Fatigue and Recovery in Academy Rugby League Players

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I, the candidate, confirm that the work submitted is my own, except where work which has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. I, the candidate, confirm that appropriate credit has been given within the thesis where reference has been made to the work of others.

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Within these publications, I, the candidate, was responsible for gaining proportionate ethical approval (where necessary), the planning of the projects, undertaking pilot testing and familiarisation (chapter four), collecting and analysing the data (including searching, screening and reviewing the literature in chapter two), and finally writing the manuscripts. Professor Russell and Dr Davis were involved in the planning of the projects as well as the drafting and revision of the manuscripts. Professor Cooke and Professor Jones were involved during the final stages of manuscript revision. Dr Hills assisted in data collection (chapter four) and was involved during the revision process of the manuscripts. Mr Higgins assisted by providing access to the players who volunteered to take part in data collection for chapter four.

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Abstract

The studies undertaken in this thesis aimed to better understand, and improve practices relating to monitoring of players' post-exercise responses, and the use of recovery strategies in academy rugby league (RL). Survey findings (chapter three) highlighted that practitioners routinely monitored player readiness and when doing so, favoured a combination of objective and subjective tools that are easily implemented. Practitioners overwhelmingly agreed that recovery strategies could be used to improve readiness to train or play, but just over half of practitioners (i.e., 55%) agreed or strongly agreed that the recovery process was prioritised and executed well within their organisation. Nevertheless, recovery strategies were used often or all of the time by 79% of practitioners, with the more 'accessible' strategies (i.e., stretching, foam rolling and gym-based recovery) being implemented most frequently. Following match-play, variables from the isometric mid-thigh pull (IMTP), countermovement jump (CMJ), and wellness questionnaire that displayed acceptable levels of between-day reliability were profiled (chapter four). Match-play induced reductions of 4.75% and 9.23% at +24 h in CMJ velocity at take-off and jump-height, respectively, whilst, despite large effect sizes being evident in the post-match period, no significant changes were found across IMTP or wellness variables (chapter four). Chapter five highlighted that when adequate post-exercise nutrition that adhered to authoritative nutritional guidelines was implemented following high-intensity training, any additional recovery strategies were not clearly beneficial. Like match-play, high-intensity training elicited reductions in performance tasks that were indicative of fatigue. Like their senior counterparts, it is evident that academy RL players also experience post-exercise perturbations. Current practice in academy RL highlights that these responses are frequently monitored, whilst recovery strategies are often implemented in attempts to enhance the restorative processes. However, due to the limited time available and the equivocal evidence underpinning most recovery strategies implemented, practitioners should consider prioritising education and priming of professional habits in relation to recognised recovery-modulating practices such as nutrition, hydration, and sleep rather than pursuing possible benefits from recovery modalities.

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List of Abbreviations

AF: Australian Football

AM: Morning

ANOVA: Analysis of Variance

BAM: Brief Assessment of Mood

C: Cortisol

CG: Compression Garments

CHO: Carbohydrates

CK: Creatine Kinase

CMJ: Countermovement Jump

CONT: Control Trial

CT: Contraction Time

CV: Coefficient of Variation

CWI: Cold Water Immersion

CWT: Contrast Water Therapy

DJ: Drop Jump

DOMS: Delayed Onset of Muscle Soreness

ECC: Excitation Contraction Coupling

EIMD: Exercise Induced Muscle Damage

ES: Effect Size

F30: Force at 30 ms; F50: Force at 50 ms; F100: Force at 100 ms; F150: Force at 150 ms; F200: Force at 200 ms; F250: Force at 250 ms

FT: Flight Time

GI: Glycaemic Index

GPS: Global Positioning System

ICC: Intraclass Correlation Coefficient

IIMD: Impact Induced Muscle Damage

IMTP: Isometric Mid-Thigh Pull

JH: Jump Height

LOA: Limits of Agreement

MEMS: Micro-Electro-Mechanical System

MT: Movement Time

NRL: National Rugby League

PF: Peak Force

PM: Afternoon

POMS: Profile of Mood States

PP: Peak Power

PPU: Plyometric Push-Up

PRFD: Peak Rate of Force Development

REC: Recovery Trial

RHIE: Repeated High Intensity Effort

RL: Rugby League

RSI: Reactive Strength Index

RSI_{mod}: Reactive Strength Index Modified

RU: Rugby Union

SD: Standard Deviation

SL: Super League

sRPE: Session Rate of Perceived Exertion

SSC: Stretch Shortening Cycle

T: Testosterone

TE: Typical Error

UK: United Kingdom

VTO: Velocity at Take-Off

WWI: Warm Water Immersion

Chapter 1.0 Introduction

Rugby league (RL) is a sport played across the world, but mostly in Australasia and the United Kingdom (UK). During a game of RL, two teams, consisting of 13 players, and an additional four substitutes, compete against each other, while aiming to outscore the opposing team by scoring a try, conversion, or drop-goal. At the professional level, the game is played for two 40 min periods, separated by a ~15 min half-time interval (Johnston et al., 2014a). To better understand the game of RL, and to subsequently aid practitioners in preparing their players for the associated demands, research into various facets of the sport has vastly increased since 2008. Throughout most research, however, the focus has predominantly been on full-time professional senior players. Whilst this may not be surprising due to the high profile nature of the two major senior RL competitions (i.e., the National Rugby League; NRL in Australasia and Super League; SL in the UK and France), the identification and development of junior players is an important aim of the different RL governing bodies and many professional clubs (Till et al., 2011; Till et al., 2015a).

The currently available research in junior RL players is mainly focused towards physical qualities, whilst some information is also available in relation to their physical activity profiles. Specifically, player monitoring practices, post-match and post-training responses, and the use and effect of recovery strategies remain poorly understood in this population. Rugby league players perform between 30-65 collisions per game, depending on playing position, whilst it is not uncommon for backs to cover up to 1000m of high-speed running distance (Hulin et al., 2017; Waldron et al., 2011). In addition, the nature of the game requires players to perform a high number of accelerations and decelerations (Delaney et al., 2016). As a result, it is well documented that rugby-specific exercise includes a high frequency and intensity of eccentric muscle actions (i.e., through high-speed running, sprinting, accelerations, and decelerations) and blunt force traumas (i.e., through collisions), which may induce perturbations in post-exercise responses that are typically indicative of fatigue (Naughton et al., 2018; Peake et al., 2017); a term that is widely used in several different contexts which acknowledges two main attributes: (1) a decline in an objective measure of performance or the inability to produce power, and (2) sensations of perceived tiredness (Kluger et al., 2013). Post-exercise responses are typically monitored through neuromuscular, biochemical, endocrine, or subjective indices. Whilst a plethora of monitoring tools and variables is available, practitioners are encouraged to consider the validity, reliability, sensitivity, and practicality of a specific tool prior to its use in their sporting population.

In addition to the fatigue-response being individual to each player, it may seem logical that those players undergoing more heavy collisions and/or a higher number of accelerations, decelerations, and high-speed running, will experience an increased fatigue response. Understanding the stimulus that players need to recover from (i.e., their physical activity profiles) is therefore particularly important for practitioners when managing player fatigue. However, superior physical qualities and suitable recovery strategies may be able to offset these responses and facilitate a quicker return of suffered perturbations to baseline values (Halson, 2008; Johnston et al., 2015b). Whilst the efficacy of most strategies remains equivocal, it is common practice for most athletes to undergo a standard routine aiming to improve recovery. Optimising processes in relation to playing monitoring and the implementation of recovery strategies may aid in the timely observation of potential underperformance, injury, or illness, whilst attempting to enhance readiness for training and match-play (Kellmann et al., 2018).

Managing the interaction between training load (i.e., field- and gym-load), fatigue, and consequent recovery and adaptation is largely complex (Dupuy et al., 2018). Professional senior sporting environments generally have more available personnel and greater financial resources to manage and optimise this process, compared to adolescent environments. Nevertheless, given the primary aim of development in academy players (Till et al., 2015a), and the relatively short period that players are exposed to professional training and guidance, it may be worthwhile for professional academy players to also benefit from effective monitoring processes and recovery strategies. Indeed, additional opportunities to develop through training or match-play because of the effective use of these processes may be especially important for academy players. To better understand and inform these practices in relation to player monitoring, post-exercise responses, and the use of recovery strategies in academy RL players, additional context-specific research is required.

Chapter 2.0 Literature review

Chapter Summary

- Rugby league players typically require 72 h to recover from post-match perturbations following exposure to repeated eccentric muscle actions and/or blunt force traumas. Such perturbations are often monitored through neuromuscular, biochemical, or endocrine, or perceptual measures.
- There is a lack of research assessing post-match responses in more ecologically valid scenarios (i.e., those in which regular training and recovery strategies were employed) whilst also reporting detailed activity profiles. Responses to academy rugby match-play have only been assessed minimally.
- Various contextual factors in relation to physical activity profiles, physical qualities, as well as validity and reliability of testing tools and variables may differ between academy and senior players. Given the effect of these factors on post-exercises responses, they should be carefully considered.
- The evidence behind most implemented recovery strategies remains equivocal, whilst nutrition, hydration, and sleep are recognised as recovery-modulating factors. The use and efficacy of a recovery strategy that complements existing practice in an academy rugby league environment remains to be assessed.

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2.1 Rugby league in the United Kingdom

Whilst being played across the whole of the UK, the largest levels of RL participation can be found in Northern England, which is highlighted by the fact that at SL level, all but one of the teams in the 2021 campaign are from this part of the country. Historically, this is not surprising, as since its separation from Rugby Union (RU) in 1895, RL has mostly been played by working class Northern people who were unable to play without financial compensation for missing work (Brewer & Davis, 1995). Players from the Southern part of England, who were more likely to have other sources of income, were able to sustain the sport of RU on an amateur basis, which therefore caused rugby to split into two codes (Brewer & Davis, 1995).

In the current system of RL in the UK, players play on an amateur basis up to the age of 16 years. However, at the age of 14 years, professional clubs are able to recruit players onto their under-16 years program (i.e., scholarship). This program runs for two seasons, but players do not yet sign a contract with the club and are still allowed to play for their amateur teams also (Whitehead et al., 2019). Following the scholarship program, the club will decide whether to either release players (i.e., they will not progress their RL career within the club), or, if players have been identified as having SL potential, they are signed on a part-time professional contract, which will see them join the academy (Whitehead et al., 2019). Players are eligible to play for the academy for a total of three years, between the ages of 16-19 years, and will do so on an exclusive basis (i.e., they are no longer able to train or play for other teams). Following this period, players are either released from the club, or they are given a full-time professional contract to train and play with the senior team. Professional academy RL is therefore the final level prior to senior SL, which highlights the importance of successfully preparing adolescent players for the demands and expectations that are associated with the highest level (Whitehead et al., 2019). Accordingly, given the relatively short period that young players are exposed to a professional training environment (i.e., five years) prior to the club deciding whether to sign or release a player, it is essential that players are given the best possible opportunity to develop and progress into a professional senior environment.

