological validity of session RPE method for quantifying internal training load in fencing. *Int J Sports Physiol Perform*. 2016;12(1).
93. Fanchini M, Rampinini E, Riggio M, et al. Despite association, the acute: chronic work load ratio does not predict non-contact injury in elite footballers injury in elite footballers. *Sci Med Footb*. 2018;2:108-114.
94. Coutts AJ. In the age of technology, Occam's razor still applies. *Int J Sports Physiol Perform*. 2014;16(6):2014.

Appendix

A - Subjective Training load
B- Total Recovery Score and Subjective fatigue questionnaire
C - Ethics form for the Western Province Rugby Institute's Database
D- Consent form
E- Individual Subjective Training Loads graphs
F- Individual Subjective Fatigue graphs
G- Individual Composite Recovery graphs
H -Individual Maximal Heart Rate graphs
I – Individual Heart Rate Recovery graphs

Appendix A

Subjective Training Load

Question 13 of 20

Did you do any discipline specific training yesterday? If yes, how long (in minutes)?

Yes No

min

How would you rate the intensity/difficulty level of your disciple specific session?

If required, please note details of session in the box below

Question 14 of 20

Did you do a 2nd Discipline specific session yesterday? If yes, how long (in minutes)?

Yes No

min

How would you rate the intensity/difficulty level of your 2nd disciple specific session?

If required, please note details of session in the box below

Question 15 of 20

Did you do any form of cardiovascular training (running, rowing, cycling) yesterday? If yes, how long (in minutes)?

Yes No

min

How would you rate the intensity/difficulty level of your cardiovascular session?

Question 16 of 20

Did you do any resistance training yesterday? If yes, how long (in minutes)?

Yes No

min

How would you rate the intensity/difficulty level of your resistance session?

Question 17 of 20

Did you do any other (Pilates, yoga, other discipline specific etc.) form of training yesterday? If yes, what did you do and how long did you do it for (in minutes)?

Yes No

min

How would you rate the intensity/difficulty level of your session?

Question 18 of 20

Did you participate in a match/event yesterday? If yes, how long (in minutes)?

Yes No

min

How would you rate the intensity/difficulty level of your match/event?

Question 19 of 20

Did you consult with any health care practitioner (Biokineticist, Medical Doctor, Physiotherapist etc) yesterday? If yes, what was the consultation about?

Yes No

Appendix B

Total Recovery Score and Subjective fatigue questionnaire

Discard changes | Print　　　　**Ruan Rust |**

General Monitoring Questionnaire

Question 1 of 20

Did you train yesterday?

○ Yes ○ No

Question 2 of 20

Please report your body mass this morning:

[ ] kg

Question 3 of 20

How would you rate your level of general fatigue this morning?

Question 4 of 20

Rate your recovery from your previous training session

Question 5 of 20

Have you done any of the following to supplement your recovery in the past 24 hours?

☐ A. Ice Baths

☐ B. Stretching

☐ C. Massage

☐ D. Pool Session

☐ E. Compression Garments

☐ F. I did something for recovery that is not mentioned above

Question 6 of 20

Have you eaten regularly and in adequate amounts in the past 24 hours?

Question 7 of 20

In the previous 24 hours have you had a recovery meal/shake within 60 minutes after training?

Question 8 of 20

How would you rate your fluid intake in the last 24 hours?

Question 9 of 20

In the previous 24 hours have you spent enough time doing activities which you find relaxing and enjoy? e.g. Reading, TV, cards or facebook?

○ Yes ○ No

Question 10 of 20

How would you rate your quality of sleep in the past 24 hours?

Question 11 of 20

Have you had any of the following symptoms or conditions in the past 24 hours?

☐ A. Headache

☐ B. Diarrhoea

☐ C. Cough

☐ D. Cold/Flu

☐ E. Sore Throat

☐ F. Achy Joints

Any additional symptoms of sickness or conditions not listed above?

Appendix C

Ethics form for the Western Province Rugby Institute's Database

The names and details of all persons with access to the data base.

Western Province Rugby Institute
Medical and Sport Science Department
0837960040
jo@sastraining.co.za

Ruan Rust
Division of Exercise Science and Sports Medicine,
Department of Human Biology,
University of Cape Town.
0843416714
rstrua001@myuct.ac.za

Johan van Wyk
Western Province Rugby Institute
Medical and Sport Science department
0837960040
jo@sastraining.co.za

Llewellyn Morkel
Western Province Rugby Institute
Medical and Sport Science department
0827363331
Llewellyn@sastraining.co.za

Professor Mike Lambert,
Division of Exercise Science and Sports Medicine,
Department of Human Biology,
University of Cape Town.
0826594858
mike.lambert@uct.ac.za

1. The sample population.

All players part of the Western Province Rugby Institute.

2. **Source of the data.**
   Medical records, data submitted to Player Monitoring and Assessment System (AMAS), Recovery data (heart rate recovery data and vertical jump/standing broad jump data).

3. **The process of the data collection.**
   Medical data:

   Players undergo a musculoskeletal screening at the beginning of each year, weak links are identified and short and long-term goals are set for each player. Johan van Wyk monitors short and long-term injuries by arranged injury report meetings every day. The injury data includes date injured, date back on field, diagnoses, referrals and mechanism of injury. The physiotherapists also keep treatment notes of each injury.

   Individual rehabilitation sessions are accounted for in the physiotherapy treatment notes.

   AMAS data:

   Each player was added to the AMAS system, where the Player is required to answer 20 questions ranging from training intensity, training duration, recovery modalities; self reported fatigue and subjective muscle soreness.

   Variables monitored are as follows:
   - Accumulative total training load per player
   - Accumulative weekly training load per players
   - Accumulative total training load per phase of training (mesocycle)
   - Changes in modalities of training (resistance vs. field vs. cardio) throughout phases of training.
   - Self reported fatigue
   - Recovery modalities

   Recovery data:

   Every Monday morning, all players will undergo the HIMS test (3 x 2minute shuttle runs incremental in nature with a 1 minute rest period between shuttles) , whereby heart rate recovery will be measured , this will be done through the use of a heart rate monitor. In conjunction with the HIMS test, all players will have three jumps to record a maximum jump height (countermovement jump).

4. **Personal data that are collected.**

Name, Date of birth, age, gender, area in which they live, ID number, medical aid details.

5. **How the data are protected so that confidentiality is maintained.**
   The only people with access are the staff members in section 1.

   Paper Based: It is stored in a filing cabinet in the WPRI physiotherapy practice.
   Electronic: Protection of all electronic access is by passwords.

6. **What happens to data once it is no longer needed for research or audit.**
   The paper copies will be stored at MRC/UCT research Unit for Exercise Science and sports Medicine and disposed after 10 years.
   The electronic data will be kept for future inquiries.

7. **Permission to access the player's records from the person who is responsible for the records.**
   Permission is obtained from the head of the Medical and Sport Science department of the Western Province Rugby Institute.

8. **Intended Use of the Database: Methods/Aims: Expected medical, scientific and research benefits.**
   Medical, Scientific

   - The purpose of the database is to provide feedback to the WPRI Staff (physiotherapists, conditioning coaches and rugby coaches) with regards optimal player management (integration of training, recovery, competition and treatment),
   - Information on periodization of training
   - Provides information on maximal amount of load players are able to tolerate without a soft tissue injury.
   - Generate a training threshold, whereby maximal load can be safely prescribed.
   - Database provides a check on clinical practice and player management.
   - Data on injuries also helps the WPRI medical department to observe cluster

   Research benefits

All the information described above has relevance for research, in particular determining the cause-effect relationships between training load, recovery and soft tissue injuries.

9. The process for releasing information on the database to fellow researchers.

All WPRI staff of the Medical and sports Science department will have access to the data. The authorship of any publications arising from these data will be discussed at the onset of a project.

10. Informed consent.

- Informed consent was not obtained for the player's data to be used for research was not obtained. This permission will be obtained in retrospect (the informed consent form follows below)
- The benefits to the players will be noticed once the data are analysed. There are two main areas, (i) prevention of lowering risk of injury, (ii) creating thresholds whereby maximum load can be tolerated safely.

Appendix D

Informed Consent Form

Dear Participant

I, Ruan Rust, will be conducting a study to describe the changes in total training load, recovery scores and its relationship with soft tissue injuries during a full season. All the data collected during the 2015 season where you were part of the Western Province u/19 squad will be used for this purpose. The following data will form part of the study:

- Injuries- Diagnoses
  Time missed from on-field rugby
  Referrals
  Mechanism of injury
- Training duration: Strength and conditioning sessions.
  Rugby field sessions
  Conditioning sessions
  Rehabilitations sessions
  Matches
- Training intensity: Strength and conditioning sessions.
  Rugby field sessions
  Conditioning sessions
  Rehabilitations session
  Matches
- Subjective fatigue
- Recovery modalities - Nutrition and health
  - Relaxation
  - Sleep and rest
- Recovery Scores - Heart Rate Recovery
  - Neuromuscular fatigue (vertical jump)

By placing your signature below it serves as confirmation that you have had adequate time to ask questions about the study and are willing that your data are used for analysis. You have the right to withdraw your data at any time, you may ask questions at any time during the study and all the information recorded is confidential. Your identity will not ever be disclosed in the data analysis.

____________________ _______________________ _________

Signature of Volunteer Name (Please Print) Date

____________________ ___________________________ _________

Signature of Witness Name (Please Print) Date

____________________ Ruan Rust _________

Signature of Investigator Name (Please Print) Date

If you have any queries you are welcome to contact either:

Professor Mike Lambert,
Division of Exercise Science and Sports Medicine,
Department of Human Biology,
University of Cape Town,
Tel: 021-6504550
E-mail: Mike.Lambert@uct.ac.za

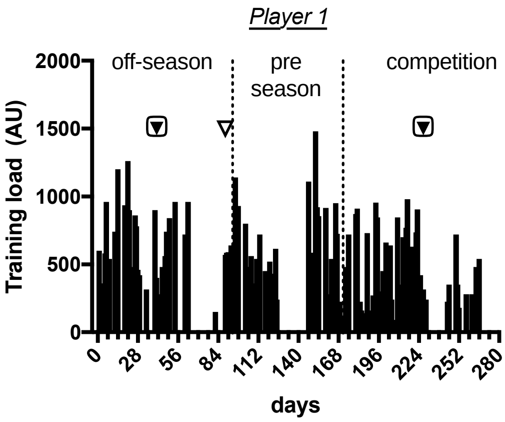
Or

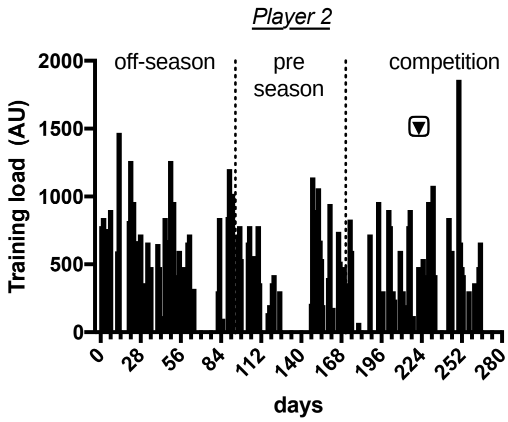
Faculty of Health Sciences Human Research and Ethics Committee:

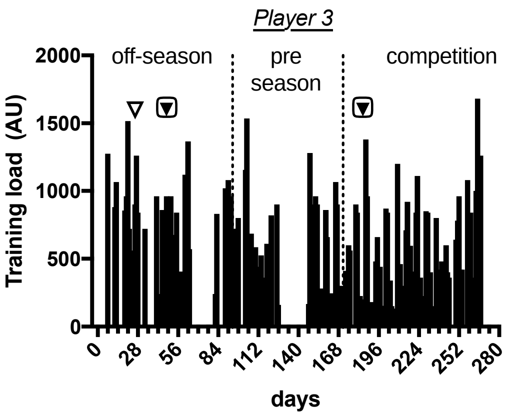
Professor Marc Blockman
Faculty of Health Sciences Human Research and Ethics Committee
University of Cape Town
Tel: 021 406 6492
E-mail: marc.blockman@uct.ac.za

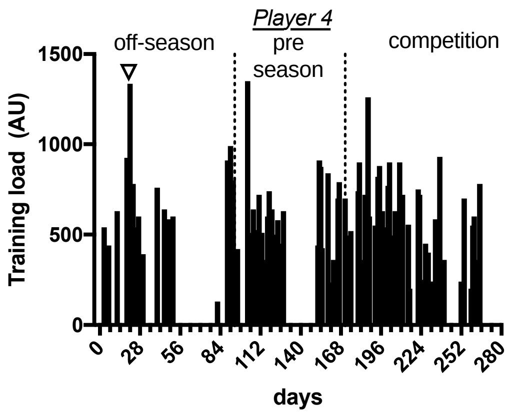
Appendix E

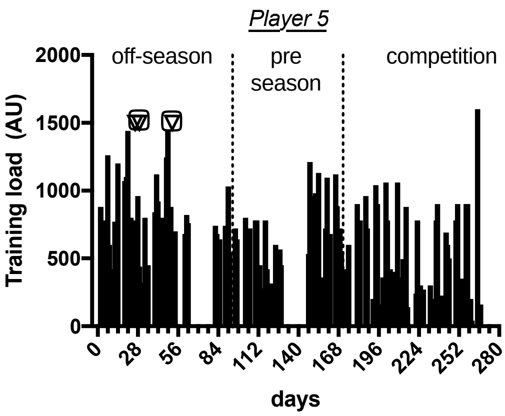
Individual Subjective Total Training load graphs

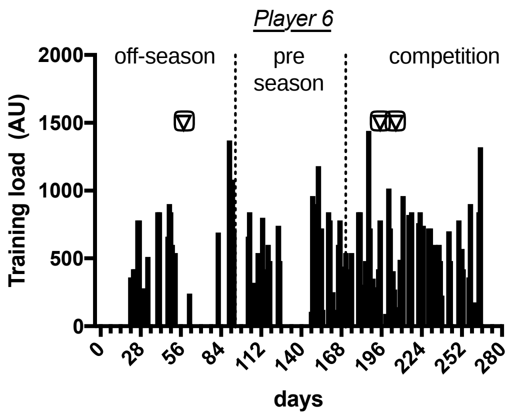


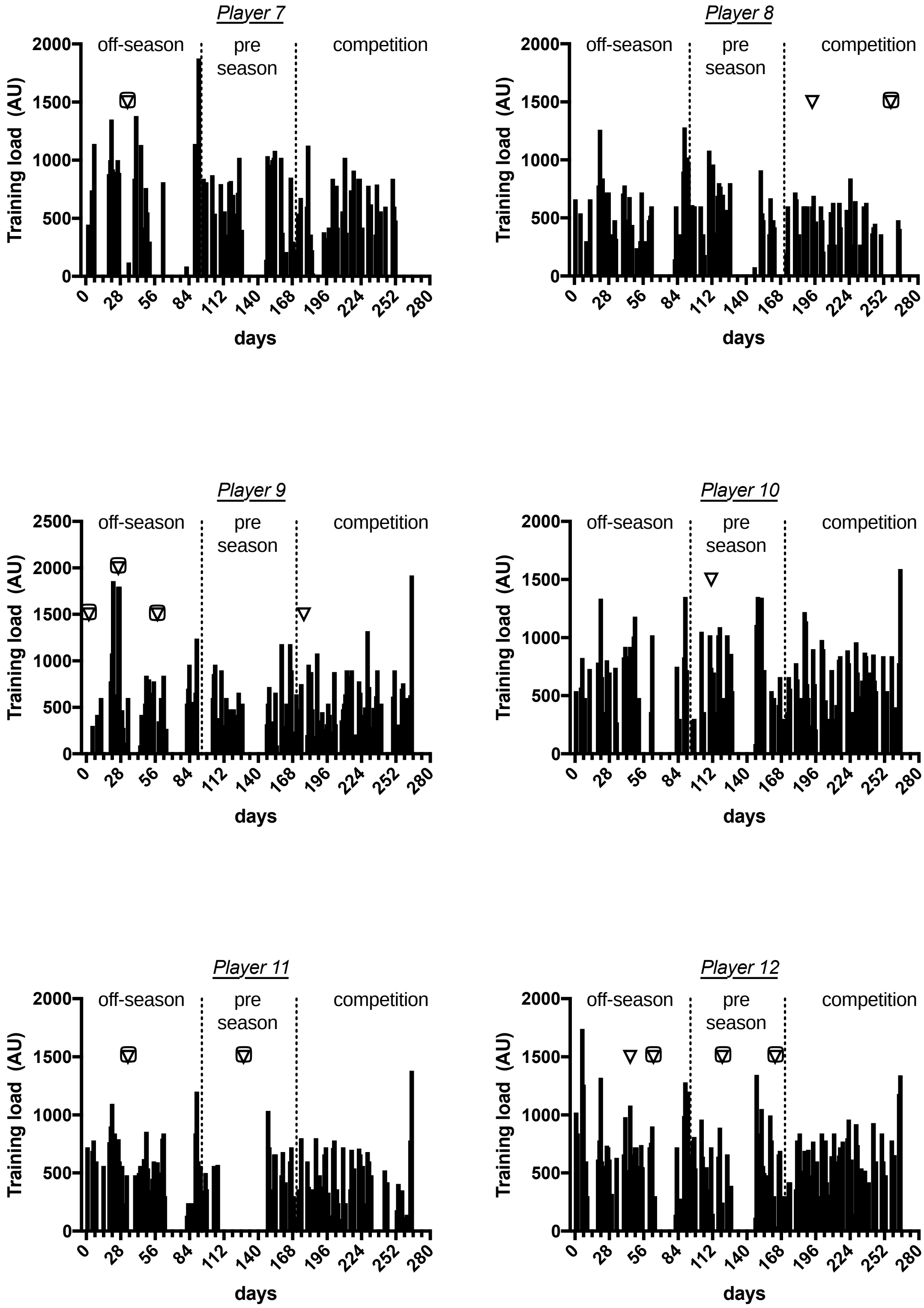


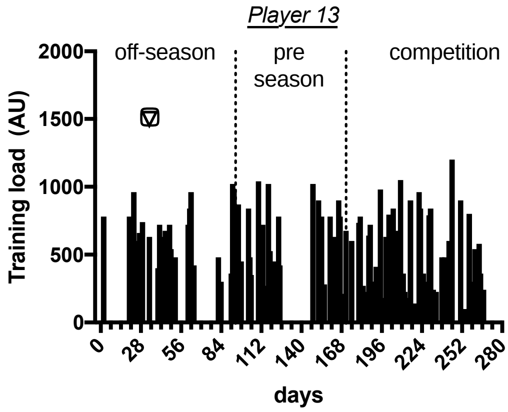


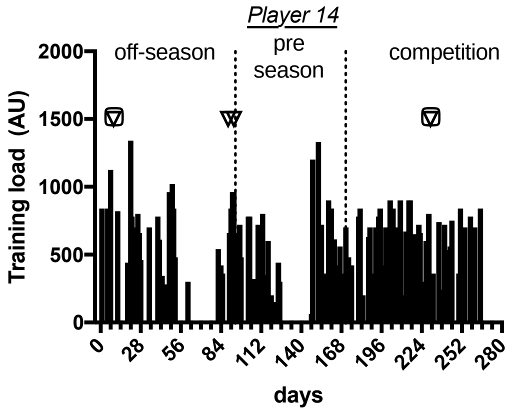


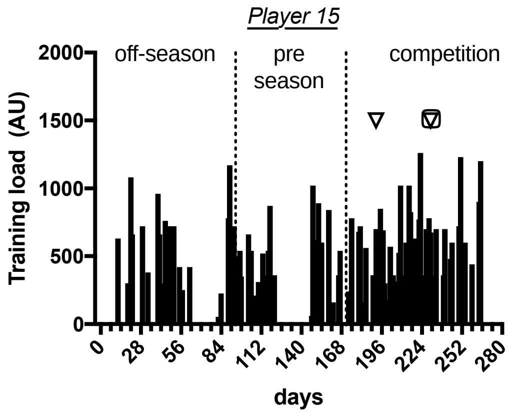


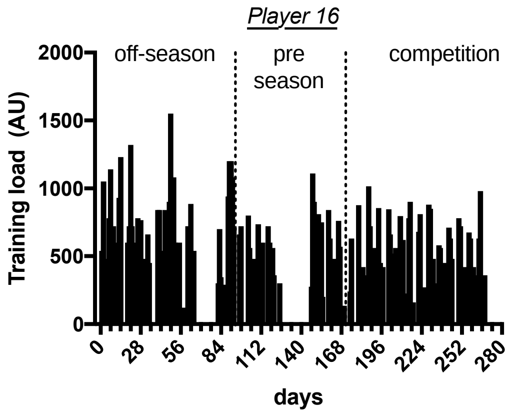


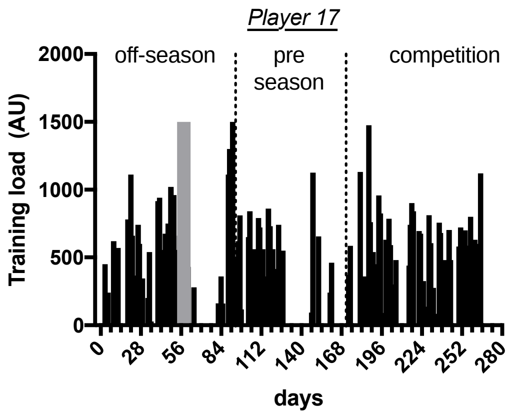

Player 7
Player 8
Player 9
Player 10
Player 11
Player 12
off-season
pre season
competition
Training load (AU)
days

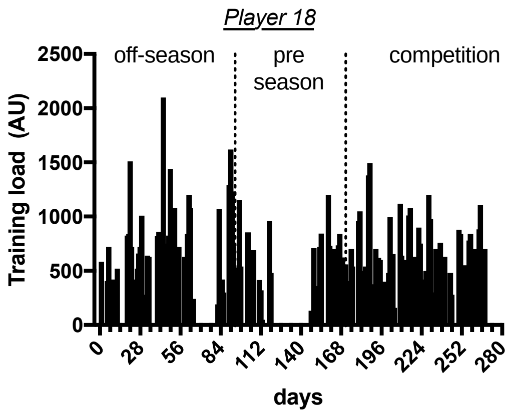

Player 13
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

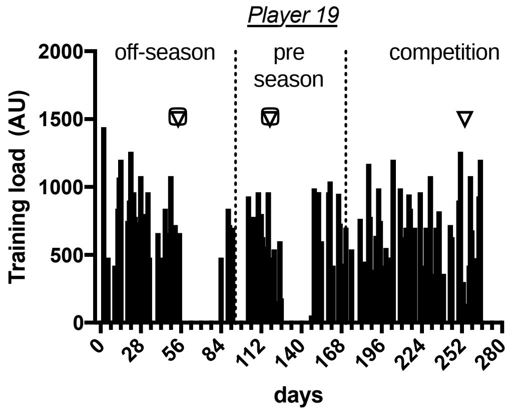

Player 14
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

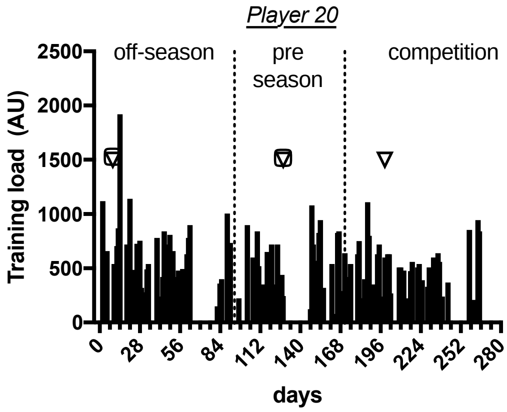

Player 15
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

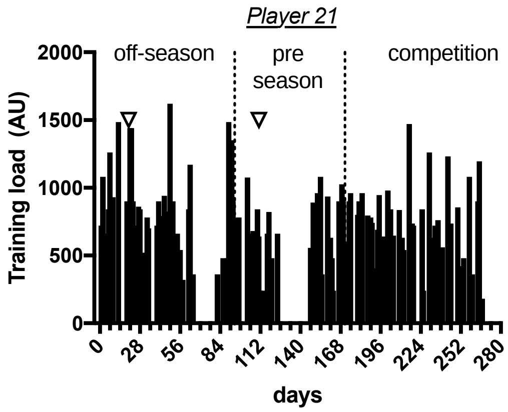

Player 16
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

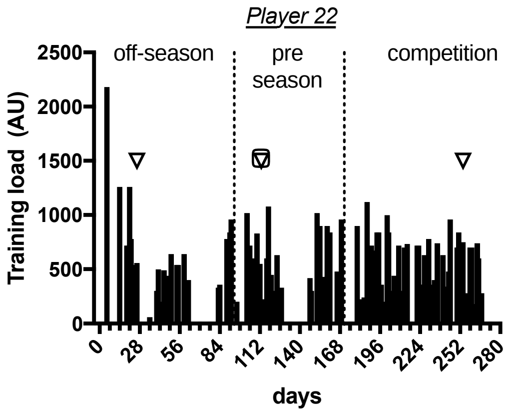

Player 17
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

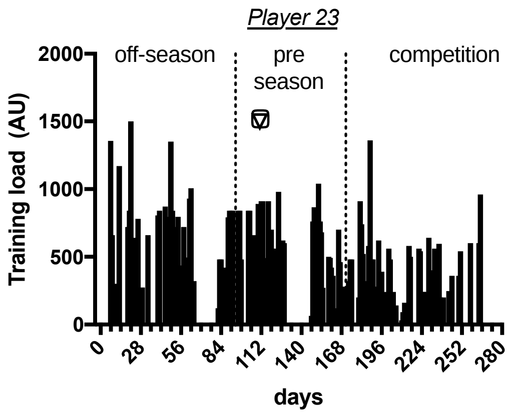

Player 18
off-season
pre season
competition
Training load (AU)
2500
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

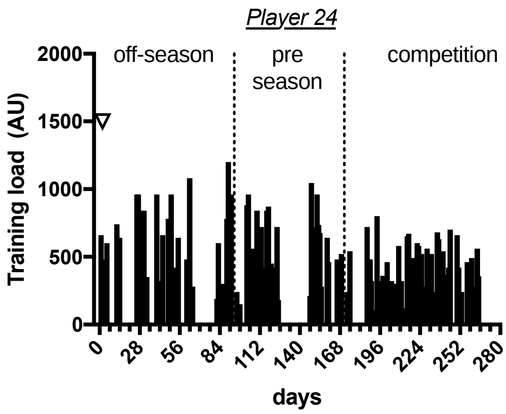

Player 19
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

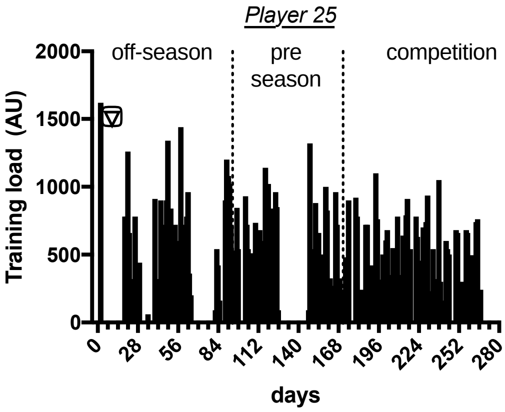

Player 20
off-season
pre season
competition
Training load (AU)
2500
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

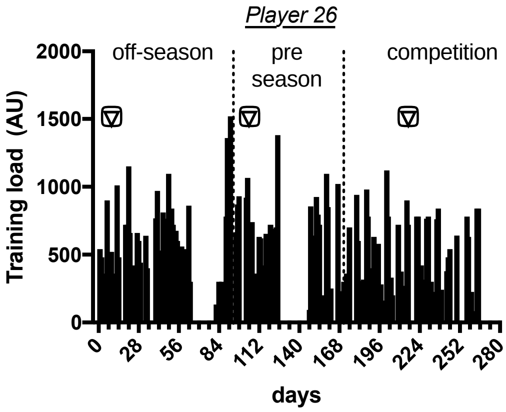

Player 21
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

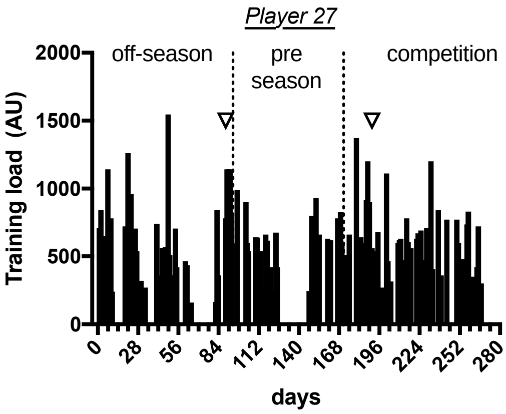

Player 22
off-season
pre season
competition
Training load (AU)
2500
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

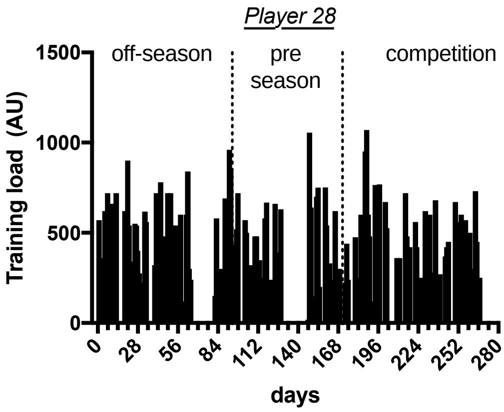

Player 23
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

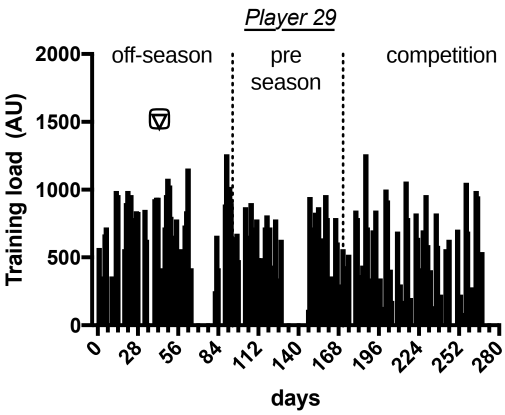

Player 24
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

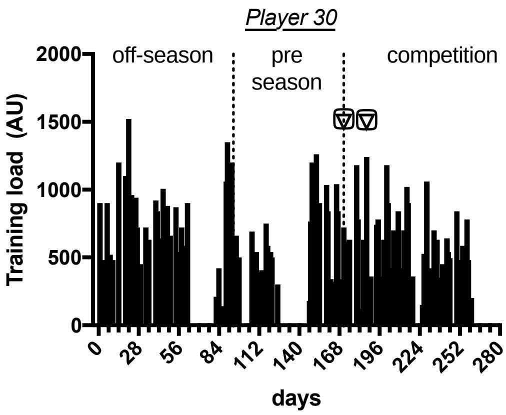

Player 25
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

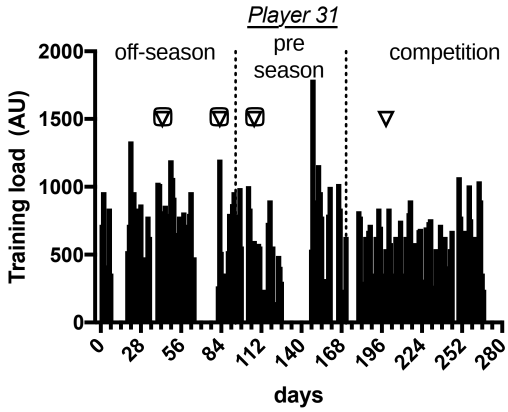

Player 26
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

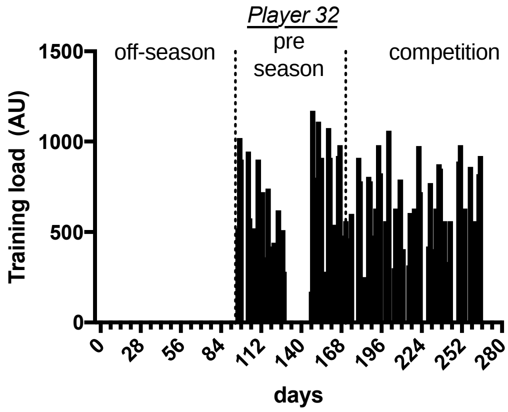

Player 27
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

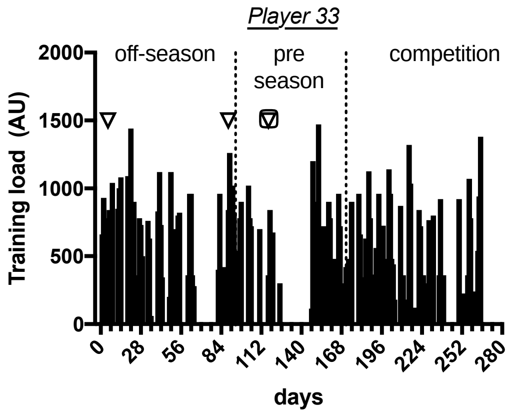

Player 28
off-season
pre season
competition
Training load (AU)
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

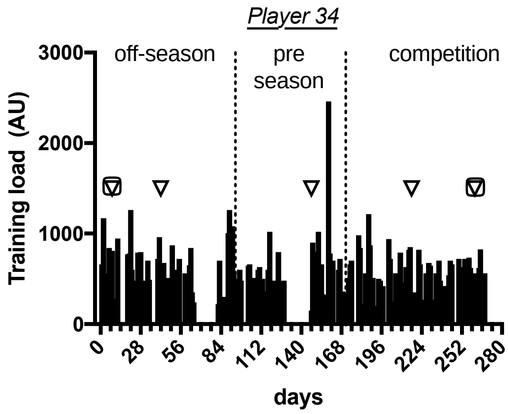

Player 29
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

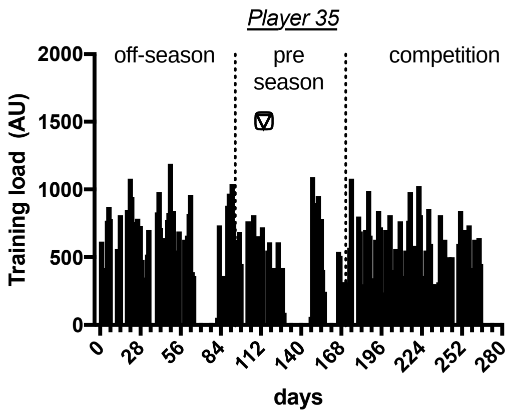

Player 30
off-season
pre season
competition
Training load (AU)
2000
1500
1000
500
0
0 28 56 84 112 140 168 196 224 252 280
days

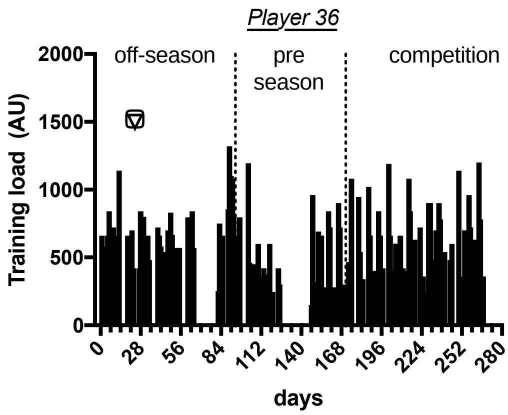

Player 31
off-season
pre season
competition
Training load (AU)
0
500
1000
1500
2000
days
0 28 56 84 112 140 168 196 224 252 280


Player 32
off-season
pre season
competition
Training load (AU)
0
500
1000
1500
days
0 28 56 84 112 140 168 196 224 252 280