Academy games in the UK are being played in a competition with a total of 12 or 13 professional academies. The academy season, which is preceded by a pre-season of approximately three months, runs roughly in line with the SL competition (i.e., March-September). Teams play each other twice per season, resulting in no more than 25 games being played over the course of the year. These games are spread across the season, and whilst most games are separated by about a week, others may be separated by a couple of weeks. A shorter between-game period of just four or five days also occurs throughout the season (Figure 2.1). As illustrated, academy games predominantly take place on a Saturday afternoon, with some games being played on a Thursday evening also.

The between-game periods are important to develop tactical, technical, physical, and mental skills during training sessions. The way training is programmed (i.e., periodised) throughout the week likely differs between clubs, subject to training philosophy, game model and/or individual preferences of the coaching staff. Nevertheless, specific micro-cycle design was previously proposed in a RU context (Tee et al., 2018). This model (Figure 2.2) is based around the concept of tactical periodisation, which is hugely popular in soccer. This method of training simultaneously integrates the physical element with the tactical, technical, and mental element of training, whilst a different physical focus (e.g., submaximal work-capacity, collision, speed) is emphasised on each training day. Given that this model is specifically designed for senior teams to achieve winning performances, its suitability in academy rugby teams needs to be evaluated. It therefore remains unclear what current practice looks like in relation to training regimes in academy RL.

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
			1st	2nd	3rd	4th
5th	6th	7th	8th	9th	10th	11th
12th	13th	14th	15th	16th	17th	18th
19th	20th	21st	22nd	23rd	24th	25th
26th	27th	28th	29th	30th	31st	

Figure 2.1 Example of a fixture list of an academy team in a single month during the 2018 season. The grey boxes highlight the days a match took place.

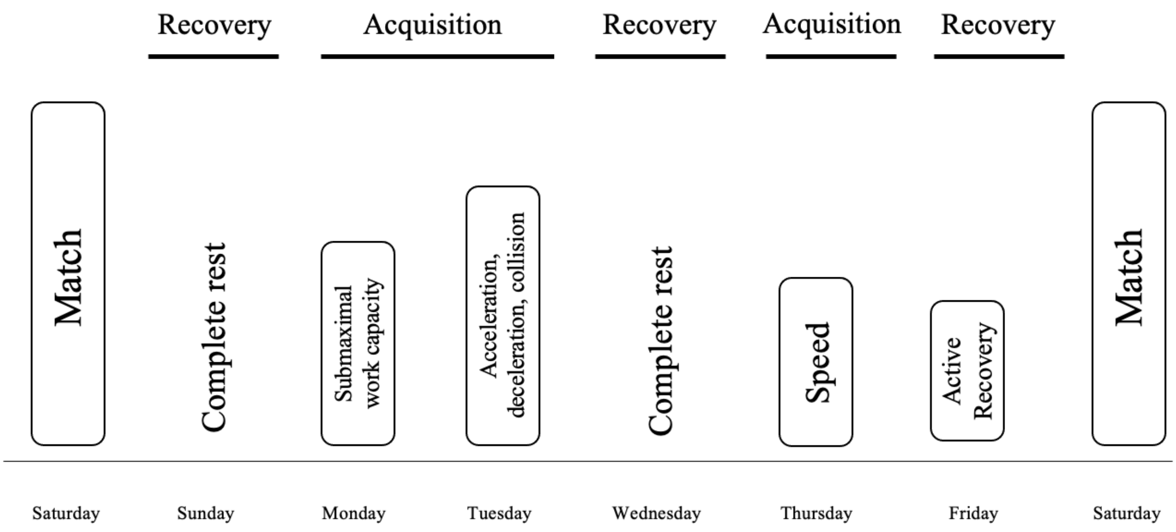

Figure 2.2 A proposed structure of a tactical periodisation model in rugby union. Adopted from Tee et al. (2018)

2.2 Activity profiles in rugby league

Of the 13 players that are on the field at the same time, there are six forwards and seven backs. Forwards are generally split between hit-up forwards (i.e., two prop forwards and one loose forward), wide-running forwards (i.e., two back-rowers) and a single hooker. Backs may be separated between outside backs (i.e., two centres, two wingers, and one full-back) and adjustables (i.e., one scrum-half and one five-eight) (Gabbett et al., 2008a; Johnston et al., 2014a). In relation to their technical skills and physical activity profiles, large differentiation exists between subgroups of positions (i.e., forwards vs backs), and more specifically between individual positions (Johnston et al., 2014a). Interestingly, in some literature assessing positional demands, certain positions are grouped differently to the division described above. Specifically, whilst being a forward, the hooker is sometimes included within the category of adjustables (Twist et al., 2014). This may be explained through similarities across certain technical demands but seems somewhat illogical considering the amount of physical collisions the hooker endures compared to the half-back and five-eight (Gissane et al., 2001). Similarly, the full-back may also be considered amongst the adjustables (Glassbrook et al., 2019) but is arguably exposed to more high-speed running (Weaving et al., 2019). Within their positions, players have different roles and tasks, which is likely to affect their involvement within fatigue-inducing mechanisms such as collisions and high-speed running. Over- or underestimation of certain activity profiles may therefore occur when specific positions are considered together.

2.2.1 Senior match-play activity profiles

Early research assessing the activity profiles of RL match-play was performed using manual coding of video footage and the subjective analysis of movements (King et al., 2009; Meir et al., 2001a; Sirotic et al., 2009). Ever since the introduction and continuous development of Global Positioning System (GPS) and micro-electro-mechanical system (MEMS) devices, a plethora of research projects have identified the activity profiles of senior RL match-play (Austin & Kelly, 2013, 2014; Gabbett et al., 2012; McLellan & Lovell, 2013; Sykes et al., 2011; Twist et al., 2014; Waldron et al., 2011). Initially, research often described the activity profiles of match-play over a specific duration (i.e., a half or a full match), predominantly highlighting average locomotor demands in relation to parameters such as distance covered, distance per minute (m·min^{-1}), high-intensity running (>5.5 m·s^{-1}) and sprinting (>7.0 m·s^{-1}) (Johnston et al., 2014a), as well as collision demands (Gabbett, 2012a; Hulin et al., 2017). Rugby league players cover an average total distance of 5000-8000 m per game (Johnston et al., 2014a; Twist et al., 2014; Waldron et al., 2011), whilst backs generally cover more distance than forwards because of their increased playing time. When expressed as relative distance, positional differences are less clear as both positional subgroups cover between 90-100 m·min^{-1} when on the field (Johnston et al., 2019; Weaving et al., 2019). Backs are exposed to greater distances covered at higher speeds as they may cover up to 1000 m of high-intensity running (Waldron et al., 2011). Forwards instead, are involved in more collisions and tackles (Gabbett et al., 2012). Indeed, players are exposed to an average of 30-65 collisions (Hulin et al., 2017), depending on playing position, with the highest frequency of collisions in hit-up forwards (Gabbett et al., 2012).

Whilst an understanding of the average activity profiles is important, it fails to reflect the peak locomotor demands of competition and does not allow practitioners to prescribe such scenarios in training (Johnston et al., 2019; Weaving et al., 2019). Therefore, researchers observed physical match profiles over shorter (e.g., 5 min) periods (Hulin et al., 2015; Kempton et al., 2013; Waldron et al., 2019), and whilst this method captures the higher intensities that may occur during these shorter epochs, an underestimation of the most intense periods of play still exists (Johnston et al., 2019). Indeed, to accurately describe the most intense passages of play, moving or rolling averages have recently been used (Delaney et al., 2016; Delaney et al., 2015; Johnston et al., 2019; Weaving et al., 2019). This approach takes a specified duration (usually ranging from 1-10 min) and calculates a moving average of all the data points over the specified period from the start to the end of a match. The highest activity profiles elicited in any period, would be classified as the peak locomotor demands (Varley et al., 2012).

Alongside peak running intensities (i.e., total distance, relative distance, high-speed running, sprinting), parameters such as accelerations, decelerations, and repeated high-intensity efforts (RHIE) are essential to provide a valid representation of the most intense passages of match-play (Delaney et al., 2016;

Delaney et al., 2015; Johnston et al., 2019; Weaving et al., 2019). Players generally cover between 50-100 accelerations and decelerations per match (Glassbrook et al., 2019), whilst some evidence suggests that hookers and adjustables experience greater peak acceleration/deceleration load compared to other positional subgroups (Delaney et al., 2016). High acceleration ($\geq$ 2,5 m·min^{-1}), high-speed running, or collisions are all considered high-intensity efforts, and when three or more of these efforts occur with less than 21 seconds of recovery in between each effort, they are defined as RHIE. Players generally cover up to 25 RHIE during match-play (Glassbrook et al., 2019). Such information could be used when physically preparing professional academy players for the senior level. However, contextual factors (e.g., technical, and tactical skill involvements, previous epoch, starter vs substitute, minutes played) as well as individual responses to certain scenarios should also be considered when describing true 'worst-case scenarios' (Novak et al., 2021).

Nevertheless, positional differences in duration-specific peak relative distances (Delaney et al., 2015; Weaving et al., 2019) and peak average accelerations (i.e., the intensity of changes in speed) (Delaney et al., 2016) were highlighted across SL and NRL competition (Delaney et al., 2015; Weaving et al., 2019). Combining both the locomotor and collision demands, a thorough holistic overview of activity profiles in senior professional RL (SL vs NRL) has also been provided, highlighting peak periods of play of 1- to 5-min periods in relation to peak running intensities, accelerations and collisions (Johnston et al., 2019). Over a 60-second period, peak match-speed in professional RL players ranged from 171 m·min^{-1} without collisions, to 110 m·min^{-1} when players were involved in three collisions. The 5-min period elicited a peak match-speed of 116 m·min^{-1} and 85 m·min^{-1} when players were exposed to none and three collisions respectively (Johnston et al., 2019). Naturally, with the addition of more collisions, there is a reduction in average speed and accelerations. Altogether, studies have clearly identified the physical activity profiles of professional senior RL.

2.2.2 Academy match-play activity profiles

In contrast with the plethora of research that has assessed match profiles in senior RL players, academy match profiles have only been analysed minimally. Where a single study found large differences between professional senior and academy players in relation to whole-game total distance and sprint distance (McLellan et al., 2011b), others found no differences in running demands (Dempsey et al., 2018; Gabbett, 2013; Whitehead et al., 2019). Specifically, Whitehead et al. (2019) highlighted that peak running demands were in fact similar between professional academy and senior playing standards (Whitehead et al., 2019). Indeed, both one-minute (i.e., ~164 to 178 $m \cdot min^{-1}$) and 10-minutes (i.e., ~94 to 106 $m \cdot min^{-1}$) peak average running speeds were within the ranges reported for NRL and SL (i.e., ~159 to 179 $m \cdot min^{-1}$ and ~90 to 109 $m \cdot min^{-1}$ respectively) (Delaney et al., 2016; Delaney et al., 2015; Weaving et al., 2019). This study, however, failed to quantify accelerations and decelerations or the frequency and intensity of collisions, which are known to be important parameters when describing activity profiles during match-play. It is anticipated that the combination of greater body mass and improved physical attributes leads to greater impact forces during collisions in the senior game compared to those experienced in academy RL (De Lacey et al., 2014; Johnston et al., 2014a). Given the positive relationship between physical activity profiles and post-exercise fatigue (Oxendale et al., 2016), it is important these are understood when profiling post-match or post-training responses in academy RL players.

2.2.3 Training activity profiles

The foundations of performance in match-play are laid during training, where the development of various technical, tactical, physical and physiological characteristics takes place (Lovell et al., 2013). To physically prepare players for the peak activity profiles that are endured during match-play, it would be worthwhile to utilise training to replicate or at times exceed some of the match-play peak external load. Specifically, training the peak physical activity profiles of match-play (i.e., the worst-case scenarios) for a shorter period is likely to prevent under-preparation and will aid in the physical development of players. Monitoring of training load, both internal and external, can assist in this process, and while training load assessment is common amongst professional clubs to ensure appropriate loading and to reduce the risk of injury (Halson, 2014a), there is a scarcity of studies exploring training loads across both academy and senior RL (Black et al., 2018). Specifically, some studies were able to give an indication of training loads, but these only explored pre-season training periods (Weaving et al., 2014), specific training drills (Gabbett et al., 2012), or through reporting of limited parameters (Gabbett, 2004; Weaving et al., 2014). Notably, a single study was able to quantify the locomotor demands of professional senior training sessions throughout pre-season and the regular season (Black et al., 2018). Some research has also shed light on the training durations in academy RL (McCormack et al., 2020). The average training time (both gym- and field-based training) completed in academy players was 809 ± 224, 620 ± 214, 598 ± 239, and 603 ± 231 min during the pre-season, and the early, mid, and late stages of the in-season, respectively (McCormack et al., 2020). The physical demands that players endure during such sessions remain unknown. Acknowledging the differences in the intensity and volume of a training session compared to match-day, training is still likely to involve a high frequency and intensity of fatigue-inducing mechanisms (i.e., collisions and/or eccentric muscle actions) that may cause post-training perturbations. Improved understanding of such responses may assist in planning of physical load throughout the week.

2.3 Fatigue mechanisms

Throughout the literature, various definitions exist around the concept of fatigue. As proposed by Enoka and Duchateau (2016), fatigue is a single entity and should not be preceded by an adjective (e.g., central, peripheral). Whilst this may suggest the likely locus of those factors limiting performance, this remains vague and uncertain (Enoka & Duchateau, 2016). Instead, studies should focus on assessing the two main attributes of fatigue, (1) a decline in an objective measure of performance or the inability to produce power, and (2) sensations of perceived tiredness (Kluger et al., 2013). Whilst the precise origin of neuromuscular fatigue remains unclear, it has been reported that both central and peripheral factors contribute. Specifically, central factors are associated with decreased neural drive to the muscle originating from the brain and/or spinal cord whilst peripheral factors are predominantly concerned with changes in contractile capabilities at, or distal to, the neuromuscular junction (Boerio et al., 2005; Ekblom et al., 2004; Enoka & Duchateau, 2016; Lepers et al., 2002). However, the main actions performed by RL players that cause muscle damage, are typically described through factors associated with peripheral functions. Indeed, as highlighted, players frequently perform sprints, runs at high intensity, accelerations, decelerations, changes of direction, and jumps, both in training and match-play (Johnston et al., 2014a; Johnston et al., 2019). Such actions rely heavily on the stretch-shortening cycle (SSC), and thus eccentric muscle actions (i.e., lengthening of the muscle) (Douglas et al., 2017). Concurrently, players are often subject to collisions with opponents or the playing surface (Johnston et al., 2019). When exposed to a high intensity or frequency of such actions, players are likely to experience exercise-induced muscle damage (EIMD) and impact-induced muscle damage (IIMD) (Naughton et al., 2018; Peake et al., 2017), resulting in a disruption of muscle tissue homeostasis and a highly complex chain of inflammatory responses (i.e., changes in clinical, physiological, cellular, and molecular changes within injured tissue (Scott et al., 2004). This inflammatory response is thought to be an integral part of the adaptation process, and will ultimately lead to an anti-inflammatory response, allowing full recovery (i.e., a return to baseline performance measures) to take place (Markus et al., 2021). The time-course of full recovery is highly dependent on the type, duration and intensity of the preceding exercise stimulus (Peake et al., 2017), but is also affected by age, sex and genetics (Markus et al., 2021), which makes the recovery process highly individual to each player.

2.3.1 Eccentric muscle actions

Although not entirely understood, various theories have been put forth to explain the mechanism and subsequent reductions in performance following repeated eccentric muscle actions. Despite being challenged previously (Telley et al., 2006), an otherwise well-supported theory was explained by Morgan (1990), which proposes that as a result of eccentric muscle actions, those sarcomeres closer to their optimum value (i.e., in which they can exert the most force), are able to resist lengthening better than those sarcomeres further from their optimum value. As a result, these ‘weaker’ sarcomeres (i.e., those further from their optimum value) become progressively weaker if this occurs on the descending limb of the lengthening curve, and upon reaching their yield point, they become overstretched (i.e., they 'pop') (Morgan, 1990). Upon overstretching, the myofilament overlap between the myosin filament (i.e., the thick filament) and the actin filament (i.e., the thin filament) no longer exists, reducing the number of activated cross-bridges, and subsequently affecting force production (Morgan, 1990; Proske & Morgan, 2001). At the end of the stretch, some of the 'popped' sarcomeres are able to recover, but those that are not, become disrupted (Talbot & Morgan, 1996). As eccentric muscle actions keep occurring, more and more sarcomeres will become disrupted, which may result in muscle damage spreading both longitudinally to adjacent sarcomeres in the myofibril and/or transversely to adjacent myofibrils (Proske & Allen, 2005). Ultimately, a point will be reached where the number of disrupted sarcomeres leads to membrane damage (i.e., in the sarcoplasmic reticulum, transverse tubules, or the sarcolemma), which is accompanied by uncontrolled movement of Ca^{2+} into the sarcoplasm (Proske & Allen, 2005).

There is some disagreement whether the disruption of sarcomeres and the subsequent free movement of Ca^{2+} into the sarcoplasm is the catalyst event leading to disruption of the excitation-contraction coupling (ECC), or whether damage to the ECC is the primary event underpinning EIMD (Proske & Morgan, 2001; Warren et al., 2002). The ECC is a physiological mechanism which, through stimulation by a neuron (i.e., excitation), causes a physical interaction between myosin and actin (i.e., contraction) (Calderón et al., 2014). Specifically, through this mechanism, acetylcholine is triggered through the central nervous system, and following travel through the synaptic cleft, is bonded by a receptor. This allows an action potential to travel past the surface of cells and down transverse tubules. At this point, the action potential triggers the release of Ca^{2+} from the sarcoplasmic reticulum into the cytoplasm where contact is made with actin and myosin, activating the cross-bridge cycle, and allowing muscle contractions to take place (Calderón et al., 2014). If, as a result of muscle damage, Ca^{2+} were to move uncontrollably into the sarcoplasm, it would no longer be usable in its role to promote the creation of cross-bridges, consequently affecting force-producing abilities (Proske & Allen, 2005). Despite the disagreement regarding the primary event leading to EIMD, it appears that both mechanisms play a crucial role in the effect of eccentric muscle actions on the structure and function of muscle fibres.

Following the occurrence of muscle damage, a series of events occur, changing the chemical milieu of the cells across damaged and surrounding areas. Through this change in milieu, recruitment of immune cells (e.g., cytokines, acute-phase proteins, leukocytes, lymphocytes) to the site of damage is triggered, causing oedema and an increase in muscle temperature (Markus et al., 2021). Initially, neutrophils act to clear cellular debris, whilst thereafter, proinflammatory macrophages dominate the cell profile, secreting proinflammatory cytokines (e.g., interleukin-6, interleuking-8, tumor necrosis factor) which cause the phagocytosing of damaged tissue, and the initiation of myoblast proliferation (Markus et al., 2021; Peake et al., 2017). At this point, proinflammatory macrophages elicit an antagonist reaction, which induces the recruiting of more anti-inflammatory cytokines, which will further stimulate myoblast proliferation and expansion of the satellite cell pool (Markus et al., 2021). As satellite cells are recruited to the areas of damage, they fuse to surrounding muscle. This is where they produce daughter cells, and subsequently new myonuclei (i.e., the nuclei of a muscle fibre) within muscle. This increases the capacity for protein synthesis, and as such, satellite cells have an important role in the adaptation process (Douglas et al., 2017).

2.3.2 Blunt force trauma

Alongside eccentric muscle actions, a high intensity and frequency of physical collisions and contact are known to cause muscle damage through blunt force trauma (i.e., injury of the body by forceful impact or falls) (Naughton et al., 2018). Indeed, various studies (McLellan & Lovell, 2012; Oxendale et al., 2016; Smart et al., 2008; Takarada, 2003) have highlighted the positive correlation between the frequency and intensity of physical contact and the level of post-exercises fatigue, whilst others found increased perturbations following sessions that included physical contact compared to those that did not (Mullen et al., 2015; Roe et al., 2017b). Although post-match recovery markers are likely influenced by both IIMD and EIMD, physical contact is an important contributor to muscle damage following rugby-specific exercise. Whilst IIMD may differ from EIMD as a result of augmented inflammatory infiltrate and subsequent secondary damage response (Merrick, 2002), it appears that many commonalities are shared by IIMD and EIMD in the regeneration and remodelling process of muscle tissue (Naughton et al., 2018). Indeed, heavy impacts may disrupt capillary networks, produce intramuscular bleeding, oedema, and inflammation (Elmer et al., 2012). The inflammatory response is helped by local vasodilation to assist the binding of neutrophils and macrophages to the damaged site, and the subsequent release of cytokines and other pro-inflammatory factors (Smith et al., 2008). The high levels of mechanic stress cause increased membrane permeability, resulting in a release of intracellular muscle specific enzymes and proteins into the blood stream. All these changes along with an associated rise in intramuscular pressure (Järvinen et al., 2005), are also linked to the myofilament overlap and the reduced ability of creating cross-brides, consequently affecting force generating capacity.