Player 33
off-season
pre season
competition
Training load (AU)
0
500
1000
1500
2000
days
0 28 56 84 112 140 168 196 224 252 280

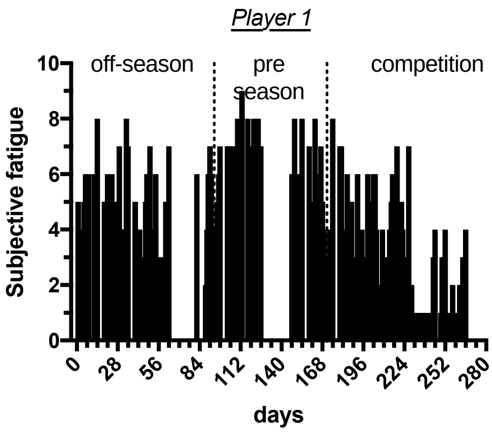

Player 34
off-season
pre season
competition
Training load (AU)
0
1000
2000
3000
days
0 28 56 84 112 140 168 196 224 252 280

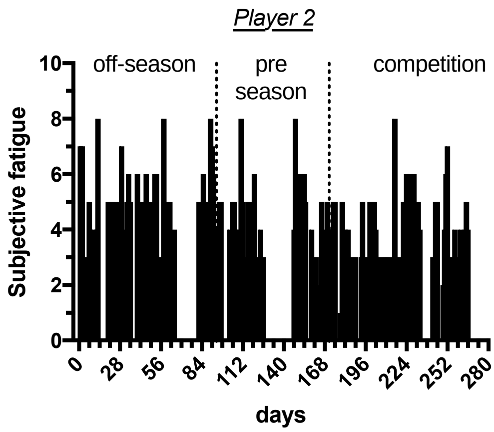

Player 35
off-season
pre season
competition
Training load (AU)
0
500
1000
1500
2000
days
0 28 56 84 112 140 168 196 224 252 280

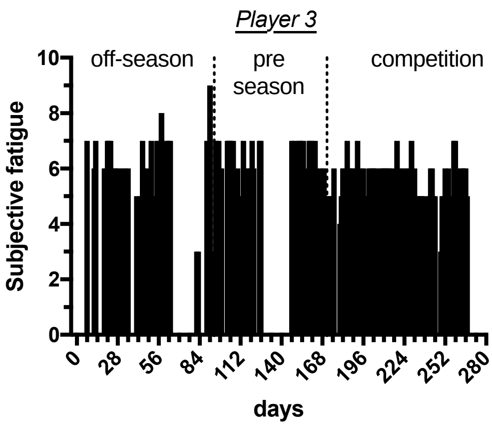

Player 36
off-season
pre season
competition
Training load (AU)
0
500
1000
1500
2000
days
0 28 56 84 112 140 168 196 224 252 280

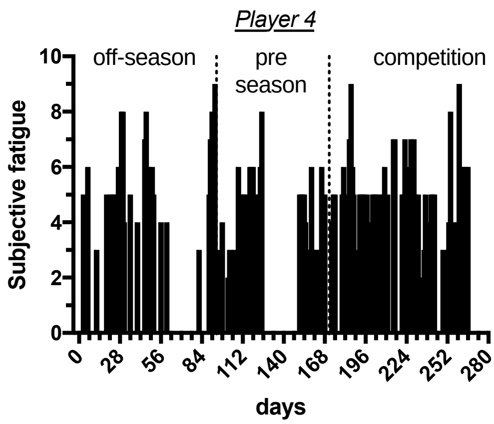
Appendix F

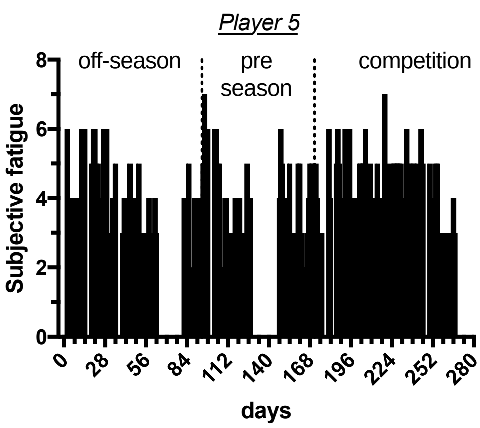
Individual Subjective Fatigue graphs

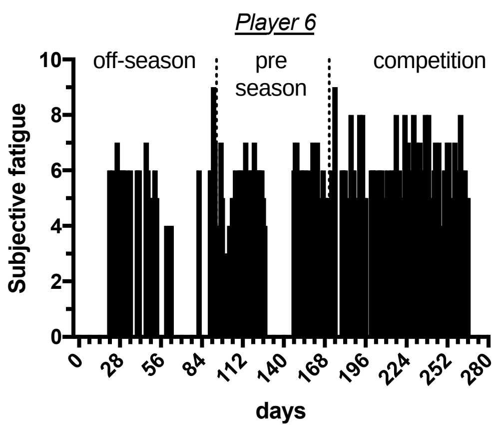


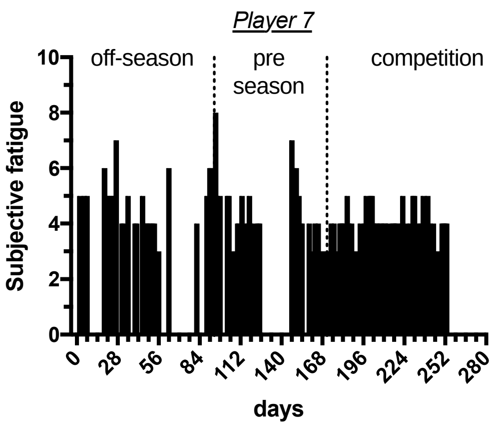


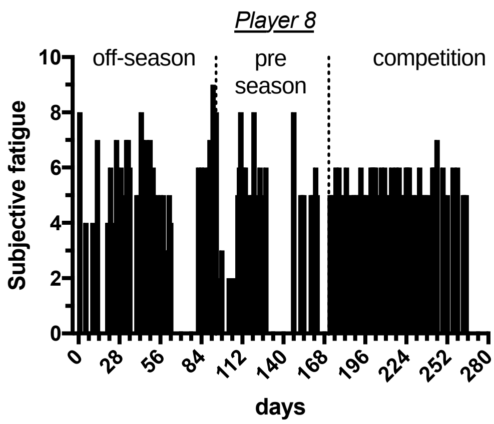


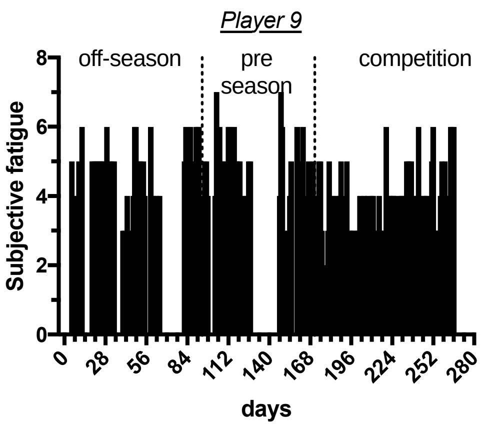


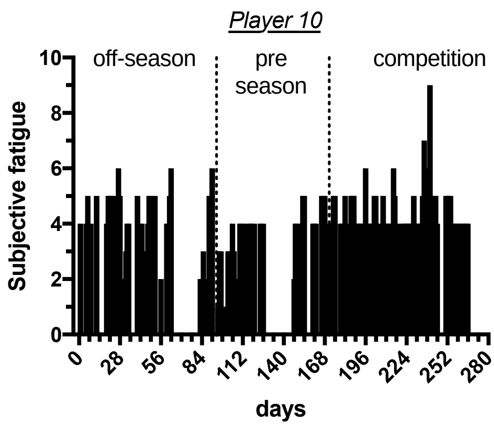


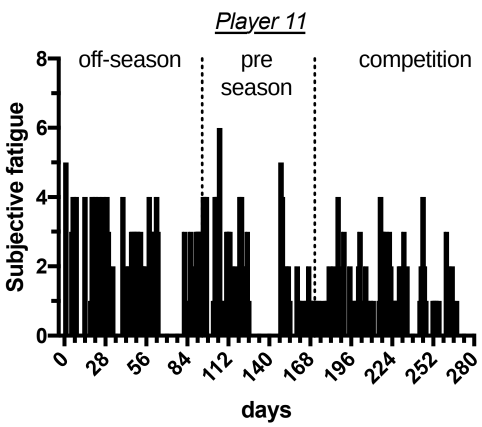


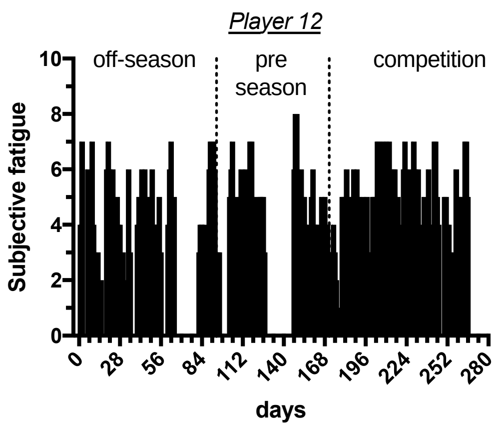

Player 7
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days

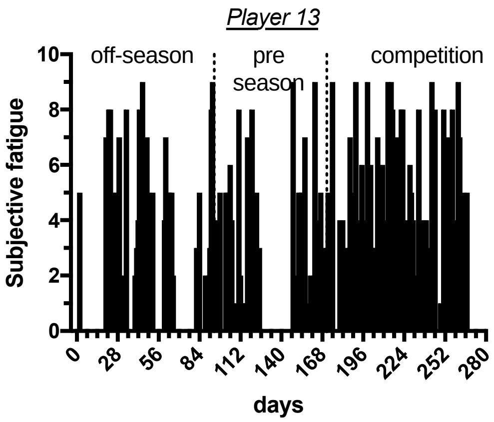

Player 8
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days

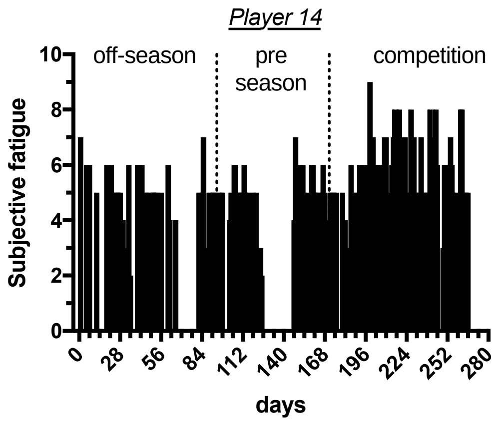

Player 9
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8
0 28 56 84 112 140 168 196 224 252 280
days

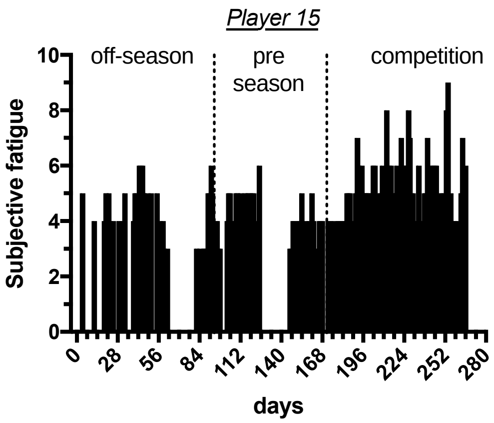

Player 10
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days

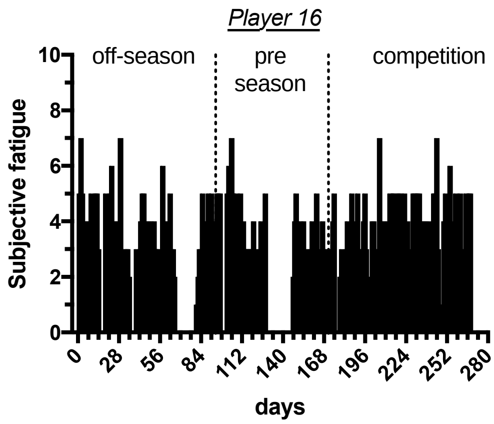

Player 11
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8
0 28 56 84 112 140 168 196 224 252 280
days

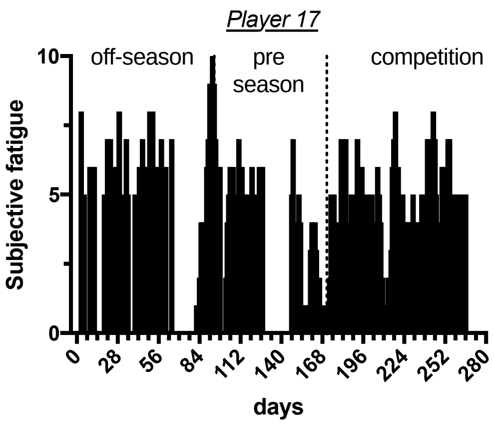

Player 12
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days

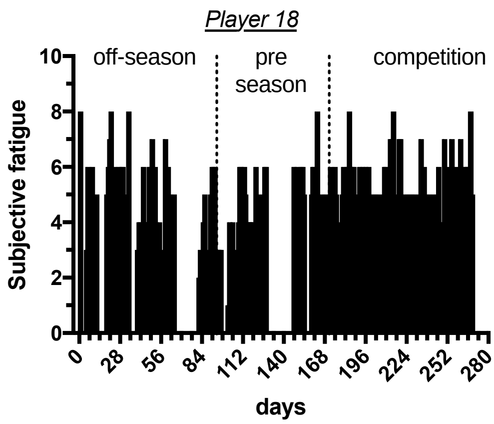

Player 13
off-season
pre season
competition
Subjective fatigue
days
0 28 56 84 112 140 168 196 224 252 280
0 2 4 6 8 10


Player 14
off-season
pre season
competition
Subjective fatigue
days
0 28 56 84 112 140 168 196 224 252 280
0 2 4 6 8 10

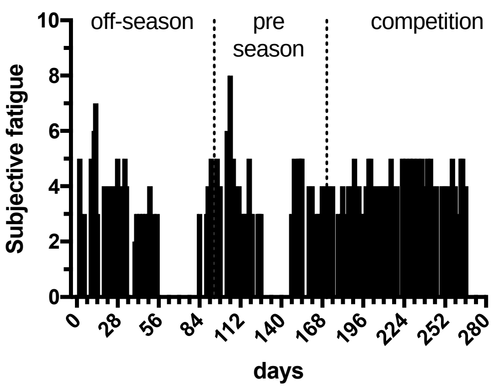

Player 15
off-season
pre season
competition
Subjective fatigue
days
0 28 56 84 112 140 168 196 224 252 280
0 2 4 6 8 10


Player 16
off-season
pre season
competition
Subjective fatigue
days
0 28 56 84 112 140 168 196 224 252 280
0 2 4 6 8 10

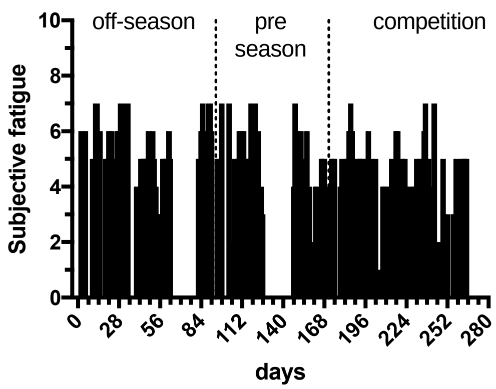

Player 17
off-season
pre season
competition
Subjective fatigue
days
0 28 56 84 112 140 168 196 224 252 280
0 5 10


Player 18
off-season
pre season
competition
Subjective fatigue
days
0 28 56 84 112 140 168 196 224 252 280
0 2 4 6 8 10

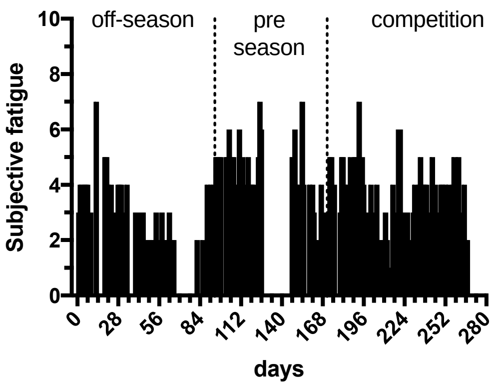
Player 19



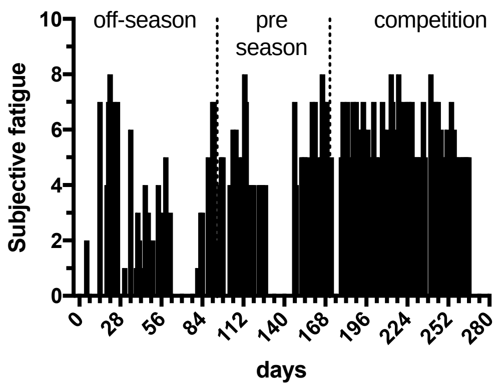
Player 20



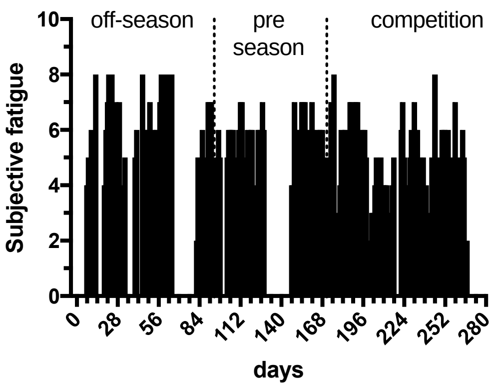
Player 21



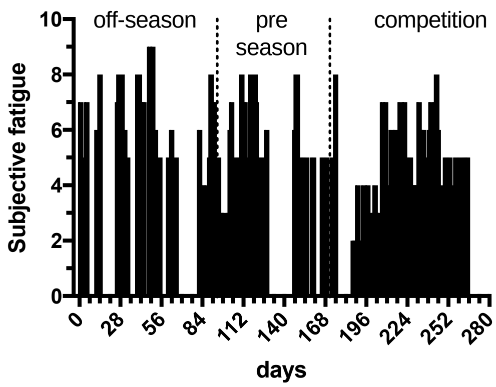
Player 22

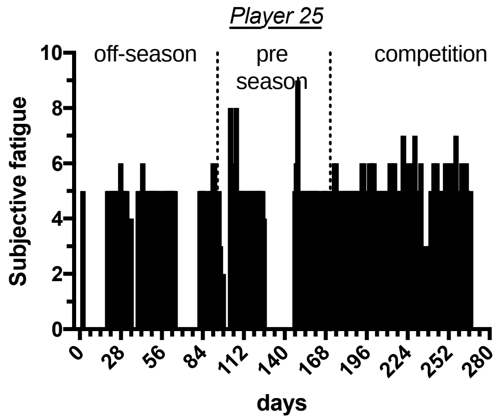


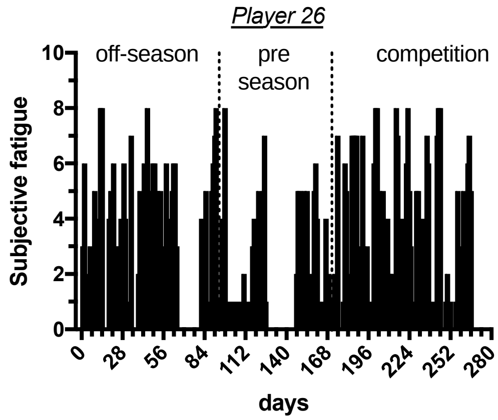
Player 23

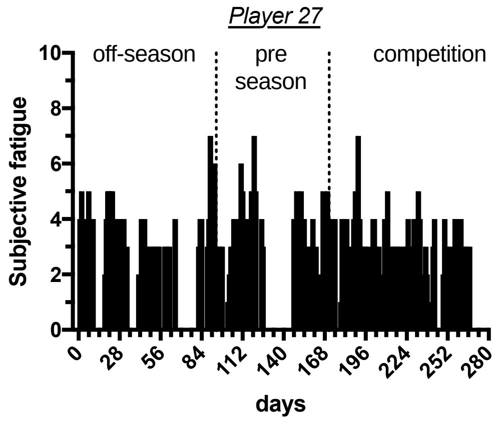


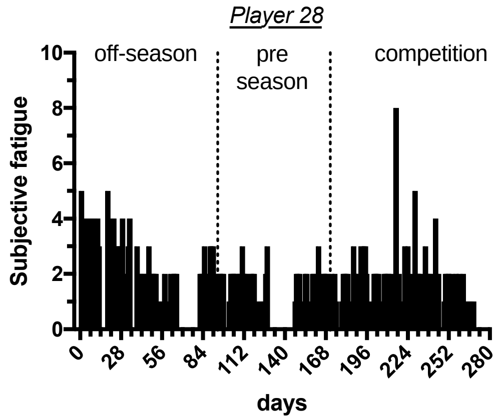
Player 24

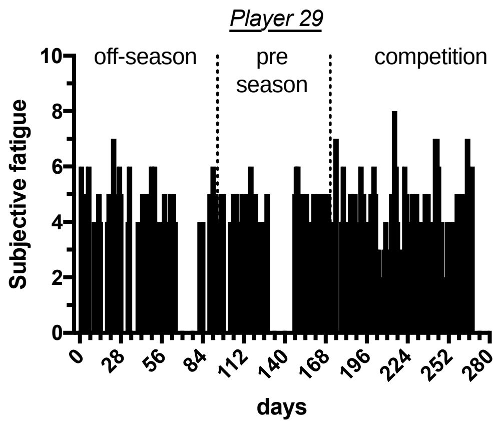


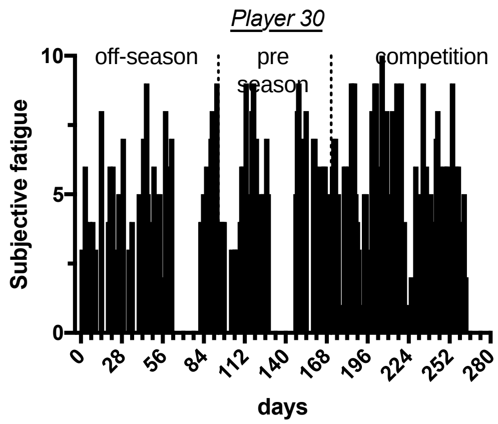

Player 25
off-season
pre season
competition
Subjective fatigue
0
2
4
6
8
10
0
28
56
84
112
140
168
196
224
252
280
days

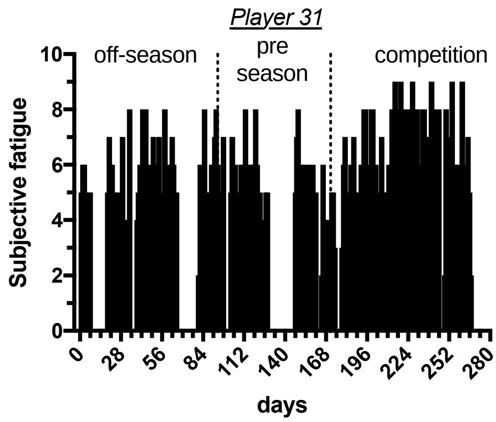

Player 26
off-season
pre season
competition
Subjective fatigue
0
2
4
6
8
10
0
28
56
84
112
140
168
196
224
252
280
days

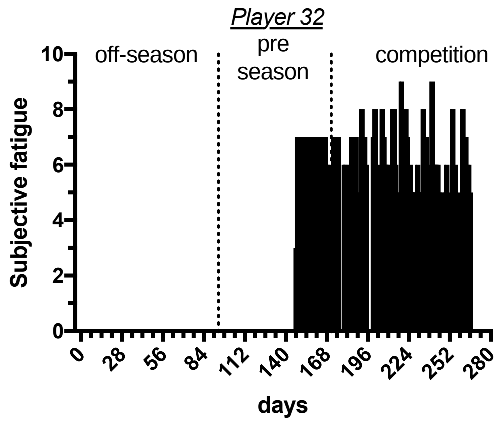

Player 27
off-season
pre season
competition
Subjective fatigue
0
2
4
6
8
10
0
28
56
84
112
140
168
196
224
252
280
days

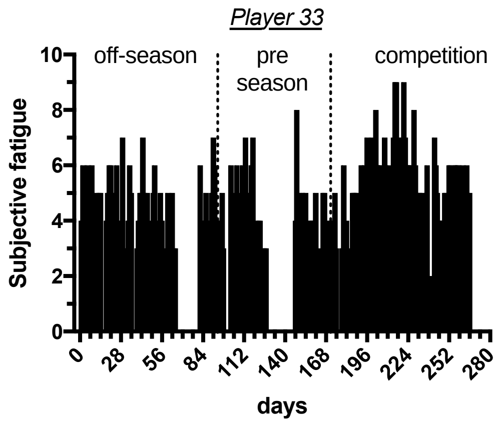

Player 28
off-season
pre season
competition
Subjective fatigue
0
2
4
6
8
10
0
28
56
84
112
140
168
196
224
252
280
days

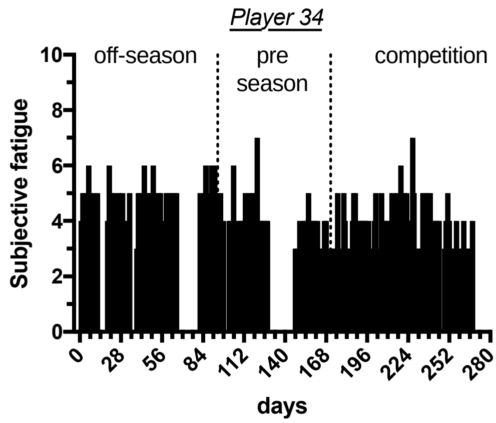

Player 29
off-season
pre season
competition
Subjective fatigue
0
2
4
6
8
10
0
28
56
84
112
140
168
196
224
252
280
days

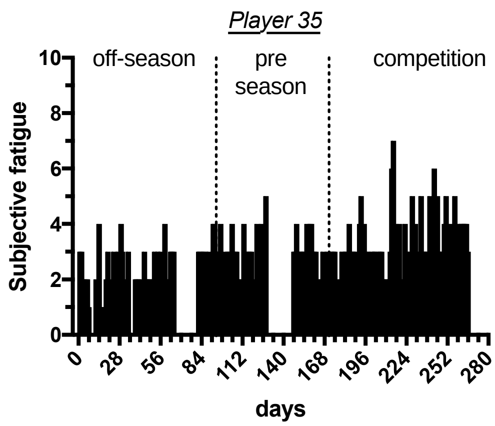

Player 30
off-season
pre season
competition
Subjective fatigue
0
5
10
0
28
56
84
112
140
168
196
224
252
280
days

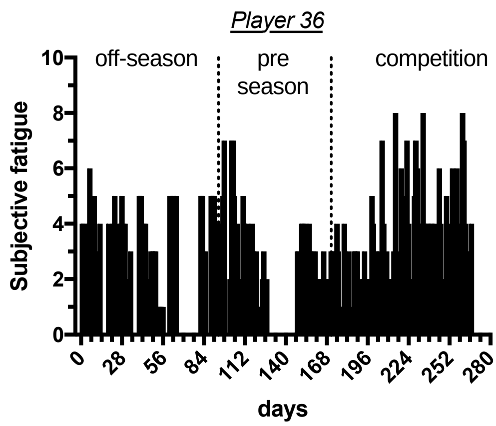

Player 31
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days


Player 32
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days


Player 33
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days

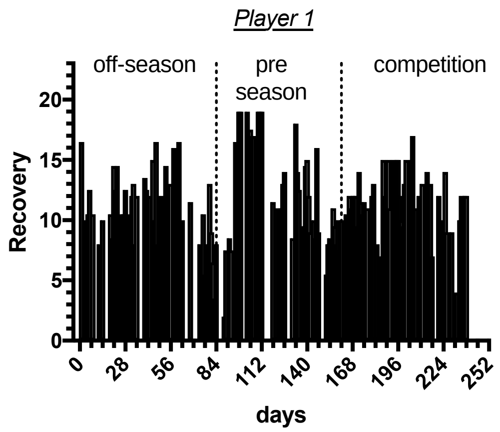

Player 34
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days

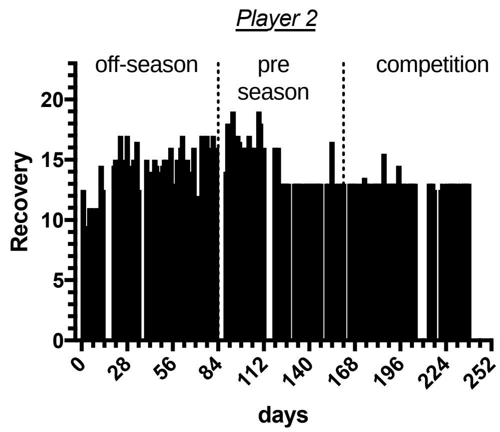

Player 35
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days

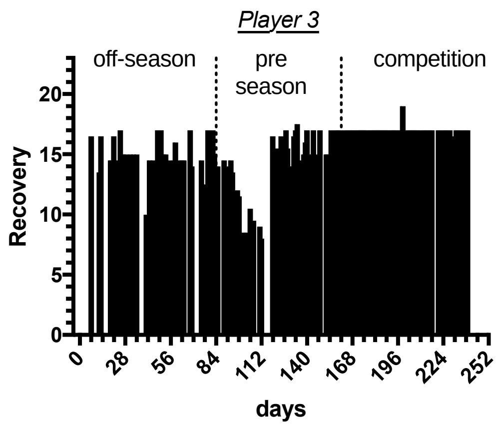

Player 36
off-season
pre season
competition
Subjective fatigue
0 2 4 6 8 10
0 28 56 84 112 140 168 196 224 252 280
days

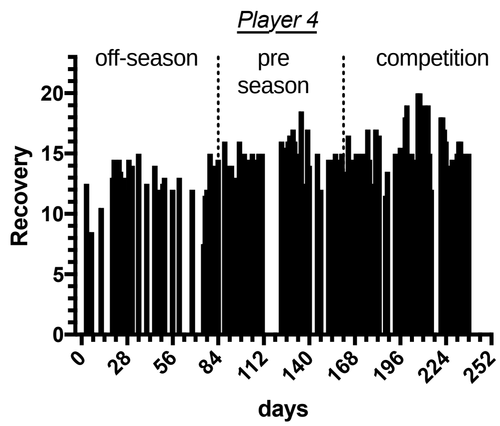
Appendix G

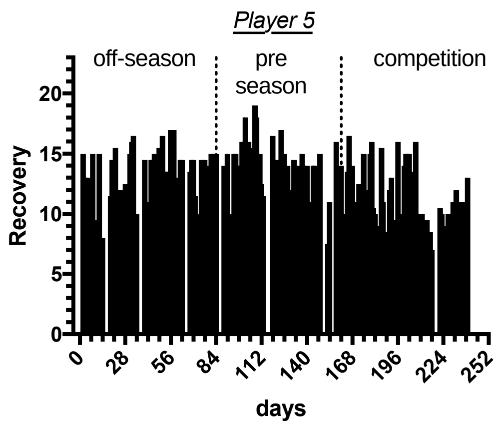
Individual Composite Recovery graphs

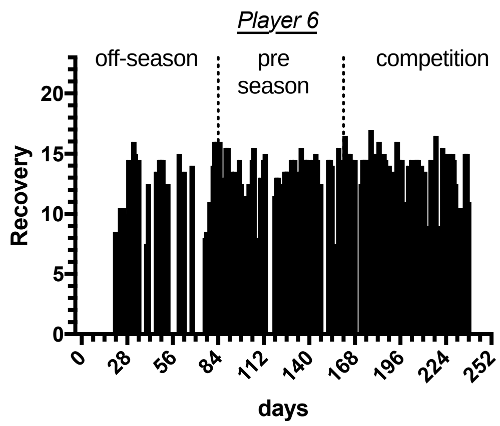


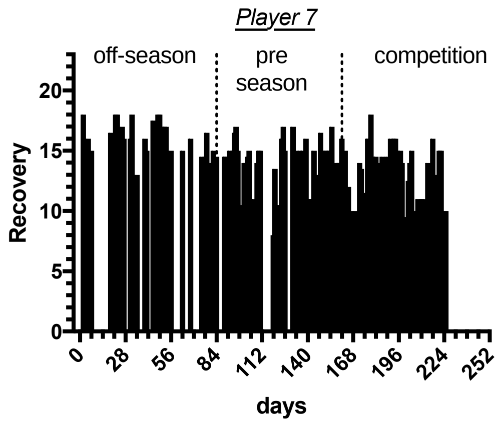


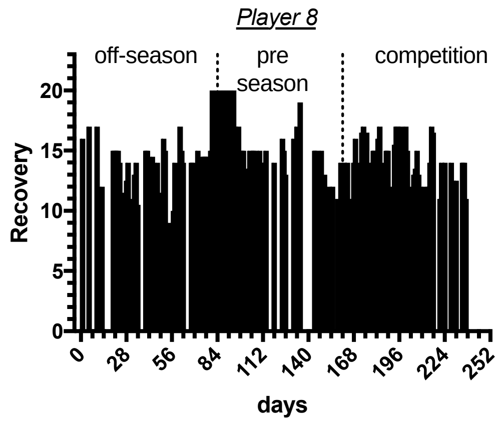


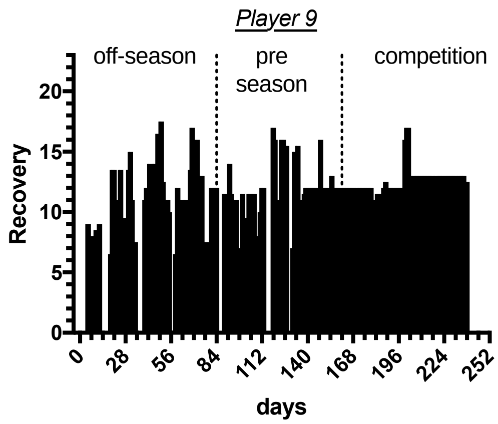


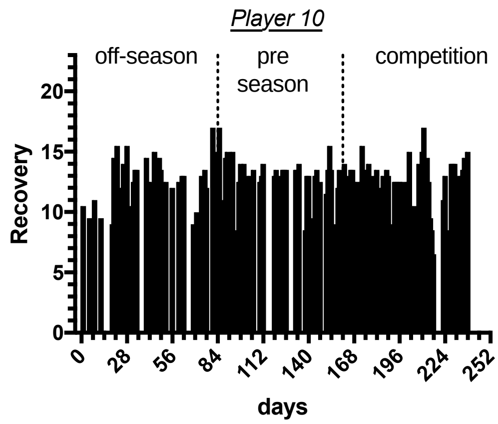


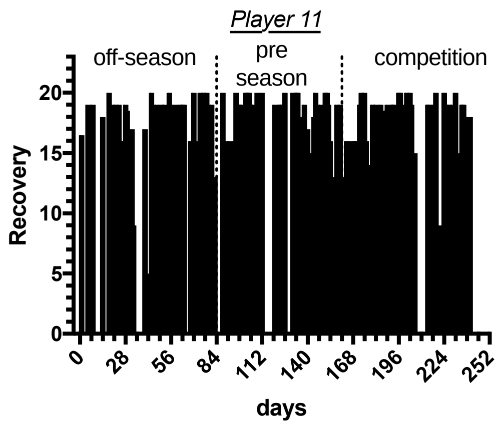


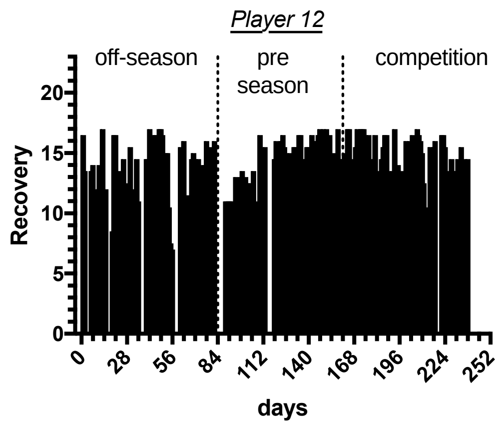

Player 7
off-season
pre season
competition
Recovery
0
5
10
15
20
days
0 28 56 84 112 140 168 196 224 252