2.3.3 Delayed onset of muscle soreness

A term commonly associated with muscle damage is delayed onset of muscle soreness or DOMS (Paulsen et al., 2012). Although some uncertainty remains regarding the precise mechanisms responsible for DOMS, two pathways (i.e., the B_2-bradykinin receptor and the cyclooxygenase-2 pathway) are generally involved in mechanical hyperalgesia (i.e., enhanced sensitivity to pain), which results in the sensation of soreness (Paulsen et al., 2010; Peake et al., 2017). As inflammatory cells infiltrate the damaged skeletal muscle, they release chemical mediators such as histamines, bradykinins and prostaglandins, which directly or indirectly (i.e., by binding to extracellular receptors to upregulate the expressions of neurotrophins) act on muscle nociceptors to produce soreness (Hyldahl & Hubal, 2014). The associated oedema and rise of tissue temperature, because of recruitment of cytokines, leukocytes, and lymphocytes, cause additional soreness and a subsequent decrease in wellness (Markus et al., 2021).

2.4 Post-exercise responses

Muscle damage elicits a cascade of physiological events which remove, regenerate, and remodel the damaged tissue, ultimately leading to adaptation in preparation for future exposure (Peake et al., 2017). Various assessments may be used to provide an indication of the extent of muscle damage that has taken place. However, considerable methodological variation exists amongst studies profiling post-exercise responses in rugby players. With respect to the mode of exercise stimulus, responses to training (Coutts & Reaburn, 2008; Elloumi et al., 2012; Johnston et al., 2016a; Roe et al., 2017b), simulated match-play (Green et al., 2017; Mullen et al., 2015; Pereira et al., 2018; Twist & Sykes, 2011), tournaments or intensified periods of competition (Clarke et al., 2015; Johnston et al., 2013a, 2015a; Tee et al., 2017), a full season (Alaphilippe et al., 2012; Gastin et al., 2013), or a (single) competitive match (McLellan & Lovell, 2012; McLellan et al., 2010, 2011a; Oxendale et al., 2016; Roe et al., 2016c) have all been examined. Acknowledging the likely differences between these various stimuli, the current section of the literature review aimed to provide a contextual overview and describe post-match recovery timelines whilst highlighting the methodology and measures used between studies. Acknowledging some of their unique physical demands, particularly with respect to tackles and collisions, RL and RU also share many similarities. For this reason, both codes have been included in the current section to provide a thorough overview of the available literature.

Incongruence exists between studies in the reporting of activity profiles (i.e., playing time, distance covered, high-speed running, number of carries, number and intensity of collisions and total match loads) with publications either providing a comprehensive analysis (Jones et al., 2014; McLellan & Lovell, 2012; McLellan et al., 2010; Oxendale et al., 2016; Roe et al., 2016c; Twist et al., 2012), whereas others include only limited information (Cunniffe et al., 2010; Lindsay et al., 2015b; McLean et al., 2010; Shearer et al., 2015; Takarada, 2003), if any at all (Elloumi et al., 2003; Johnston et al., 2015b; McLellan et al., 2011a; West et al., 2014). Also, the training that is concurrently performed after match-play is inconsistently reported with some studies employing high experimental control and omitting training for the full duration of the study (Roe et al., 2016c; Takarada, 2003; West et al., 2014), whereas others report adherence to a normal training regime (McLean et al., 2010; McLellan & Lovell, 2012; McLellan et al., 2010). Accordingly, questions remain as to the ecological validity (i.e., the extent to which the findings are able to be generalised to real-life settings) (Lewkowicz, 2001) of the protocols adopted within these investigations.

Nevertheless, post-match responses to competitive rugby match-play have typically been assessed via measurement of neuromuscular (Duffield et al., 2012; McLellan & Lovell, 2012; Roe et al., 2016d), biochemical and endocrine (Cunniffe et al., 2010; Elloumi et al., 2003; Jones et al., 2014; Lindsay et al., 2015b; McLellan et al., 2010; Takarada, 2003) or perceptual (Fletcher et al., 2016; Gastin et al., 2013) responses; with the majority of studies reporting more than one marker of recovery (Johnston et al., 2015b; McLean et al., 2010; McLellan et al., 2011a; Oxendale et al., 2016; Roe et al., 2016c; Shearer et al., 2015; Twist et al., 2012; West et al., 2014). Currently, no clear consensus exists regarding post-match recovery profiles and the timelines of such responses, whilst also considering the type of measurements performed as well as recognition of the different training regimes, recovery protocols, and other sources of methodological variation, such as study population. Notably, only a small number of studies assessed post-match responses following academy rugby. The inclusion or exclusion of these contextual variables is likely to affect the magnitude and duration of the post-match response, which would have implications on the practical application of such data. In order to provide a correct interpretation of the post-exercise response, such contextual variables are to be accounted for.

2.4.1 Neuromuscular responses

In a total sample of 177 players (mass 93.5±7.3 kg; height: 1.84±0.02 m), the 11 studies that profiled a neuromuscular response following match-play implemented various measurement techniques, including isometric tests on the knee extensors (Duffield et al., 2012), an adductor squeeze test (Roe et al., 2016d), and a plyometric push-up (PPU) (Johnston et al., 2015b; Oxendale et al., 2016; Roe et al., 2016c), whilst the most common measure was the countermovement jump (CMJ) (Duffield et al., 2012; Johnston et al., 2015b; McLean et al., 2010; McLellan & Lovell, 2012; McLellan et al., 2011a; Oxendale et al., 2016; Roe et al., 2016c; Shearer et al., 2015; Twist et al., 2012; West et al., 2014) (Table 2.1).

Although different CMJ variables (e.g., peak rate of force development; PRFD, peak force; PF, mean power) were reported (McLellan & Lovell, 2012; McLellan et al., 2011a; Roe et al., 2016c), peak power output (PP) (Johnston et al., 2015b; McLean et al., 2010; McLellan & Lovell, 2012; McLellan et al., 2011a; Shearer et al., 2015; West et al., 2014) and flight-time (FT) (McLean et al., 2010; Oxendale et al., 2016; Twist et al., 2012) were the most frequently analysed. Reductions in PP (<31.5%) occurred <30 min post-match, returning to baseline values within 48-72 h (Figure 2.3) whereas post-match reductions in FT (<4%) recovered after 48 h (Figure 2.4). The average age of the players in the studies profiling a neuromuscular response was ~22 years, whilst three studies (two of which used the same sample) focused on younger (i.e., <20 years old) athletes (Johnston et al., 2015b; Roe et al., 2016c; Roe et al., 2016d). Three studies (McLellan & Lovell, 2012; Oxendale et al., 2016; Twist et al., 2012) provided detailed information regarding the activity profile of the exercise stimulus and four studies (McLellan & Lovell, 2012; McLellan et al., 2011a; Oxendale et al., 2016; Twist et al., 2012) reported the use of recovery strategies post-match.

Table 2.1 Studies investigating the recovery profile of neuromuscular responses following rugby match-play.

Study	Players	Code + Level	Stimulus	Recovery strategies	Measures taken	Results
(Johnston et al., 2015b)	Professional U20 players (n: 21; age: 19±2 years; stature: 1.81±0.06 m; mass: 89.9±10.0 kg)	RL; feeder team competition to the NRL	Not reported	Not reported	CMJ (PP) (%Δ from baseline)	+30 min: -6.5±7.0% ↓ from baseline, +24 h: -3.1±8.2% ↔, +48 h: -1.5±5.9% ↔
(McLean et al., 2010)	Professional players (n: 12; age: 24±4 years; height: 1.85±0.06 m; mass: 101.9±8.4 kg)	RL; NLR team	Match load: Game 1: 421±173 AU Game 2: 411±213 AU Game 3: 411±217 AU	MD+1: Recovery session. No details reported.	CMJ (FT) (Δ from baseline)	+24 h: ↓ from baseline (*d*: 1.67), +96 h: ↔ (*d*: 0.96)
(McLellan & Lovell, 2012)	Professional players (n:22; age: 24±7 years; stature: 1.88±0.02 m; mass: 94.6±26.8 kg)	RL; NRL team	Distance: 7886±1695 m (B), 7462±1566 m (F); #tackles: 11±9 (B), 26±15 (F); #carries: 12±5 (B), 14±5 (F)	Post-match: cycle (10min), CWI, light meal → MD+1 (AM): stationary cycling (10min), CWI, physiotherapy + massage available → MD+1 (PM): cycle (10min), CWI, physiotherapy + massage available, active rest	CMJ (PP)	+30 min: 3109±892 W ↓ from baseline (4539±976 W), +24h: 2865±824 W ↓, +48 h: 4286±1142 W ↔, +72 h: 4843±1087 W ↔, +96 h: 4621±1379 W ↔, +120 h: 4447±1274 W ↔
(McLellan et al., 2011a)	Professional players (n:17; age: 19±1 years; stature: 1.88±0.02 m; mass: 89.6±15.8 kg)	RL; NRL team	Not reported	Post-match: cycle (10min), CWI → MD+1 (AM): cycle (10min), CWI, physiotherapy + massage available → MD+1 (PM): active rest	CMJ (PP)	+30 min: 3123±850 W ↓ from baseline (4429±991 W), +24 h: 3479±717 W ↓, +48 h: 4540±898 W ↔, +72 h: 4632±959 W ↔, +96 h: 5050±979 W ↔, +120 h: 4485±875 W ↔
(Oxendale et al., 2016)	Professional players (n: 17; age: 25±4 years; stature: 1.84±0.06 m; mass: 98.5±10.3 kg)	RL; SL team	Playing duration: 55±21 min (F), 67±25 min (B); distance: 4675±1678 m (82±7 m/min) (F), 5640±2191 m (83±10 m/min) (B); high-intensity running: 307±194 m (F), 481±262 m (B); #high-intensity accelerations: 5±3 (F), 9±6 (B); #high-intensity decelerations: 8±5 (F), 10±6 (B); #collisions: 54±37 (F), 31±5 (B); #RHIE: 14±10 (F), 10±5 (B)	MD+1: Low-intensity exercise and massage (30 min). MD +2: Players encouraged to rest.	CMJ (FT)	+12h: 0.612 s ↓ from baseline (0.637 s), +36 h: 0.6115 s ↓, +60 h: 0.623 s ↔
(Shearer et al., 2015)	Professional players (n:12; age: 25±4 years)	RU; professional team in South Wales, UK	Playing duration: 82±11 min.	Participants instructed to follow normal individual recovery strategies. No details reported.	CMJ (PP)	+12 h: 5628±660 W ↓ from baseline (6119±526 W), +36 h: 5777±684 W ↓, +60 h: 5976±497 W ↓

(Twist et al., 2012)	Professional players (n: 23; B:10, F:13) (age: 26±5 years; stature: 1.83±0.07; mass: 91.9±11.6 kg (B), 102.0±6.7 kg (F))	RL; SL team	Playing duration: 80±0 min (B), 51±16 min (F); #tot contacts: 25±8 (B), 38±19 (F); #defensive contacts: 14±8 (B), 26±14 (F); #offensive contacts: 12±3 (B), 13±6 (F)	MD+1: Deep-water running & swimming (20 min) MD+1 (PM): Players encouraged to rest.	CMJ (FT)	F: +24 h: 0.59±0.06 ↓ from baseline (0.61±0.04 s), +48 h: 0.6±0.05 s ↓ B: +24 h: 0.64±0.04 ↓ from baseline (0.66±0.04 s), +48 h: 0.64±0.03 ↓
(West et al., 2014)	Professional players (n: 14; age: 25±4 years; stature: 1.85±0.10 m; mass: 105.2±12.3 kg)	RU; professional team in South Wales, UK	Not reported	Not reported	CMJ (PP)	+12 h≈ 5190 W ↓ from baseline (≈6100 W), +36 h≈ 5750 W ↓, +60 h: (≈5910 W) ↓

Δ: Change, ↓: Significant decrease from baseline, ↔: No significant change from baseline, #: Number of, B: Backs, CMJ: Countermovement jump, *d* :Cohen's d, F: Forwards, FT: Flight-Time, MD: Match day, MD +1: First day post-match, NRL, National Rugby League, PP: Peak power output, RelPP, Relative Peak Power, RHIE: repeated high-intensity effort, RL: Rugby League, RU: Rugby Union, SL: Super League.

2.4.1.1 Peak power output

Out of the five studies profiling the PP response to match-play (Figure 2.3), three reported an acute response post-match (i.e., within 60 min), observing decrements ranging between 6.5% and 31.5% (Johnston et al., 2015b; McLellan & Lovell, 2012; McLellan et al., 2011a). Whilst two of these studies (McLellan & Lovell, 2012; McLellan et al., 2011a) also observed decrements of up to 37% at 24 h post-match, Johnston et al. (2015b) reported no significant differences at this time-point. This discrepancy in the magnitude of the responses between studies may be due to the exercise stimulus performed. While the smaller (i.e., ~6.5%) decrements represented responses to a lesser standard of the game (i.e., a feeder competition to the NRL), other studies measured greater (i.e., ~37%) perturbations in PP in response to in-season NRL games (McLellan & Lovell, 2012; McLellan et al., 2011a). While the two playing standards have similar game-specific skills, variation may exist in the external physical load of the matches, with NRL players typically playing the game at a higher intensity (Sirotic et al., 2009).

In contrast to those studies reporting an acute post-match response (Johnston et al., 2015b; McLellan & Lovell, 2012; McLellan et al., 2011a), others (Shearer et al., 2015; West et al., 2014) took their first measurements at 12 h post-match. At this time-point, reductions of PP of 8% (Shearer et al., 2015) and 15% (West et al., 2014) were reported to peak. Smaller reductions of up to 6% have been reported after 36 h, with almost full restoration of PP at 60 h post-match. Given that larger decrements have been reported at 24 h compared with 12 h following rugby match-play (McLellan & Lovell, 2012; McLellan et al., 2011a), omitting measurements at 24 h (Shearer et al., 2015; West et al., 2014) could lead to an underestimation of the fatigue response. As neuromuscular responses are likely to peak within 24 h of match-play, additional training that has the potential to prolong or exacerbate fatigue in the same muscle groups (i.e., high-intensity field-based training or lower-body resistance training) should, where possible, be avoided at this time if recovery is deemed to be the priority.

Increases in PP of up to 49% have been reported between 24 h and 48 h post-match (McLellan & Lovell, 2012; McLellan et al., 2011a), although not all studies support such a magnitude of change (Johnston et al., 2015a; Shearer et al., 2015; West et al., 2014). Such discrepancies may reflect the different recovery strategies used throughout the duration of these studies (i.e., CWI, stationary cycling, massage, and physiotherapy). Although conflicting findings exist (Tavares et al., 2017), CWI has been proposed to enhance the speed of restoration of neuromuscular function (Garcia et al., 2016; Webb et al., 2013), and together with several other recovery modalities (i.e., stationary cycling, massage and physiotherapy), this could at least partly explain the large increases in PP measures following the initial 24 h post-match period.

Large inverse correlations have been reported between the number of very heavy and severe impacts and PP values measured at 24 h post-match (McLellan & Lovell, 2012). At this time-point, PF has already recovered to pre-match levels, while PP shows a continued reduction, possibly indicating that the velocity component of CMJ testing was more sensitive to fatigue than the force component. As this has been supported further (Byrne & Eston, 2002; Sargeant & Dolan, 1987), it could be suggested that variables including a velocity component (i.e., PP or PRFD) are more fatigue-sensitive and are thus more useful than PF when monitoring post-match neuromuscular fatigue. While some variables may be more sensitive than others, it appears that neuromuscular fatigue mechanisms could require up to 72 h to normalise following rugby match-play (Shearer et al., 2015; West et al., 2014). While recovery of PP is commonly achieved at 72 h post-match, day-to-day depressions have been observed after this time-point (McLellan & Lovell, 2012; McLellan et al., 2011a). That being said, such findings have occurred when additional training sessions focusing on speed/agility, strength, or skills have been performed throughout the recovery period (McLellan & Lovell, 2012; McLellan et al., 2011a). In order to provide information that is most applicable to practical environments, post-match responses should be profiled in ecologically valid scenarios (i.e., alongside ‘normal’ training regimes).

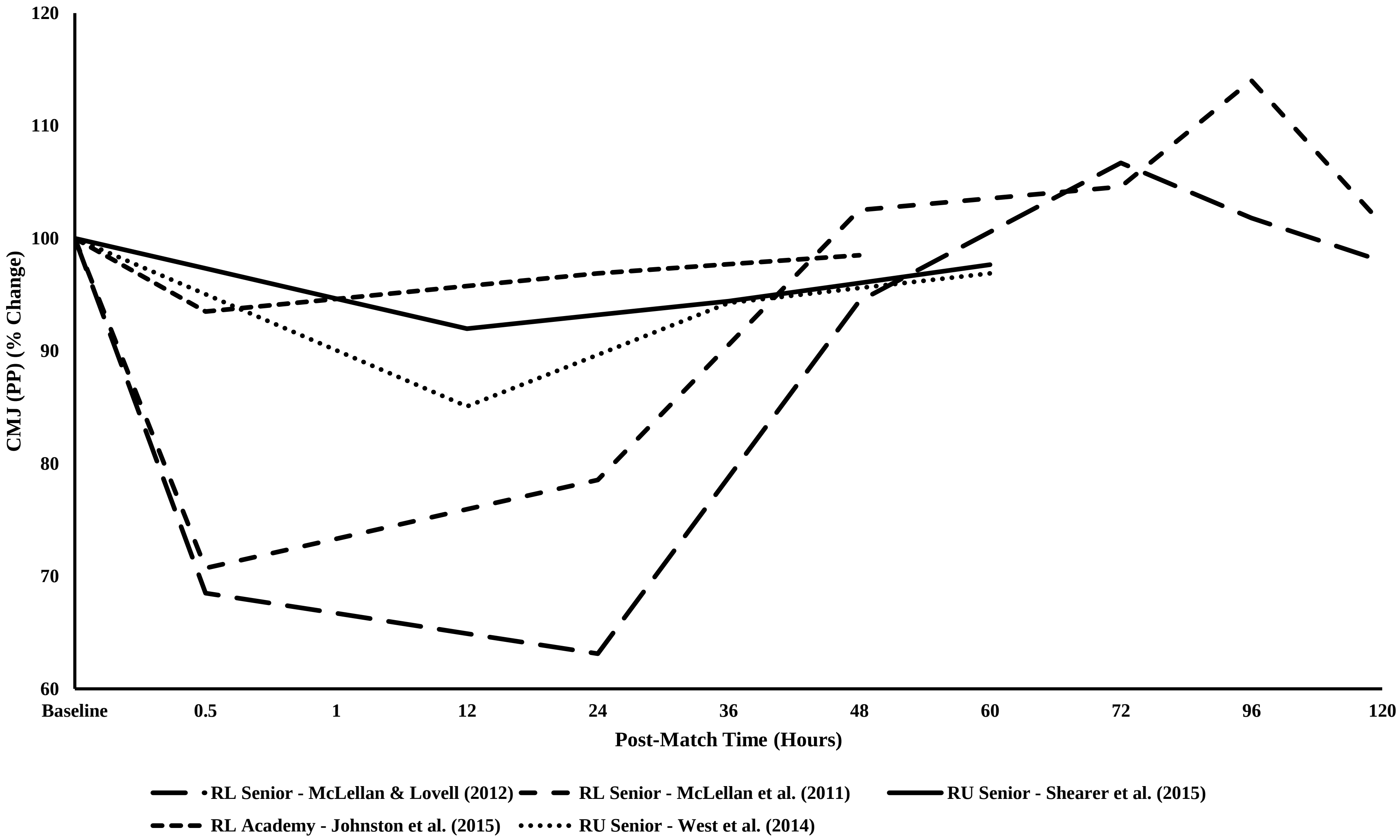

Figure 2.3 Recovery time-course percentage changes in countermovement jump (CMJ) peak power output (PP) following rugby union (RU) and league (RL) match-play

2.4.1.2 Flight-time

Three studies (McLean et al., 2010; Oxendale et al., 2016; Twist et al., 2012) reported the post-match FT response during CMJ testing (Figure 2.4). Two of these studies provided detailed information in relation to activity profiles as well as the post-match recovery strategies employed (Oxendale et al., 2016; Twist et al., 2012). All studies have described a similar pattern of response in which FT is acutely reduced (i.e., within 60 min), before further decrements occur at 24 h post-match. Changes at 48 h and beyond have mostly been reported as trivial or insignificant, indicating a return to near pre-match values (Oxendale et al., 2016; Twist et al., 2012).