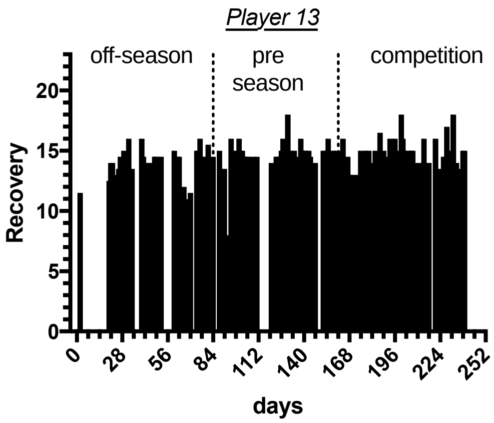

Player 8
off-season
pre season
competition
Recovery
0
5
10
15
20
days
0 28 56 84 112 140 168 196 224 252

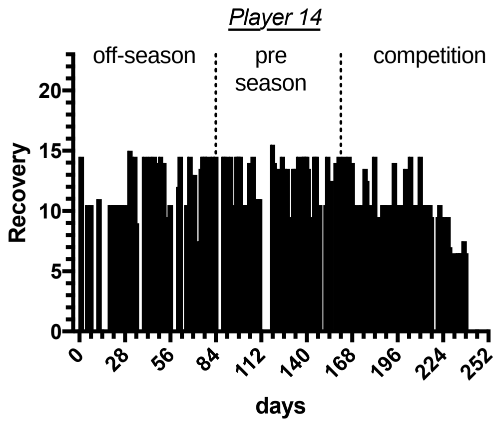

Player 9
off-season
pre season
competition
Recovery
0
5
10
15
20
days
0 28 56 84 112 140 168 196 224 252

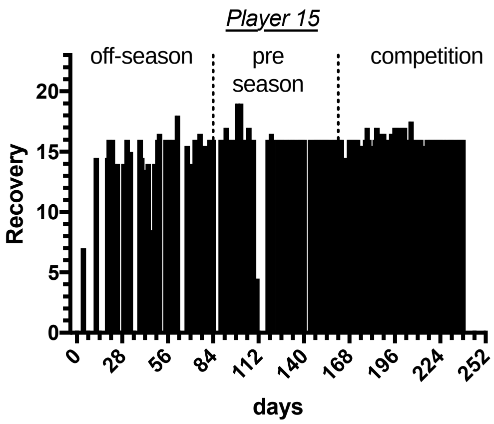

Player 10
off-season
pre season
competition
Recovery
0
5
10
15
20
days
0 28 56 84 112 140 168 196 224 252

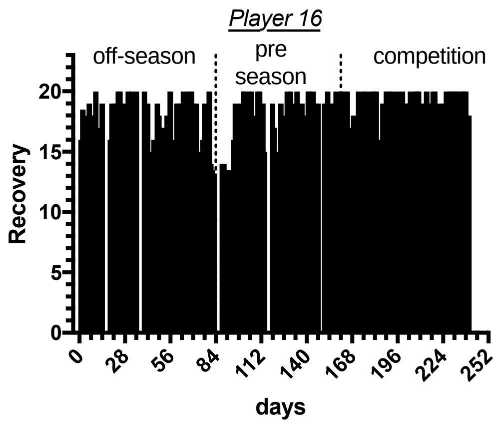

Player 11
off-season
pre season
competition
Recovery
0
5
10
15
20
days
0 28 56 84 112 140 168 196 224 252

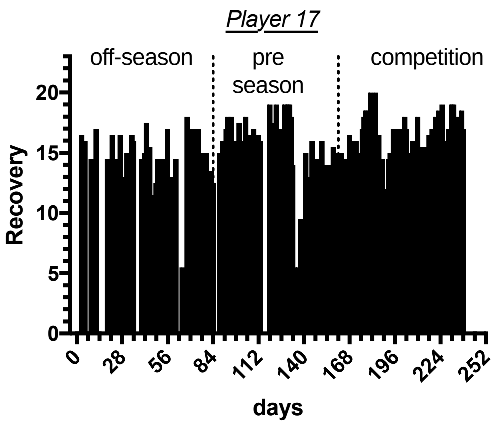

Player 12
off-season
pre season
competition
Recovery
0
5
10
15
20
days
0 28 56 84 112 140 168 196 224 252

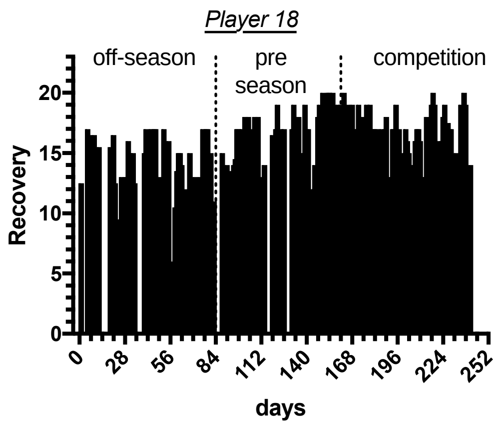

Player 13
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

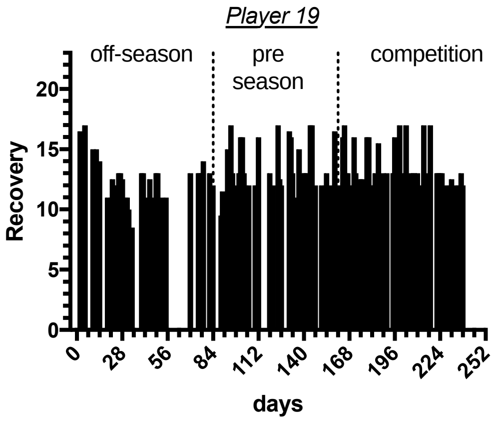

Player 14
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

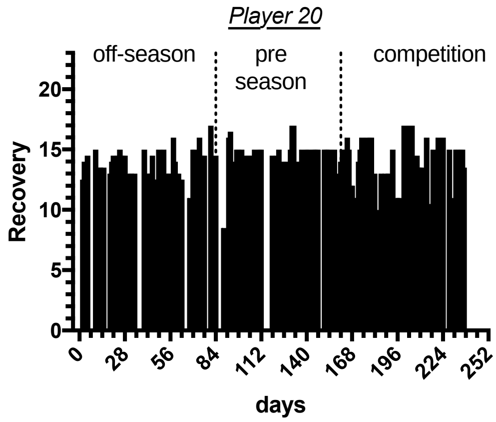

Player 15
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

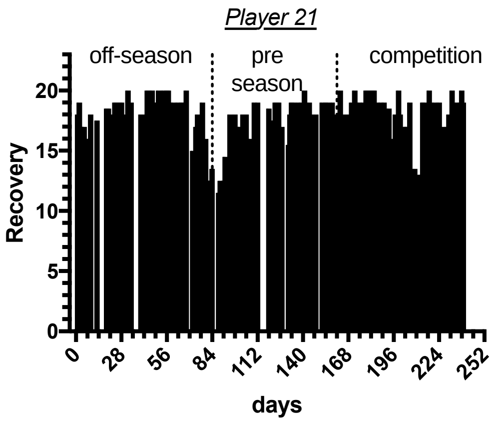

Player 16
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

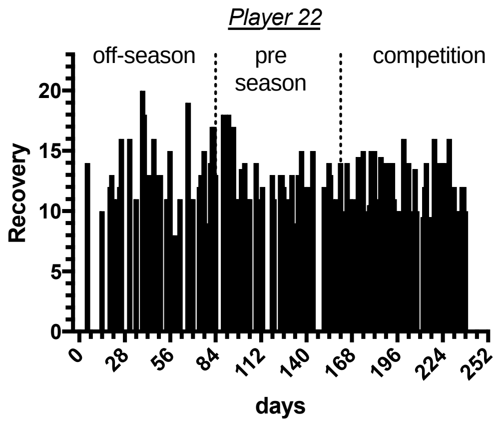

Player 17
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

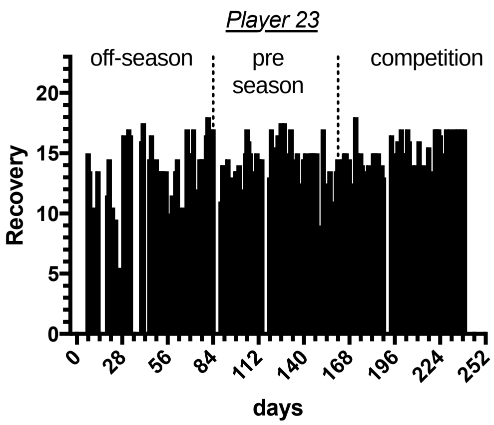

Player 18
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

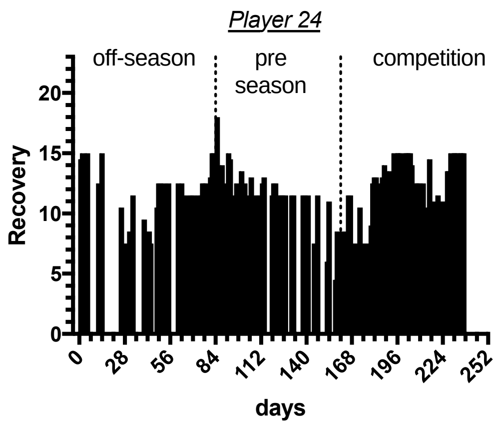

Player 19
off-season
pre
season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

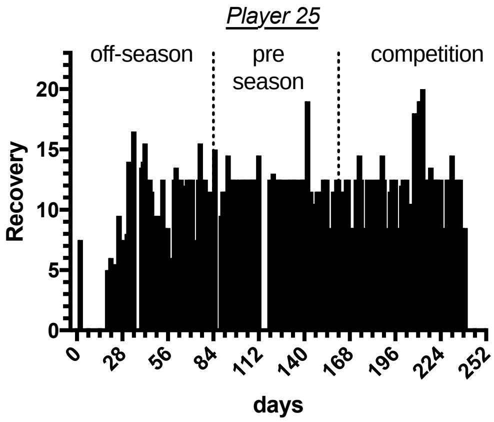

Player 20
off-season
pre
season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

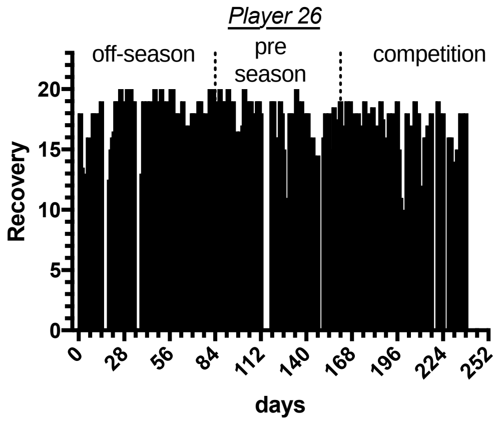

Player 21
off-season
pre
season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

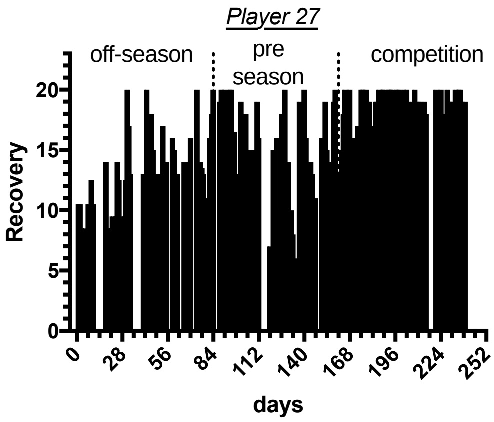

Player 22
off-season
pre
season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

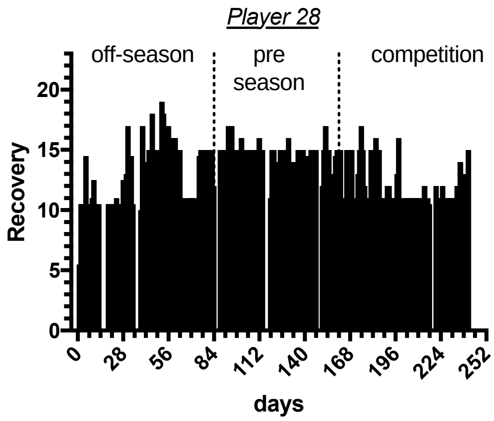

Player 23
off-season
pre
season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

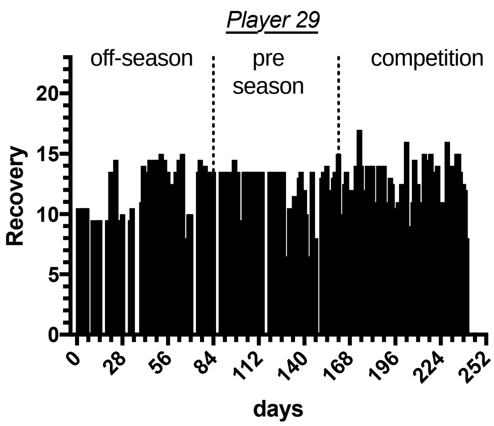

Player 24
off-season
pre
season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

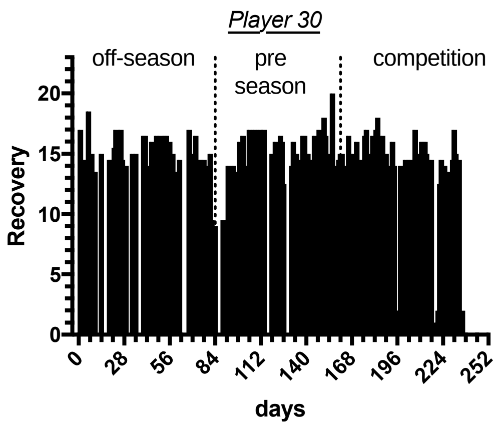

Player 25
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

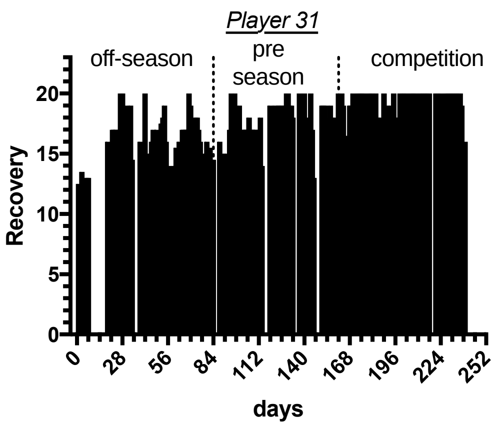

Player 26
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

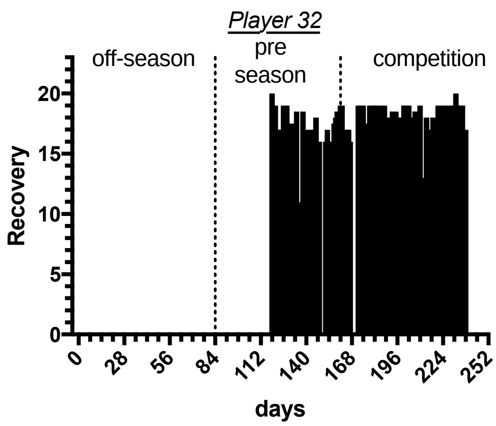

Player 27
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

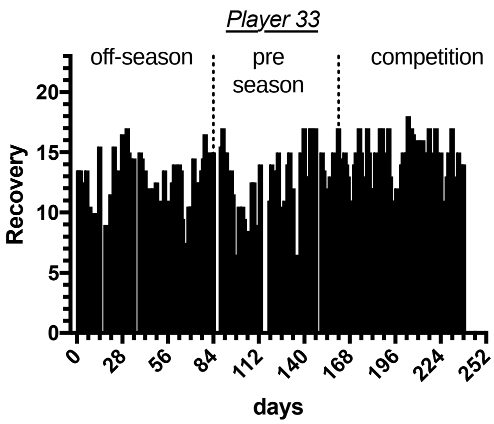

Player 28
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

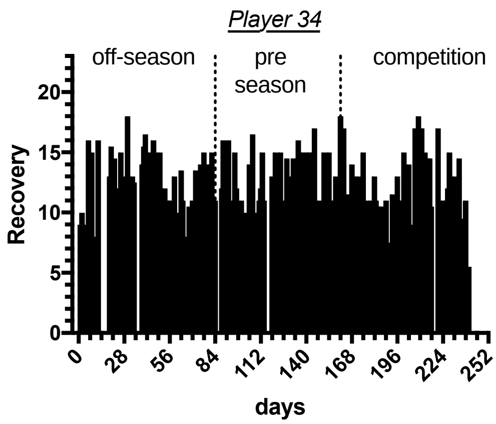

Player 29
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

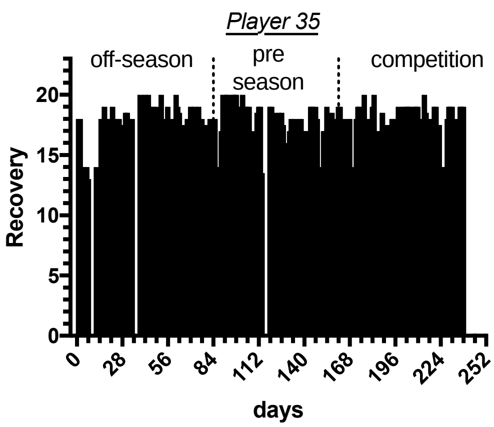

Player 30
off-season
pre season
competition
Recovery
0
5
10
15
20
0
28
56
84
112
140
168
196
224
252
days