It has been reported that the number of contacts experienced during match-play is inversely related to FT values assessed post-match (Twist et al., 2012). However, owing to the non-significance of findings, Oxendale et al. (2016) did not report FT correlations with match demands. As other CMJ variables (i.e., PP) have demonstrated strong correlations with the demands of the preceding match, and given the relationship to the fatigue response (McLellan & Lovell, 2012; Roe et al., 2017b), it would appear worthwhile for applied practitioners to consider the loading imposed by collisions and activities requiring eccentric muscle actions (i.e., high-intensity running, accelerations and decelerations) when designing post-match training and recovery protocols.

An additional CMJ variable, the flight time:contraction time (FT:CT) ratio (the relationship between the time spent in the countermovement phase and the resulting flight time) has been proposed in the literature that has examined responses to Australian Football (AF) (Cormack et al., 2008a). FT:CT showed significant reductions initially post-match and after 24 h. Unlike FT however, small decreases after 72 h were still detected (Cormack et al., 2008a). Previous research has shown changes in hip and knee angle (Augustsson et al., 2006) as well as a decrease in muscle-tendon stiffness (Toumi et al., 2006) during hopping tasks when players are in a fatigued state. These adapted mechanics could be responsible for any changes in FT:CT and may therefore be extremely useful to consider when measuring neuromuscular fatigue.

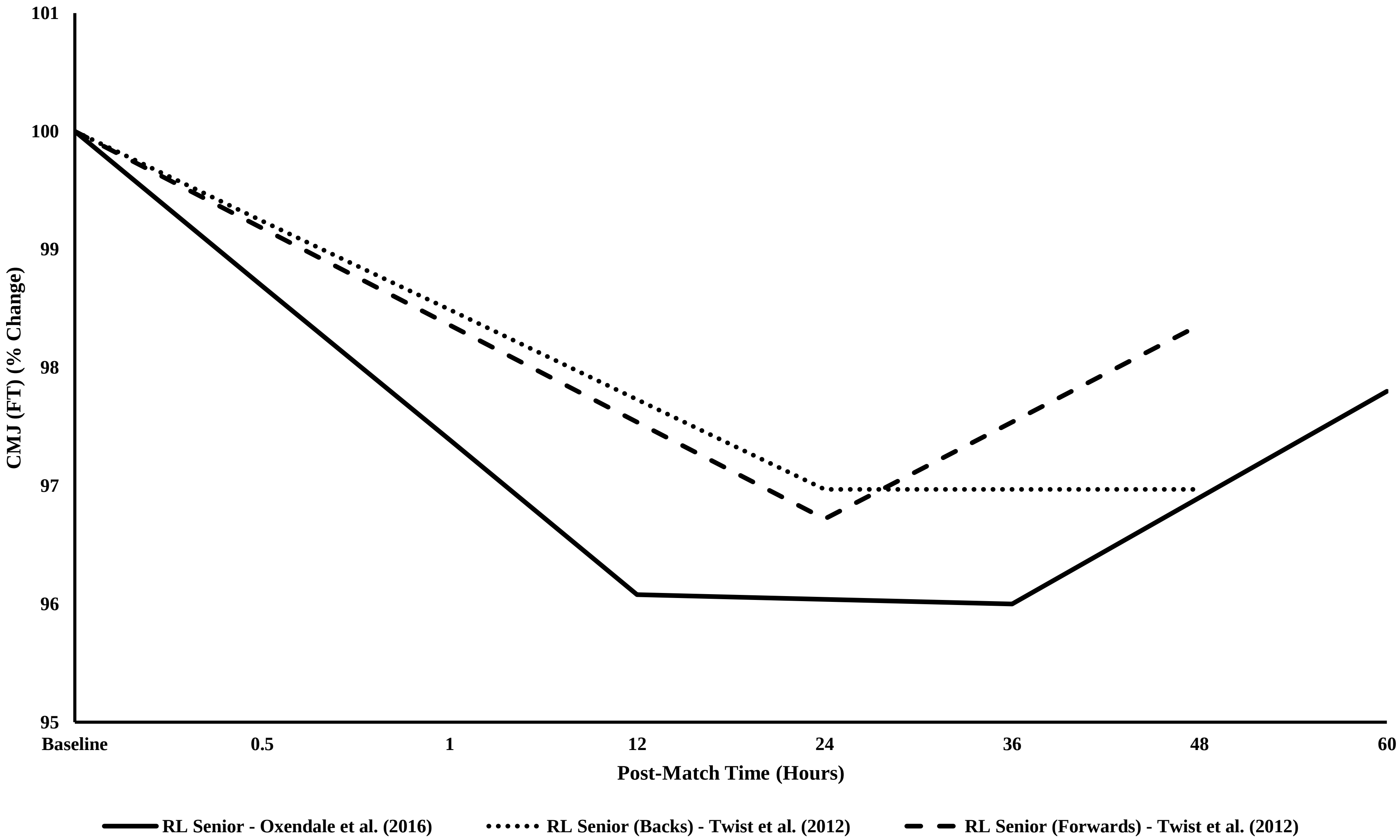

Figure 2.4 Recovery time-course percentage changes in countermovement jump (CMJ) flight-time (FT) following rugby union (RU) and league (RL) match-play

2.4.2 Biochemical or endocrine responses

In total, 14 studies (Table 2.2) assessed biochemical and/or endocrine responses following match-play in a total sample of 243 players (mass 94.9±6.5 kg; height: 1.84±0.03 m). Nine studies reported changes in creatine kinase (CK) concentrations, whereas eight studies reported relative changes in salivary or blood cortisol (C) concentrations, and six studies assessed the salivary or blood testosterone (T) response. Disturbances in CK peaked (120-451%) between 12-24 h, returning to baseline within 72 h of match-play (Figure 2.5). Initial increases in C (34-298%), and reduced T (<44%) concentrations, returned to pre-match values within 48-72 h (Figures 2.6 and 2.7, respectively). The average age of the players in the studies profiling endocrine and/or biochemical responses following match-play was ~24 years, with two studies profiling responses in younger (i.e., under-20s) (Johnston et al., 2015b) or academy RU (i.e., 16-19 years) players (Roe et al., 2016c). In total, five studies provided detailed information in relation to activity profiles (Jones et al., 2014; McLellan et al., 2010; Oxendale et al., 2016; Roe et al., 2016c; Twist et al., 2012) while four studies reported the use of recovery strategies (Jones et al., 2014; McLellan et al., 2011a; Oxendale et al., 2016; Twist et al., 2012), suggesting that the majority of these studies omit the influence of confounding variables that could influence the interpretation of the data.

Table 2.2 Studies investigating the recovery profile of biochemical and endocrine responses following rugby match-play.

Study	Players	Code + Level	Stimulus	Recovery Strategies	Measures taken	Results
(Cunniffe et al., 2010)	Professional players (n: 10; age: 26±1 years; stature: 1.87±0.03 m; mass: 103.1±3.9 kg)	RU; international team (Wales)	Playing duration: 69±9 min	Not reported	C,T,CK	C: +30 min: 534±47 $nmol \cdot L^{-1}$ ↔ from baseline (313±6.3 $nmol \cdot L^{-1}$), +14 h: 400±21 $nmol \cdot L^{-1}$ ↔, +38 h: 261±21 $nmol \cdot L^{-1}$ ↔ T: +30 min: 13.8±1.3 $nmol \cdot L^{-1}$ ↓ from baseline (24.6±0.6 $nmol \cdot L^{-1}$), +14 h: 20.2±1.3 $nmol \cdot L^{-1}$ ↔, +38 h: 24.3±2.1 ↔ CK: +30 min: 519±60 $IU \cdot L^{-1}$ ↔ from baseline (333±49 $IU \cdot L^{-1}$), +14 h: 1182±231 $IU \cdot L^{-1}$ ↑, +38 h: 750±99 $IU \cdot L^{-1}$ ↑
(Elloumi et al., 2003)	Semi-professional players (n: 20; age: 25±4 years; stature: 1.80±0.05 m; mass: 88.0±2.9)	RU; Tunisian national team	Not reported	Not reported	C,T	C: +30 min ≈20.2 $nmol \cdot L^{-1}$ ↔ from baseline (≈17.8 $nmol \cdot L^{-1}$), +2 h≈ 12.1 $nmol \cdot L^{-1}$ ↓, +4 h≈ 6.9 $nmol \cdot L^{-1}$ ↓, +12 h≈ 10.1 $nmol \cdot L^{-1}$ ↓, +24 h≈ 5.3 $nmol \cdot L^{-1}$ ↓, +36 h≈ 9.1 $nmol \cdot L^{-1}$ ↓, +48 h≈ 4.7 $nmol \cdot L^{-1}$ ↓, +60 h≈ 10.0 $nmol \cdot L^{-1}$ ↓, +72 h≈ 4.5 $nmol \cdot L^{-1}$ ↓, +84 h≈ 9.4 $nmol \cdot L^{-1}$ ↓, +96 h≈ 5.6 $nmol \cdot L^{-1}$ ↓, +108 h≈ 13.7 $nmol \cdot L^{-1}$ ↓, +120 h≈ 6.1 $nmol \cdot L^{-1}$ ↓, +132 h≈ 15.3 $nmol \cdot L^{-1}$ ↓, +144 h≈ 6.4 $nmol \cdot L^{-1}$ ↓ T: +30 min≈ 20.2 $nmol \cdot L^{-1}$ ↔ from baseline (≈365 $pmol \cdot L^{-1}$), +2 h≈ 305 $pmol \cdot L^{-1}$ ↓, +4 h≈ 315 $pmol \cdot L^{-1}$ ↓, +12 h≈ 430 $pmol \cdot L^{-1}$ ↔, +24 h≈ 400 $pmol \cdot L^{-1}$ ↔, +36 h≈ 410 $pmol \cdot L^{-1}$ ↔, +48 h≈ 415 $pmol \cdot L^{-1}$ ↔, +60 h≈ 465 $pmol \cdot L^{-1}$ ↔, +72 h≈ 355 $pmol \cdot L^{-1}$ ↔, +84 h≈ 402 $pmol \cdot L^{-1}$ ↔, +96 h≈ 402 $pmol \cdot L^{-1}$ ↔, +108 h≈ 365 $pmol \cdot L^{-1}$ ↔, +120 h≈ 390 $pmol \cdot L^{-1}$ ↔, +132 h≈ 415 $pmol \cdot L^{-1}$ ↔, +144 h≈ 410 $pmol \cdot L^{-1}$ ↔
(Johnston et al., 2015b)	Professional U20 players (n: 21; age: 19±2 years; stature: 1.81±0.06 m; mass: 89.9±10.0 kg)	RL; feeder team competition to the NRL	Not reported	Not reported	CK (%Δ from baseline)	+30 min: ↑ from baseline (relative changes not reported), +24 h: 120±92% ↑, +48 h: 55±58% ↑
(Jones et al., 2014)	Professional players (n: 28; age: 24±3 years; (B); body mass: 111.6±5.7 kg (F), 94.2±7.9 kg (B))	RU; Team in the European Cup	Game time: 80±13 min (F), 87±11 min (B), total distance: 4906±902 m (60.4±7.8 m/min) (F), 5959±1013 m (67.8±8.2 m/min) (B); high-speed running (>5 $m \cdot s^{-1}$): 231±167 m (F), 509±150 m (B); sprinting (>5.6 $m \cdot s^{-1}$):	Post-game: CWT. MD+1: Active recovery.	CK	B: +16 h: 1511±871 $U \cdot L^{-1}$ ↑ from baseline (274±155 $U \cdot L^{-1}$), +40 h: 814±412 $U \cdot L^{-1}$ ↑ F: +16 h: 1073±483 $U \cdot L^{-1}$ ↑ from baseline (368±127 $U \cdot L^{-1}$), +40 h: 657±412 $U \cdot L^{-1}$ ↑