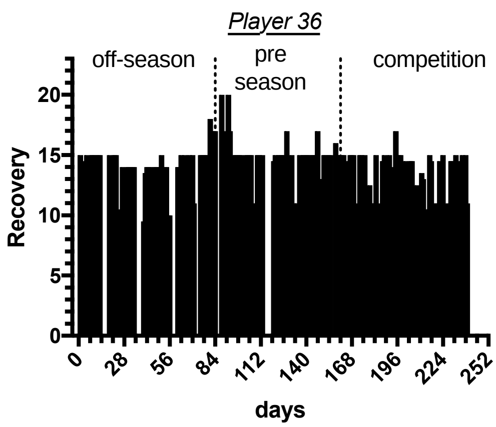

Player 31
off-season
pre season
competition
Recovery
0 5 10 15 20
0 28 56 84 112 140 168 196 224 252
days


Player 32
off-season
pre season
competition
Recovery
0 5 10 15 20
0 28 56 84 112 140 168 196 224 252
days


Player 33
off-season
pre season
competition
Recovery
0 5 10 15 20
0 28 56 84 112 140 168 196 224 252
days

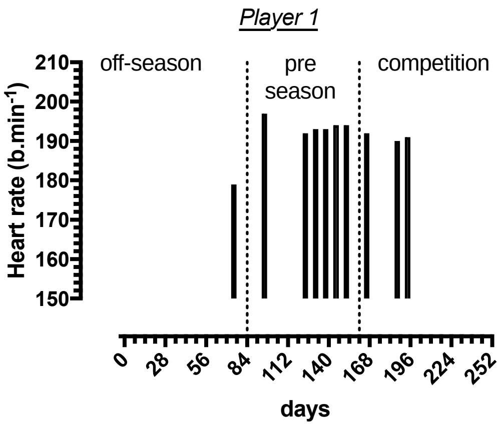

Player 34
off-season
pre season
competition
Recovery
0 5 10 15 20
0 28 56 84 112 140 168 196 224 252
days

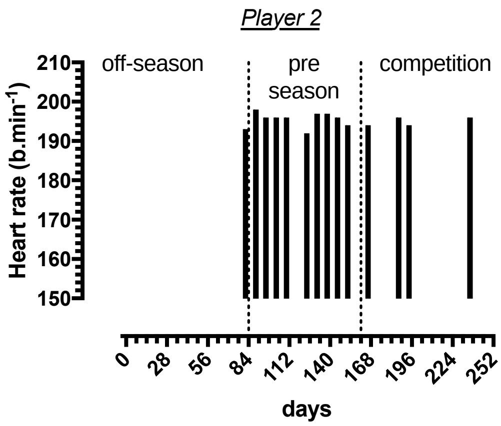

Player 35
off-season
pre season
competition
Recovery
0 5 10 15 20
0 28 56 84 112 140 168 196 224 252
days

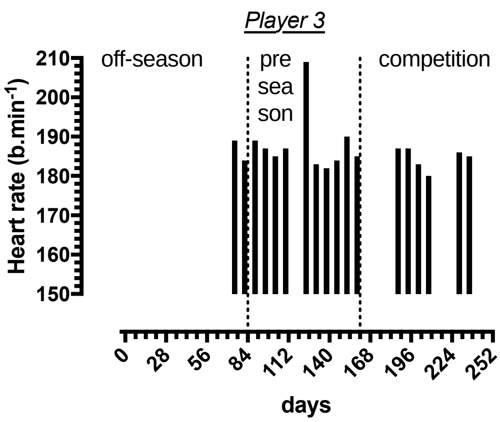

Player 36
off-season
pre season
competition
Recovery
0 5 10 15 20
0 28 56 84 112 140 168 196 224 252
days

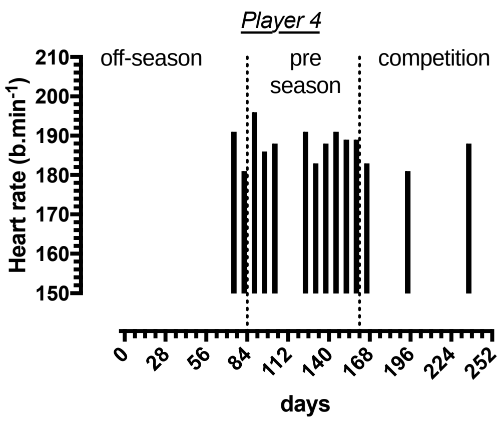
Appendix H

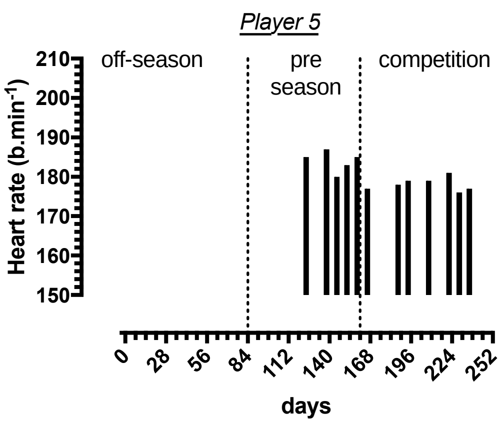
Individual Maximal Heart Rate graphs

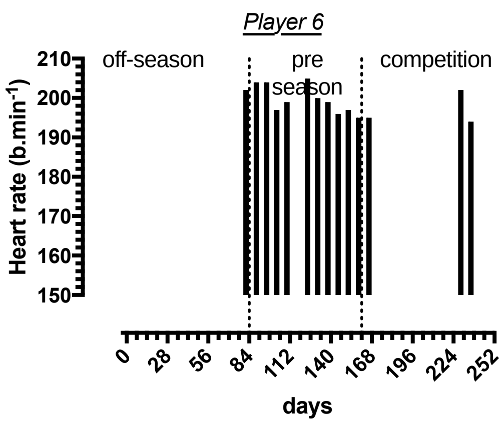


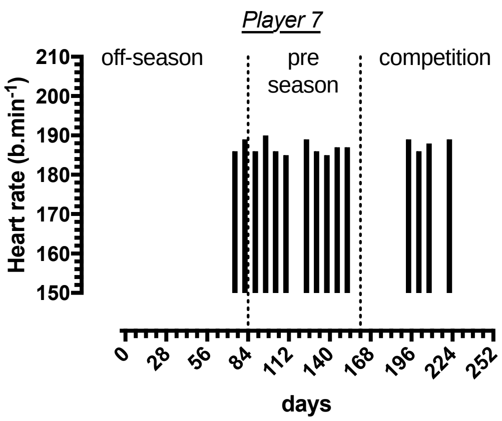


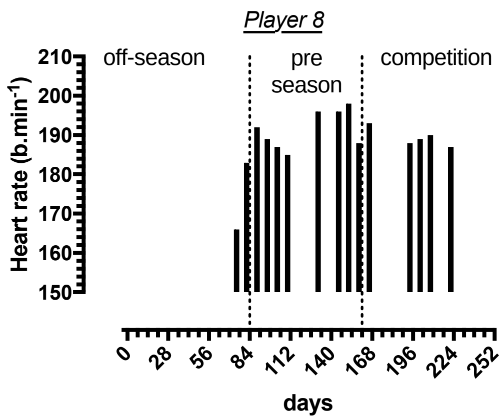


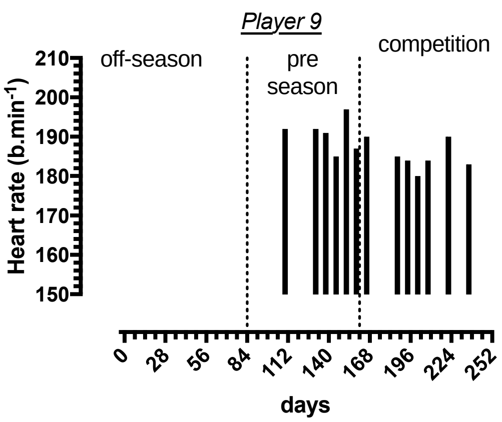


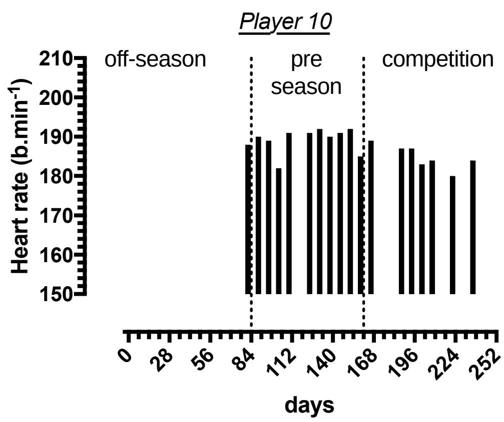


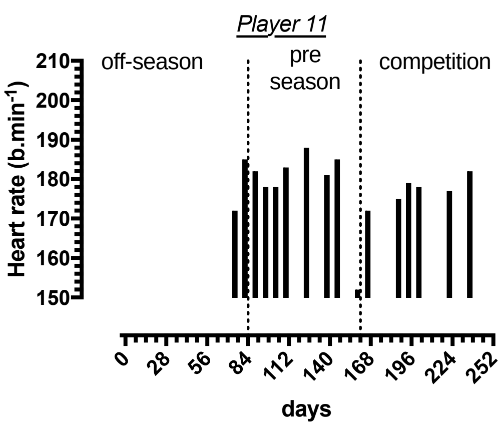


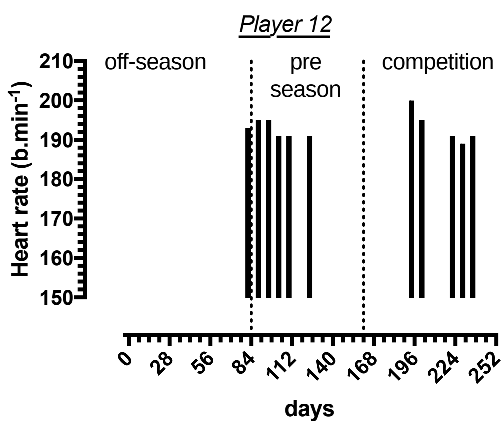

Player 7
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

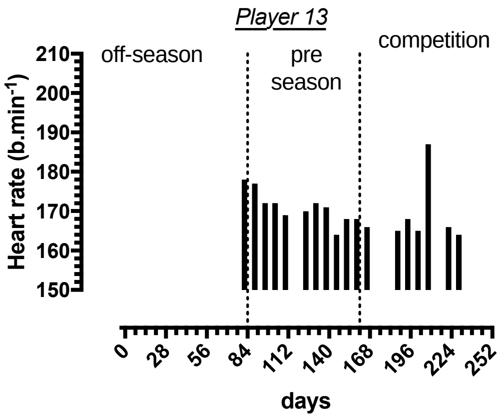

Player 8
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

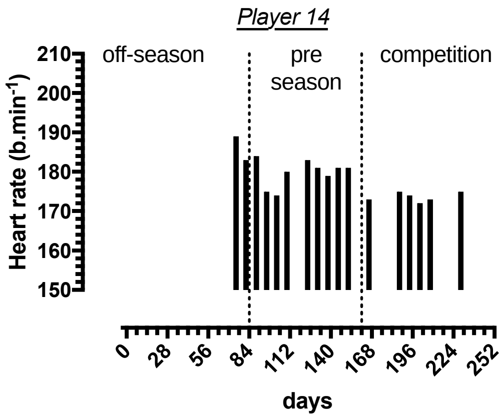

Player 9
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

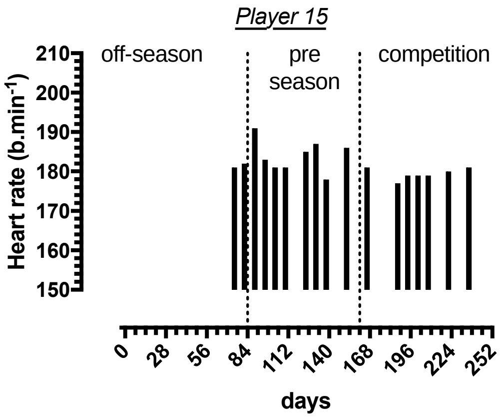

Player 10
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

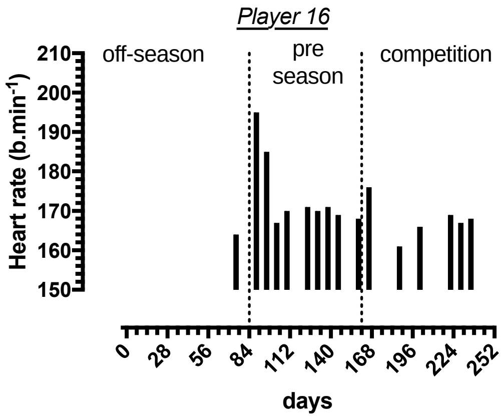

Player 11
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

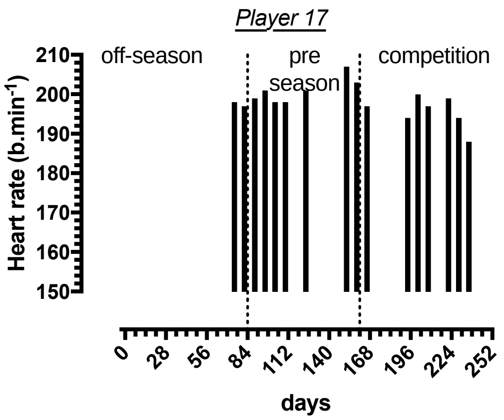

Player 12
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

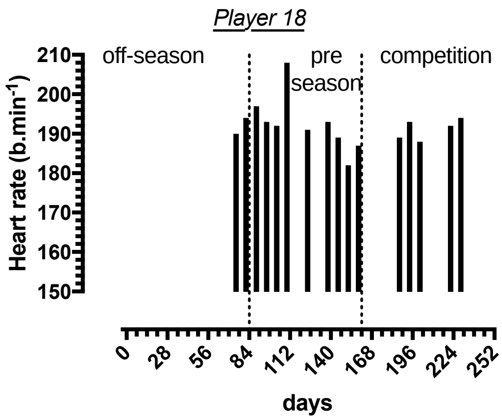

Player 13
off-season
pre
season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

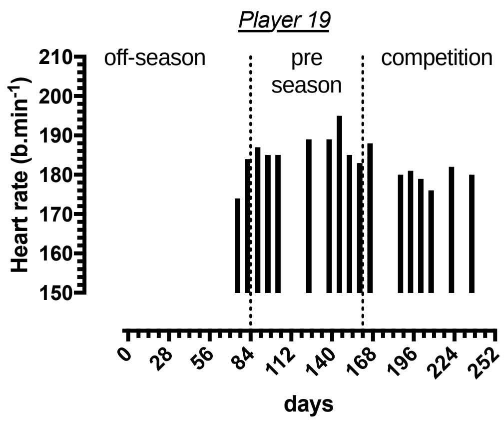

Player 14
off-season
pre
season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

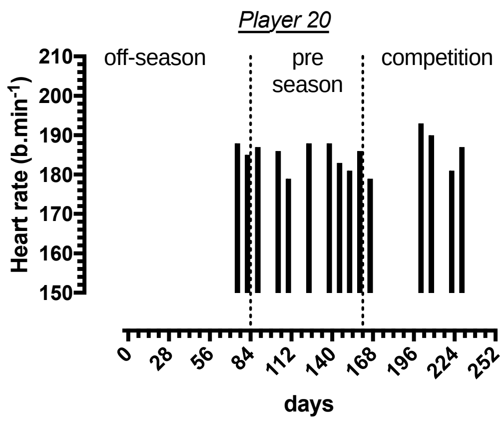

Player 15
off-season
pre
season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

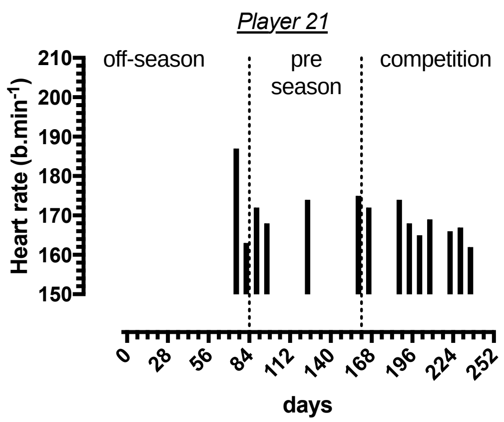

Player 16
off-season
pre
season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

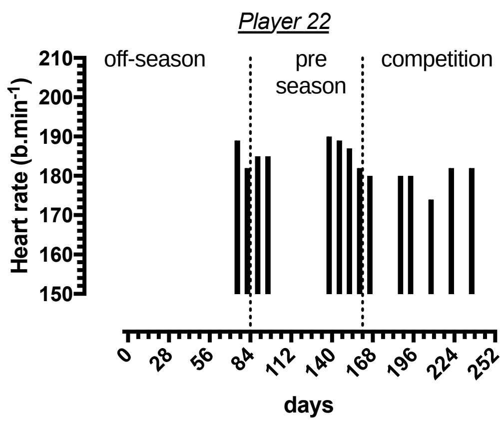

Player 17
off-season
pre
season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

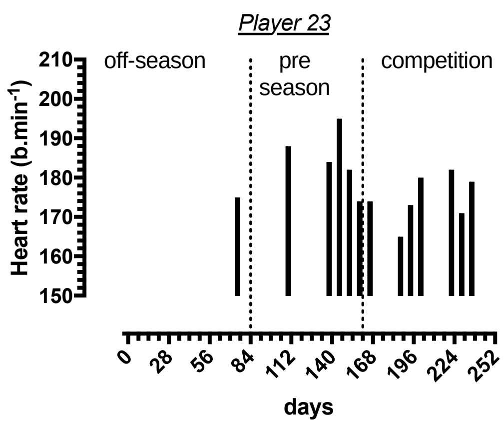

Player 18
off-season
pre
season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0
28
56
84
112
140
168
196
224
252
days