			121±112 m (F), 333±122 m (B); #total impacts: 25±9 (F), 15±7 (B)			
(Lindsay et al., 2015b)	Professional players (n: 11; stature: 1.87 m (1.81-1.89 m); mass: 96 kg (88.5-101.5 kg)	RU; Division one team in New-Zealand	Distance: 6029±690 m; #impacts: 46±25	Not reported	C	C: +30 min: 60.5±24.6.6 μmol·L^{-1} ↑ from baseline (15.2±7.2 μmol·L^{-1}), +17 h≈ 33.4 μmol·L^{-1} ↔, +25 h≈ 15.1 μmol·L^{-1} ↔, +38 h≈ 33.7 μmol·L^{-1} ↔, +62 h≈ 34.1 μmol·L^{-1} ↔
(McLean et al., 2010)	Professional players (n: 12; age: 24±4 years; height: 1.85±0.06 m; mass: 101.9±8.4 kg)	RL; NLR team	Match load: Game 1: 421±173 AU Game 2: 411±213 AU Game 3: 411±217 AU	MD+1: Recovery session. No details reported.	C & T (Δ from baseline)	C: +24 h: ↔ from baseline, +96 h: ↑ (*d*: 0.60) T: +24 h: ↔ from baseline, +48 h: ↔, +96 h: ↔
(McLellan et al., 2010)	Professional players (n:17; age: 19±1 years; stature: 1.88±0.02 m; mass: 89.6±15.8 kg)	RL; NRL team	Distance: 5747±1095 m (B), 4774±1186 m (F); distance at high-intensity running (5-5.5 m·s^{-1}): 135±49 m (B), 82±21 m (F); sprinting (>5.5 m·s^{-1}): 290±69 m (B), 149±32 m (F)	MD+1: Two recovery sessions. No details reported.	CK, C, T (%Δ compared to previous time-point)	CK: +30 min: 56% ↑ from baseline, +24 h: 91% ↑, +48 h: -32% ↔, +72 h: -3% ↔, +96 h: -18% ↔, +120 h: 12% ↔ C: +30 min: 68% ↑ from baseline, +24 h: -32% ↑, +48 h: -37% ↔, up to +120 h ↔ (relative changes not reported) T: +30 min: 14% ↔ from baseline, +24 h: 33% ↑, +48 h≈ 1.6% ↑, +72 h≈ 8.5% ↑, +96 h: -29.3% ↔, +120 h: -7.56% ↔
(McLellan et al., 2011a)	Professional players (n:17; age: 19±1 years; stature: 1.88±0.02 m; mass: 89.6±15.8 kg)	RL; NRL team	Not reported	Post-match: cycle (10min), CWI → MD+1 (AM): cycle (10min), CWI, physiotherapy + massage available → MD+1 (PM): active rest	CK, C	CK: +30 min: 454±167 U·L^{-1} ↑ from baseline (302±128 U·L^{-1}), +24 h: 941±392 U·L^{-1} ↑, +48 h: 592±201 U·L^{-1} ↑, +72 h: 553±191 U·L^{-1} ↑, +96 h: 442±154 U·L^{-1} ↑, +120 h: 365±139 U·L^{-1} ↑ C: +30 min: 21.9±4.4 nm·L^{-1} ↑ from baseline (13.1±2.6 nm·L^{-1}), +24 h: 15.3±3.5 nm·L^{-1} ↔, +48 h: 9.5±1.4 nm·L^{-1} ↔, +72 h: 9.5±1.6 nm·L^{-1} ↔, +96 h: 7±1.1 nm·L^{-1} ↓, +120 h: 9.2±1.5 nm·L^{-1} ↔
(Oxendale et al., 2016)	Professional players (n: 17; age: 25±4 years; stature: 1.84±0.06 m; mass: 98.5±10.3 kg)	RL; SL team	Playing duration: 55±21 min (F), 67±25 min (B); distance: 4675±1678 m (82±7 m/min) (F), 5640±2191 m (83±10 m/min) (B); high-intensity running: 307±194 m (F), 481±262 m (B); #high-intensity accelerations: 5±3 (F), 9±6 (B); #high-intensity decelerations: 8±5 (F), 10±6 (B); #collisions: 54±37 (F), 31±5 (B); #RHIE: 14±10 (F), 10±5 (B)	MD+1: Low-intensity exercise and massage (30 min). MD +2: Players encouraged to rest.	CK (MDif from baseline)	+12 h: 808.0±169.3 U·L^{-1} ↑ from baseline, +36 h: 525.0±136.4* U·L^{-1} ↑, +60 h≈ 95 U·L^{-1} ↑
(Roe et al., 2016c)	Professional U19 players (n: 14; age 17±1 years; stature:	RU; English academy team	Match duration: 73 min; AML: 334±121 AU; distance covered: 4691±878 m (74±6m.min^{-1}) of which 2215±461 m jogging, 663±238 m	Not recovery session	CK (%Δ from baseline)	+30 min: 138.5±33.1% ↑ from baseline, +24 h: 326.0±77.6% ↑, +48 h: 176.4±62.4% ↑, +72 h: 56.7±34.5% ↑

	1.83±0.08 m; mass: 86.2±11.6 kg)		striding and 41±40 m sprinting; APLTM: 451±102; PLTMs: 187±47			
(Shearer et al., 2015)	Professional players (n: 12; age: 25±4 years)	RU; professional team in South Wales, UK	Playing duration: 82±11 min.	Participants instructed to follow normal individual recovery strategies. No details reported.	C, T	C: +12 h: 0.55±0.11 μg/dL ↑ from baseline (0.40±0.10 μg/dL), +36 h: 0.610±0.20 μg/dL ↑, +60 h: 0.52±0.23 μg/dL ↔ T: +12 h: 147.6±60.1 pg/mL ↓ from baseline (204.9±80.8 pg/mL), +36 h: 163.6±68.5 pg/mL ↓, +60 h: 186±79.7 pg/mL ↔
(Takarada , 2003)	Amateur players (n: 15; age: 23-30 years; stature: 1.8±0.01 m; mass: 87.4±2.2 kg)	RU; Japanese amateur team	#Tackles: 14.0±7.4; Mean duration of work: 21.5±2.2 s; Mean duration of rest: 24.3±3.1 s	Not reported	CK	+0 min≈ 520 U/L ↔ from baseline (≈ 250 U/L), +45 min≈ 570 U/L ↔, +90 min≈ 600 U/L ↔, +24 h≈ 1050 U/L ↑, +48 h≈ 750 U/L ↔, +72 h≈ 300 U/L ↔
(Twist et al., 2012)	Professional players (n: 23; B:10, F:13) (age: 26±5 years; stature: 1.83±0.07; mass: 91.9±11.6 kg (B), 102.0±6.7 kg (F))	RL; SL team	Playing duration: 80±0 min (B), 51±16 min (F); #tot contacts: 25±8 (B), 38±19 (F); #defensive contacts: 14±8 (B), 26±14 (F); #offensive contacts: 12±3 (B), 13±6 (F)	MD+1: Deep-water running & swimming (20 min) MD+1 (PM): Players encouraged to rest.	CK	B: +24 h: 420.8 IU·L^{-1} ↑ from baseline (141 IU·L^{-1}), +48 h: 257 IU·L^{-1} ↑ F: +24 h: 431 IU·L^{-1} ↑ from baseline (171.7 IU·L^{-1}), +48 h: 266 IU·L^{-1} ↑
(West et al., 2014)	Professional players (n: 14; age: 25±4 years; stature: 1.85±0.10 m; mass: 105.2±12.3 kg)	RU; professional team in South Wales, UK	Not reported	Not reported	C, T	C: +12 h≈ 0.58 ug·dL^{-1} ↑ from baseline (≈0.39 ug·dL^{-1}), +36 h≈ 0.58 ug·dL^{-1} ↑, +60 h≈ 0.51 ug·dL^{-1} ↔ T: +12 h≈ 151 pg·ml^{-1} ↓ from baseline (≈ 215 pg·ml^{-1}), +36 h≈ 167 pg·ml^{-1} ↓, +60 h≈ 178 pg·ml^{-1} ↔

#: Number of, Δ: Change, ↓: Significant decrease from baseline, ↑: Significant increase from baseline, ↔: No significant change from baseline, AML: Average match load (RPE x time), APL^{TM}: Average PlayerLoad^{TM}, AU: Arbitrary units, B: Backs, C: Cortisol, CK: Creatine Kinase, *d* :Cohen's d, F: Forwards, MD: Match-day, MD +1: first day post-match, MDif: Mean difference, NRL, National Rugby League, PLTMs: PlayerLoad^{TM} slow, RL: Rugby League, RPE: Rate of perceived exertion, RU: Rugby Union, SL, Super League, T: Testosterone.

2.4.2.1 Creatine kinase concentrations

As an intracellular protein commonly associated with muscle damage, CK is found in both the cytosol and mitochondria of tissue where energy demands are high (e.g., skeletal muscle) and is important in the regeneration of cellular adenosine triphosphate (Baird et al., 2012). As the primary source of CK is cardiac muscle, the validity of reflecting changes in CK values as a consequence of the level and intensity of physical activity remains equivocal. High levels of day-to-day variation also exist in junior RU (Roe et al., 2016a) and RL players (Twist & Highton, 2013). Nonetheless, intense exercise leads to cellular disturbances (i.e., cell damage and cell disruption) which causes CK to leak from cells into the blood serum, where CK concentrations have been measured (Baird et al., 2012).