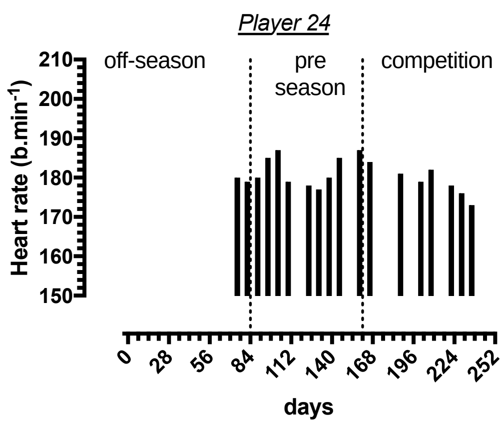

Player 19
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0 28 56 84 112 140 168 196 224 252
days

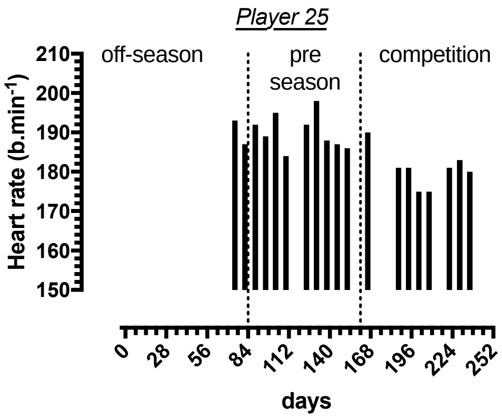

Player 20
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0 28 56 84 112 140 168 196 224 252
days

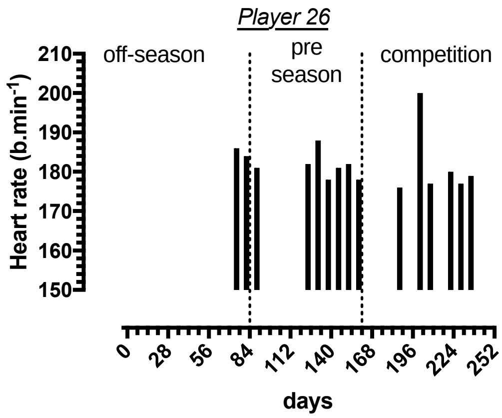

Player 21
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0 28 56 84 112 140 168 196 224 252
days

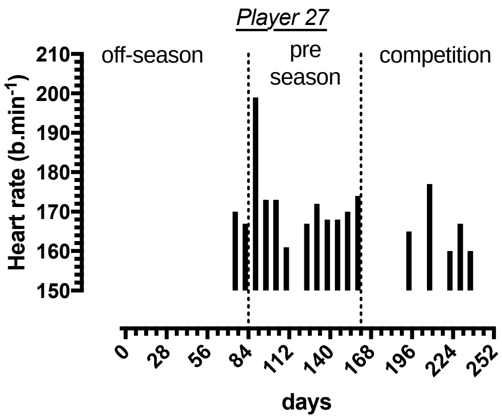

Player 22
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0 28 56 84 112 140 168 196 224 252
days

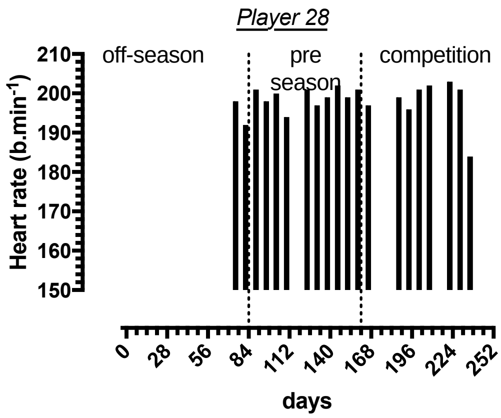

Player 23
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0 28 56 84 112 140 168 196 224 252
days

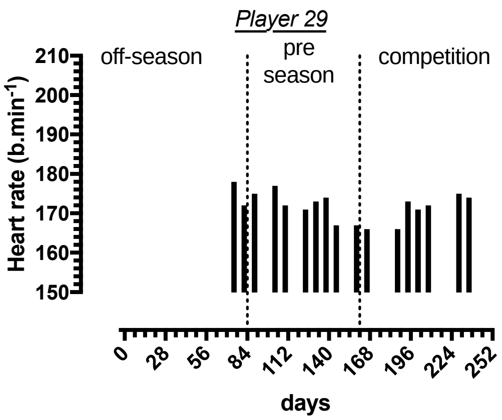

Player 24
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0 28 56 84 112 140 168 196 224 252
days

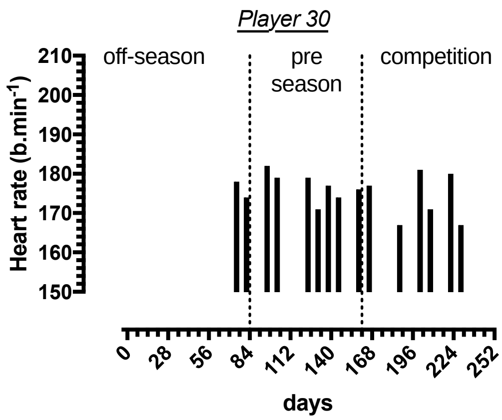

Player 25
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0
28
56
84
112
140
168
196
224
252
days

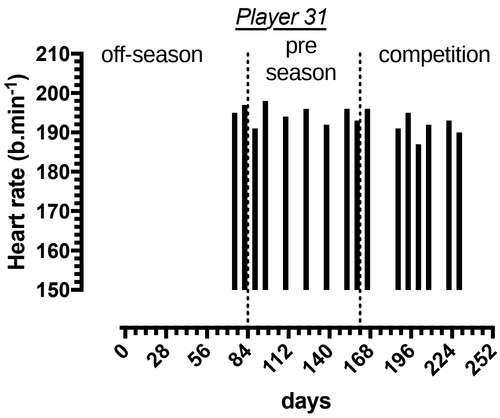

Player 26
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0
28
56
84
112
140
168
196
224
252
days

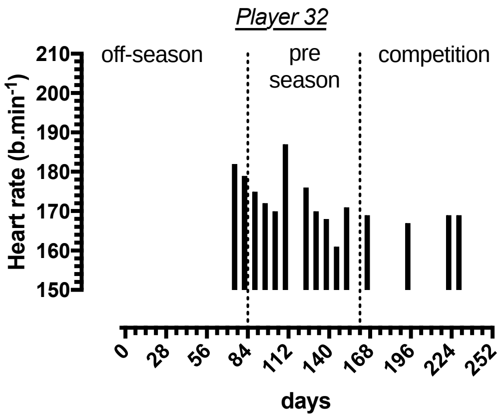

Player 27
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0
28
56
84
112
140
168
196
224
252
days

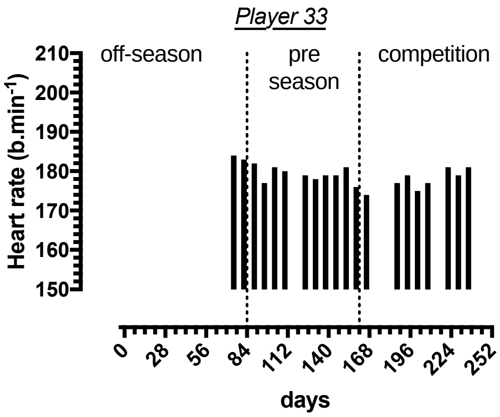

Player 28
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0
28
56
84
112
140
168
196
224
252
days

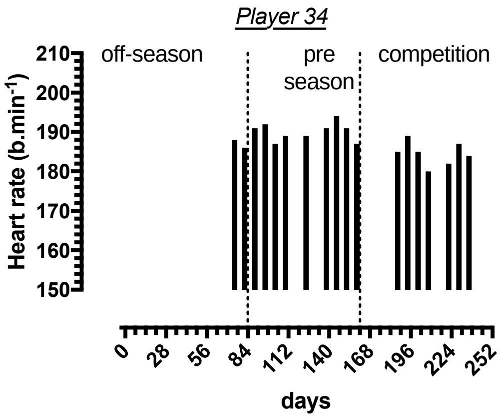

Player 29
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0
28
56
84
112
140
168
196
224
252
days

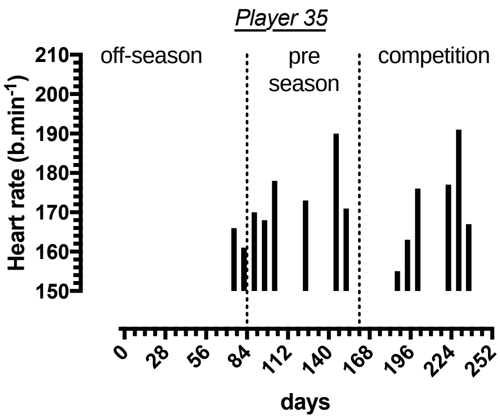

Player 30
Heart rate (b.min-1)
210
200
190
180
170
160
150
off-season
pre
season
competition
0
28
56
84
112
140
168
196
224
252
days

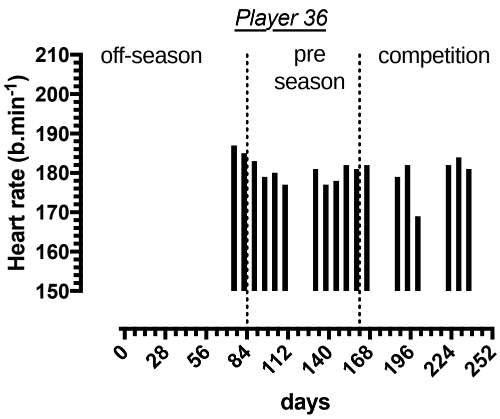

Player 31
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0 28 56 84 112 140 168 196 224 252
days


Player 32
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0 28 56 84 112 140 168 196 224 252
days


Player 33
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0 28 56 84 112 140 168 196 224 252
days

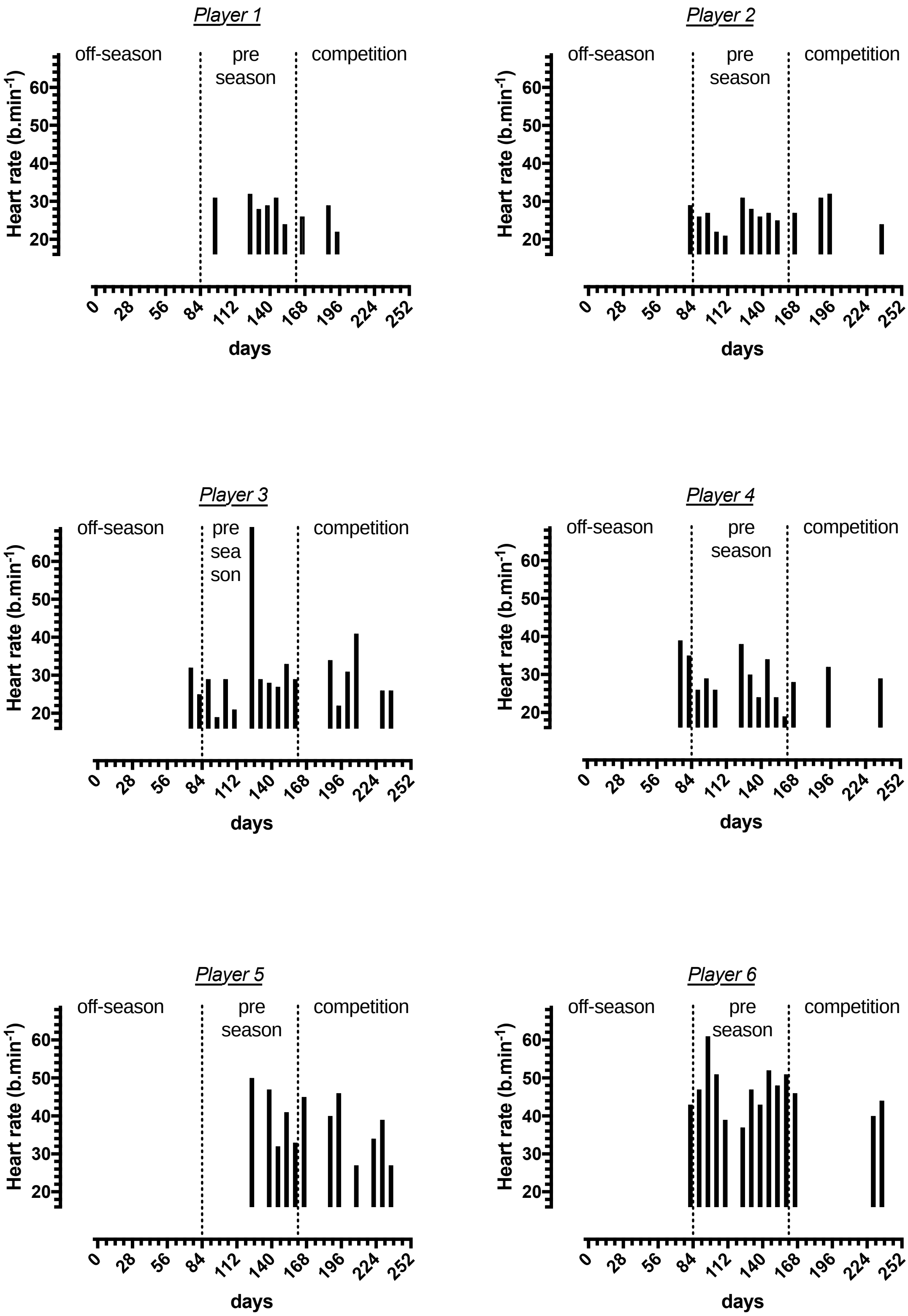

Player 34
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0 28 56 84 112 140 168 196 224 252
days

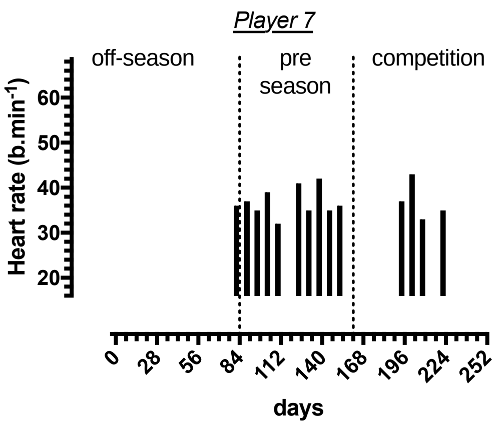

Player 35
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0 28 56 84 112 140 168 196 224 252
days

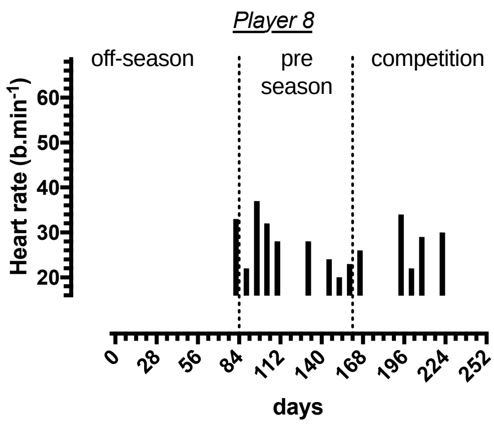

Player 36
off-season
pre season
competition
Heart rate (b.min-1)
210
200
190
180
170
160
150
0 28 56 84 112 140 168 196 224 252
days

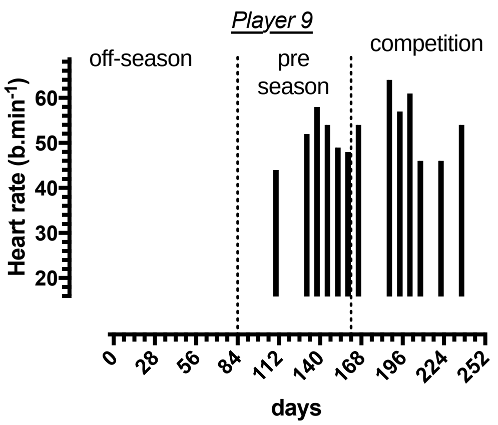
Appendix I

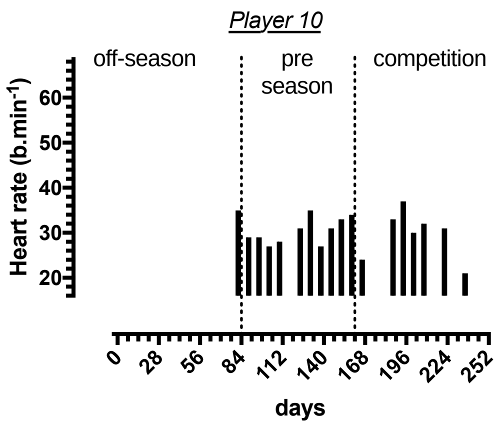
Individual Heart Rate Recovery graphs

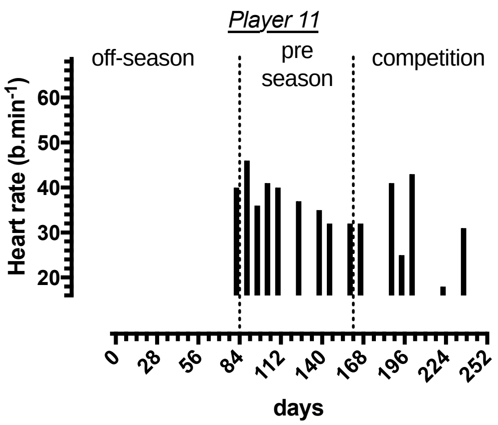


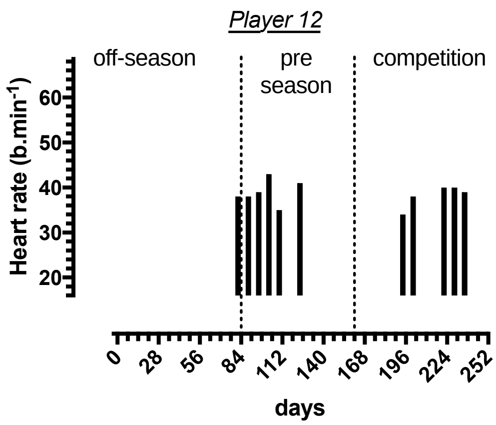

Player 7
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

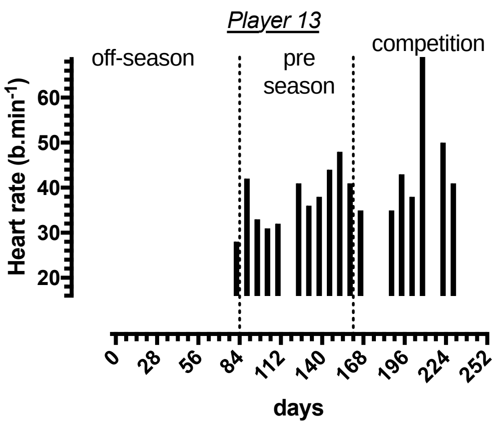

Player 8
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

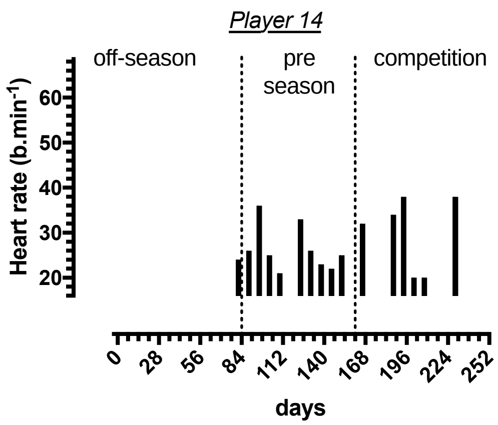

Player 9
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

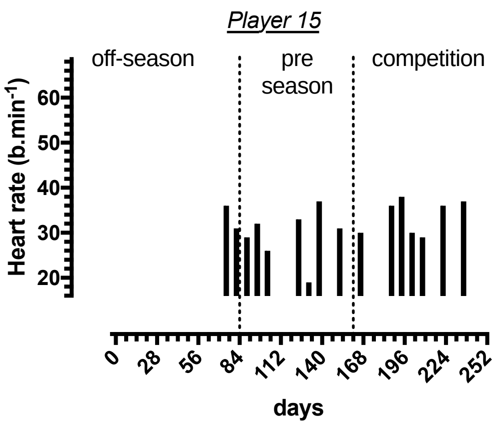

Player 10
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

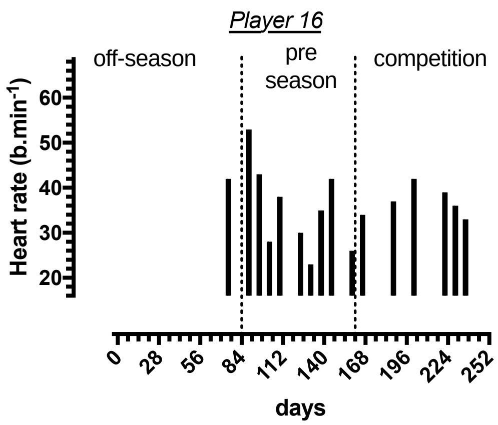

Player 11
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

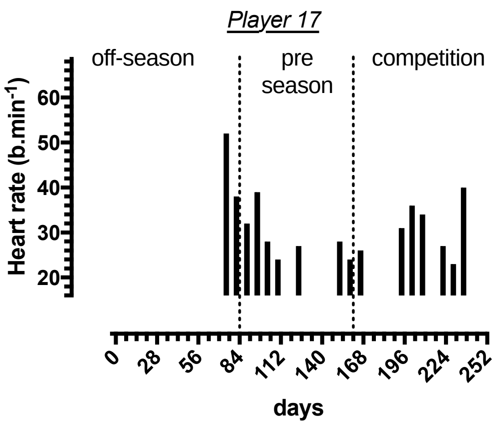

Player 12
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

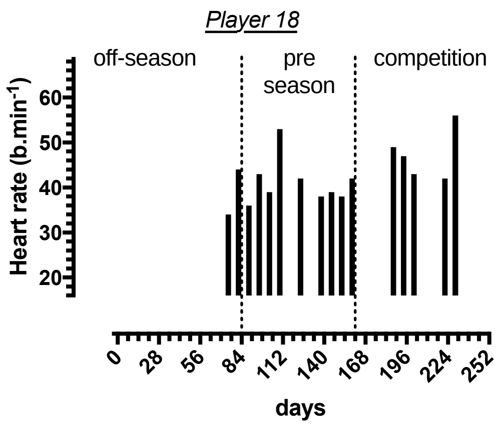

Player 13
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

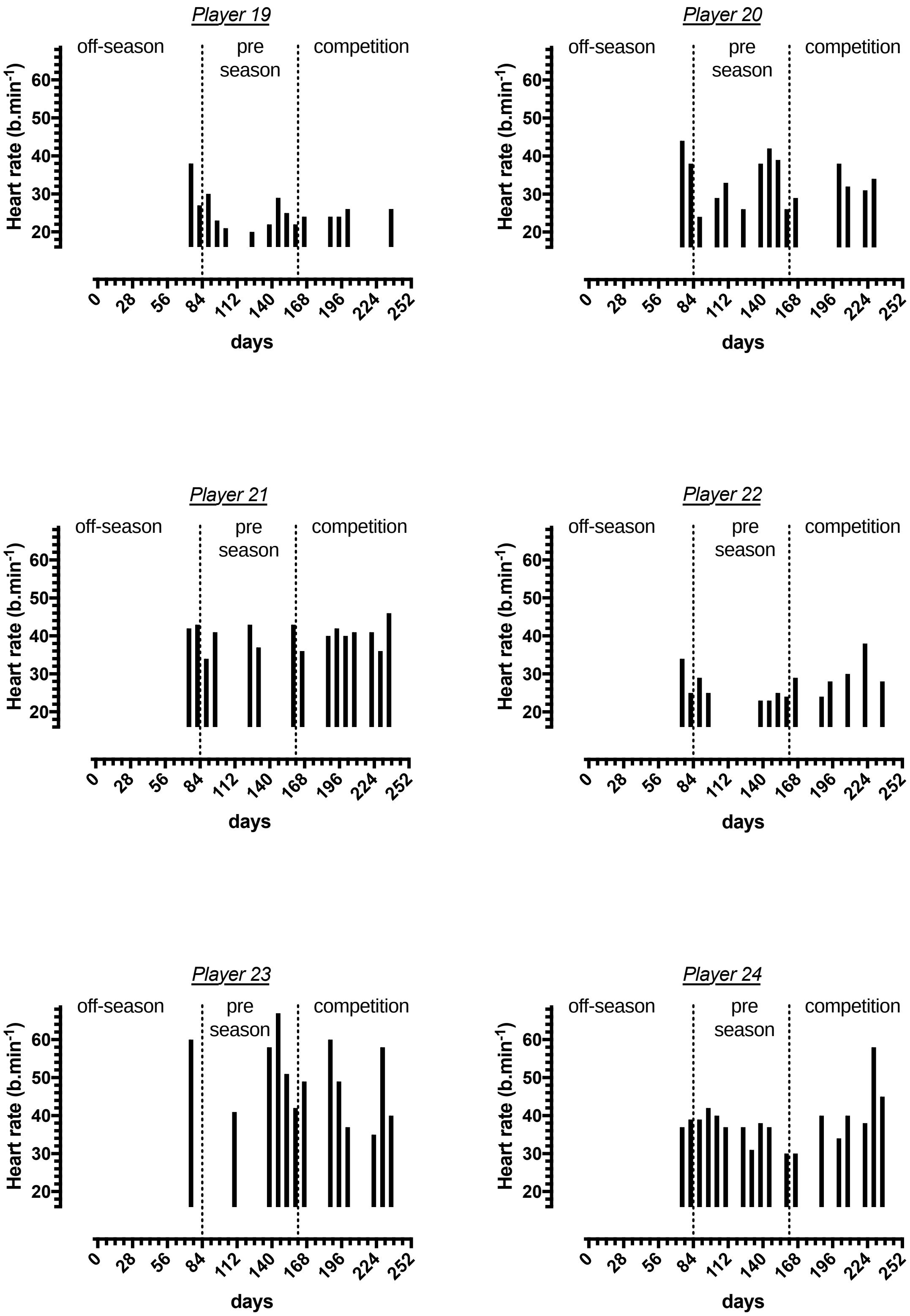

Player 14
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

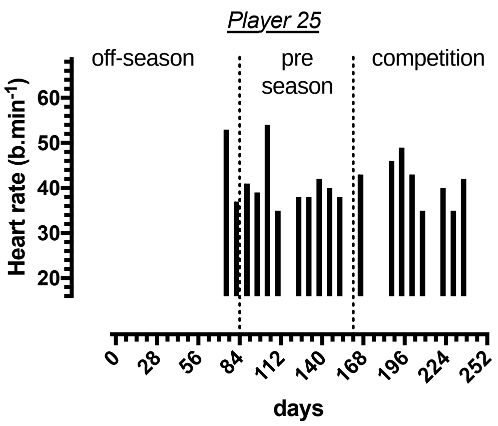

Player 15
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

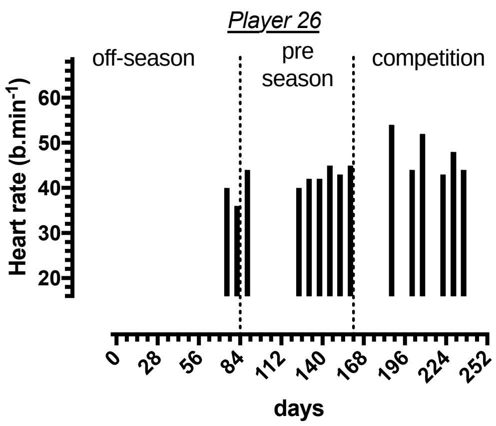

Player 16
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

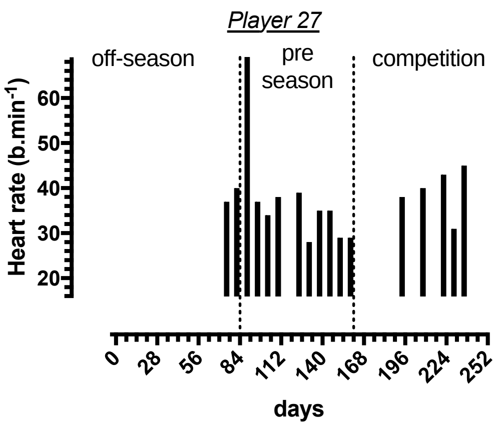

Player 17
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

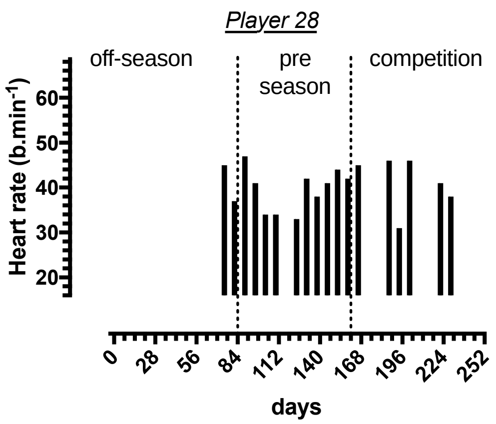

Player 18
off-season
pre season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days

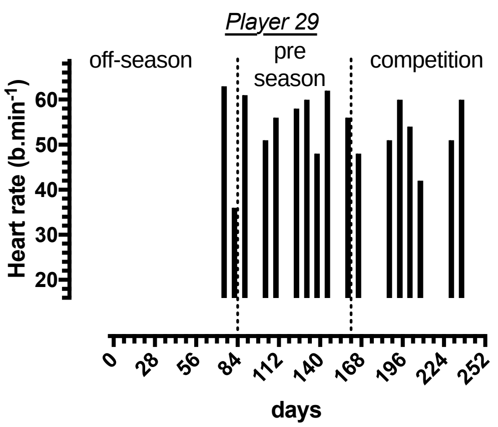

Player 19
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days
Player 20
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days
Player 21
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days
Player 22
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days
Player 23
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days
Player 24
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days

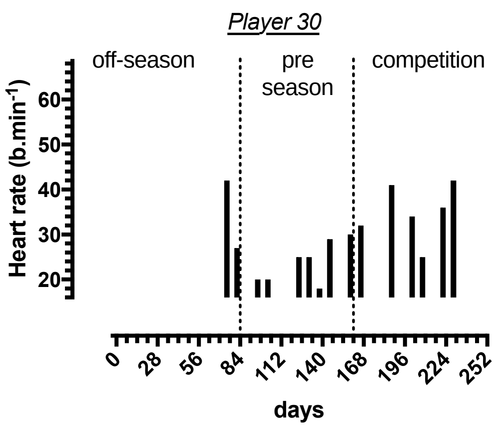

Player 25
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days

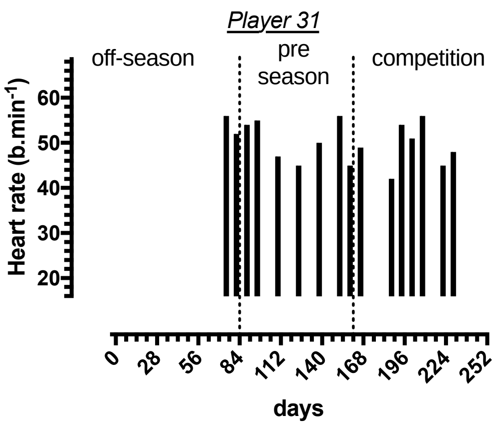

Player 26
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days

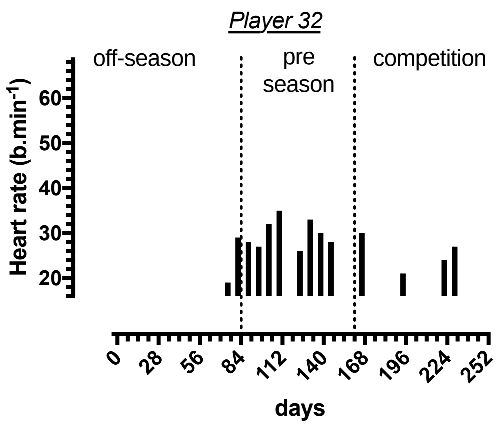

Player 27
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days

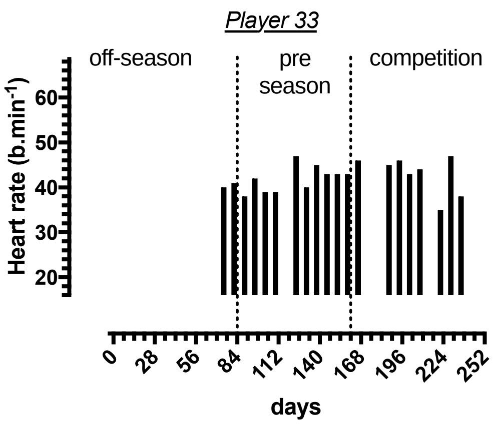

Player 28
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days

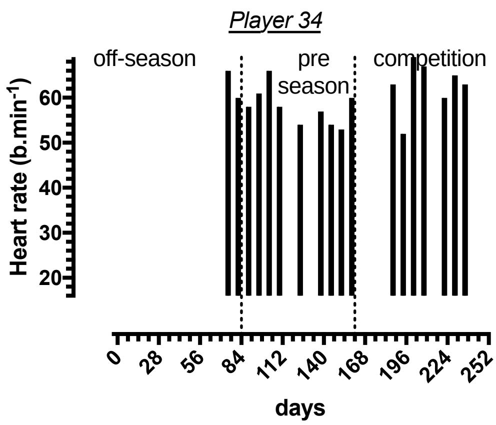

Player 29
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days

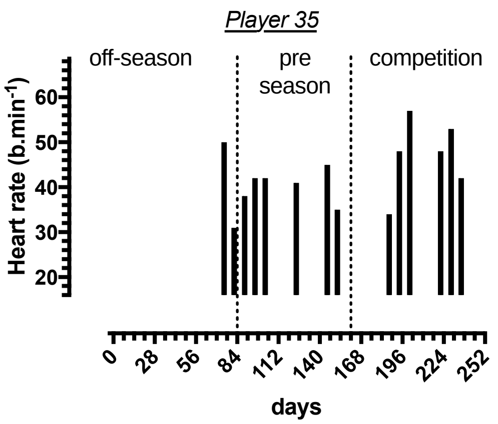

Player 30
off-season
pre season
competition
Heart rate (b.min-1)
20 30 40 50 60
0 28 56 84 112 140 168 196 224 252
days

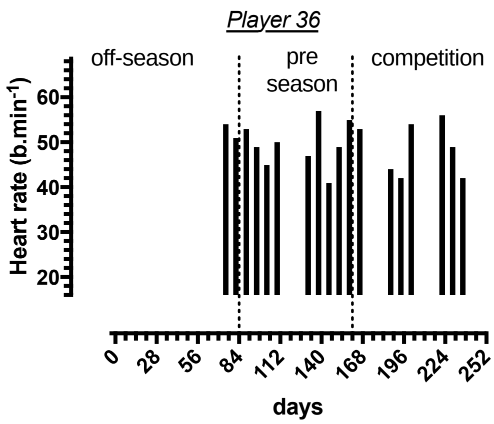

Player 31
off-season
pre
season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days


Player 32
off-season
pre
season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days


Player 33
off-season
pre
season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days


Player 34
off-season
pre
season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days


Player 35
off-season
pre
season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days


Player 36
off-season
pre
season
competition
Heart rate (b.min-1)
60
50
40
30
20
0
28
56
84
112
140
168
196
224
252
days