Throughout most studies (Figure 2.5), after an acute post-match increase, the largest increase in CK levels was found after 24 h (Johnston et al., 2015b; McLellan et al., 2010, 2011a; Roe et al., 2016c; Takarada, 2003; Twist et al., 2012). However, as some studies omitted measurements at this time-point, peak values have also been reported between 12-16 h. Therefore, whilst substantial variability exits between the magnitude of the responses in different studies (i.e., increments ranging from 120% to 451%), the highest CK concentrations were observed during the 12-24 h period following match-play (Cunniffe et al., 2010; Jones et al., 2014; Oxendale et al., 2016).

For those studies that reported responses beyond 48 h, all but one (Takarada, 2003) still observed significant increases in CK concentrations compared to baseline measures. Notably, as some studies profiled CK responses over five days (McLellan et al., 2010, 2011a), significant elevations relative to baseline remained after 120 h (McLellan et al., 2011a). While it might appear useful to assess post-match CK responses over a prolonged period (i.e., >4 days), it should be considered that large inter-individual variability exists in such measures. Indeed, because non-modifiable (e.g., age, gender, ethnicity) and modifiable (e.g., hydration status, energy status, training status) factors have been shown to influence serum CK levels (Baird et al., 2012), it could be questioned whether prolonged CK responses are an indication of continued exercise-induced muscle damage or natural perturbations. Indeed, changes in CK concentrations post-exercise may reflect merely the fact that muscle damage has occurred as opposed to the magnitude of the damage response. Nevertheless, although prolonged CK responses (i.e., >4 days) might occur, this is unlikely to significantly affect the prescription of post-match training regimes in an applied setting, as preparations for the following game will likely be taking priority (assuming a between-match period of six days).

Some studies (McLellan et al., 2010, 2011a) profiled recovery responses in ecologically valid scenarios in which training regimes (i.e., weight training, speed/agility and skills sessions) and recovery protocols (i.e., CWI, active recovery, massage and physiotherapy) were carried out and enforced as per the team's normal practices. It could be argued that these confounding variables would be expected to impact upon the recovery process. Notably, the inclusion of training (i.e., an additional stimulus in the form of speed/agility, strength or skills session) within the recovery period could prolong the return to baseline measures (Coutts & Reaburn, 2008; Elloumi et al., 2012), whereas the inclusion of effective strategies is likely to facilitate recovery (Tavares et al., 2017). Although evidence highlights that a minimum of 72 h is needed to recover CK responses to pre-match levels in ecologically valid scenarios, it should be emphasised that not all training has to be omitted within this 72 h window. Training type and intensity (e.g., active recovery to possibly facilitate the ability to train) could be adapted to avoid prolonging the initial fatigue response (Suzuki et al., 2004; Tavares et al., 2017).

External load variables such as collisions and high-speed running are positively correlated with changes in CK concentrations, indicating that players who were more frequently involved in high-intensity running or collision bouts typically experienced greater increases in CK concentrations (Jones et al., 2014; Oxendale et al., 2016; Twist et al., 2012). It is therefore recommended that future research reports these specific measures, as they are likely to affect the interpretation of CK responses and consequently the timescale of recovery. Exposure to high-speed running and collisions is known to differ according to playing position, with forwards typically performing a greater amount of collisions and backs typically covering more distance at higher intensities (Johnston et al., 2014a). As specific activity profiles (i.e., high-speed running and collision bouts) differ between codes and positions (Jones et al., 2014; Oxendale et al., 2016; Twist et al., 2012), this would consequently affect position-specific recovery timelines and should be considered in applied practice.

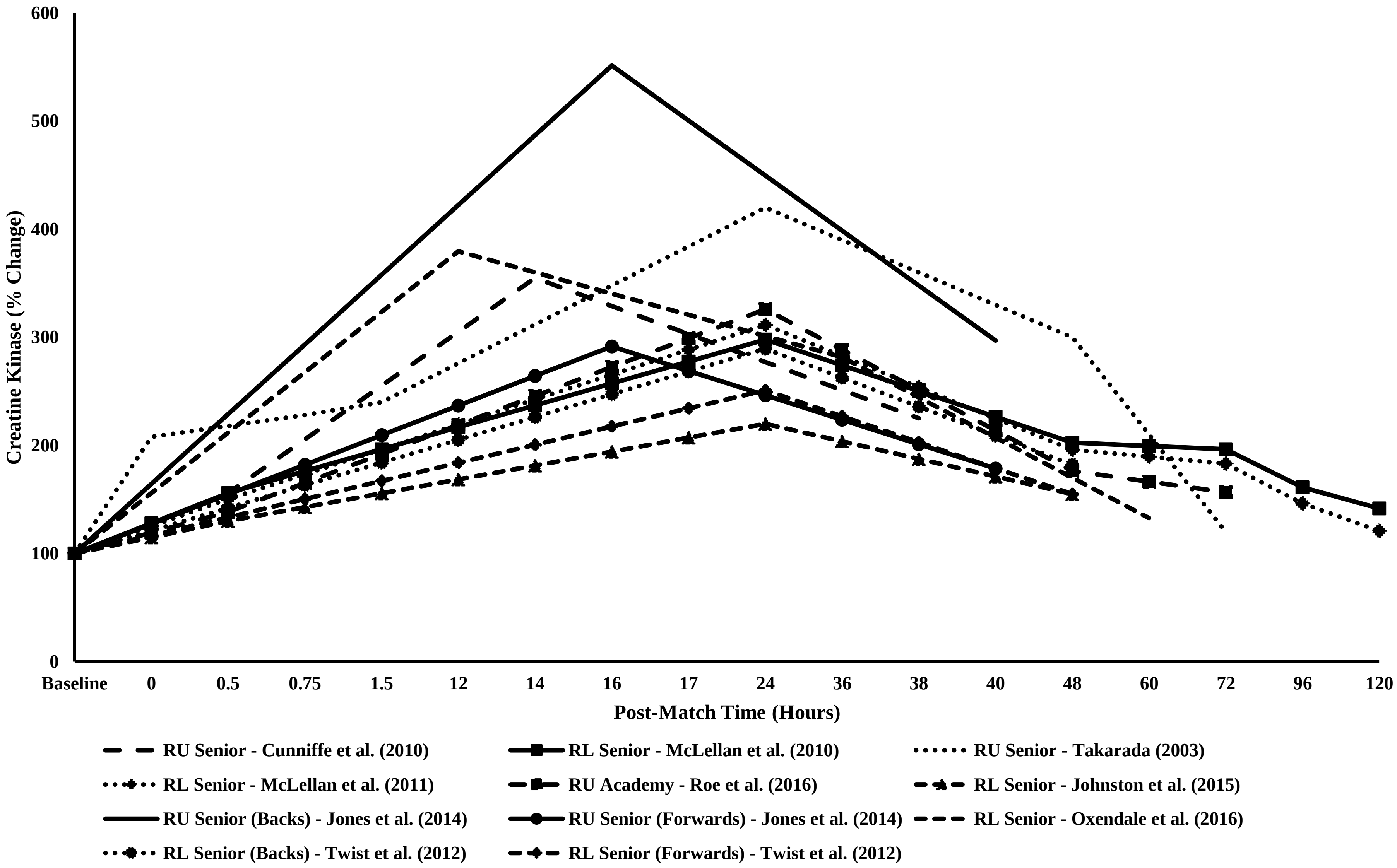

Figure 2.5 Recovery time-course percentage changes in creatine kinase concentrations following rugby union (RU) and league (RL) match-play

2.4.2.2 Cortisol concentrations

As it is considered an important catabolic hormone, the release of C is stimulated by adrenocorticotrophic hormone as a response to stress. Elevations in C result in increases in protein degradation in muscle and connective tissue (Cormack et al., 2008a). Within physiological limits, the magnitude of C secretion is generally proportional to the stress incurred (i.e., severe stress would result in a larger increase in C concentration than mild stress) (Cormack et al., 2008a). Consequently, post-match C concentrations have been used to give a representation of the level of stress that players have endured throughout the match and therefore have been used as a recovery marker. The majority of studies observed salivary C responses (Figure 2.6), whereas one study reported concentrations of serum C (Cunniffe et al., 2010). It is known that specific endocrine responses demonstrate circadian rhythmicity; a factor which alongside the potential for large individual variability, should be considered when using endocrine responses as an indication of recovery (Ljubijankić et al., 2008).

Out of the seven studies observing changes in C responses following match-play, five reported acute measurements (i.e., within 60 min following match-play) (Cunniffe et al., 2010; Elloumi et al., 2003; Lindsay et al., 2015b; McLellan et al., 2010, 2011a), whereas two studies performed their first post-match measure at a later (i.e., 12 h) time-point (Shearer et al., 2015; West et al., 2014). Of these five studies carrying out acute measurements, four studies reported an immediate rise in C concentrations, which would be the likely result of the intensity and duration of exercise (Lac & Berthon, 2000), and any anxiety responses (Passelergue & Lac, 1999) that are associated with rugby match-play. In large contrast to the increased C concentrations in the majority of studies (Cunniffe et al., 2010; Lindsay et al., 2015b; Shearer et al., 2015; West et al., 2014), a single study reported an almost immediate (i.e., within 2 h) decrease in C concentrations, which persisted throughout the duration of the study (i.e., 144 h) (Elloumi et al., 2003). However, information regarding playing time for the 20 participants, including five substitutes, was lacking. It is therefore possible that a reduced playing time for substitutes, and thus differences in the overall activity profiles experienced, may have influenced the mean C responses for the whole group. To avoid underestimation of the C response, future research incorporating post-match measurements of C concentrations should consider performing initial post-match measurements within

60 min, as multiple studies have indicated that this is a crucial period in which peak C concentrations are reported.

Despite an immediate post-match elevation in C concentrations being observed, substantial variability still exists. Indeed, Lindsay et al. (2015b) reported a four-fold increase in C concentrations at 30 min post-match, which is more than twice that observed in other studies (Cunniffe et al., 2010; McLellan et al., 2010, 2011a). An argument is made in this study that this was the result of a difference in game intensity (Lindsay et al., 2015b). However, this remains unclear as very little information was reported in relation to specific activity profiles. The only information provided related to total distance covered (6029 ± 690 m) and the number of impacts (46 ± 25), which do not differ drastically from values reported in other studies (McLellan et al., 2010) and are therefore unlikely to explain differences in the C concentrations observed. This finding emphasises the point that contextualisation of activity profiles is required to improve the interpretation of recovery data collected throughout such studies.

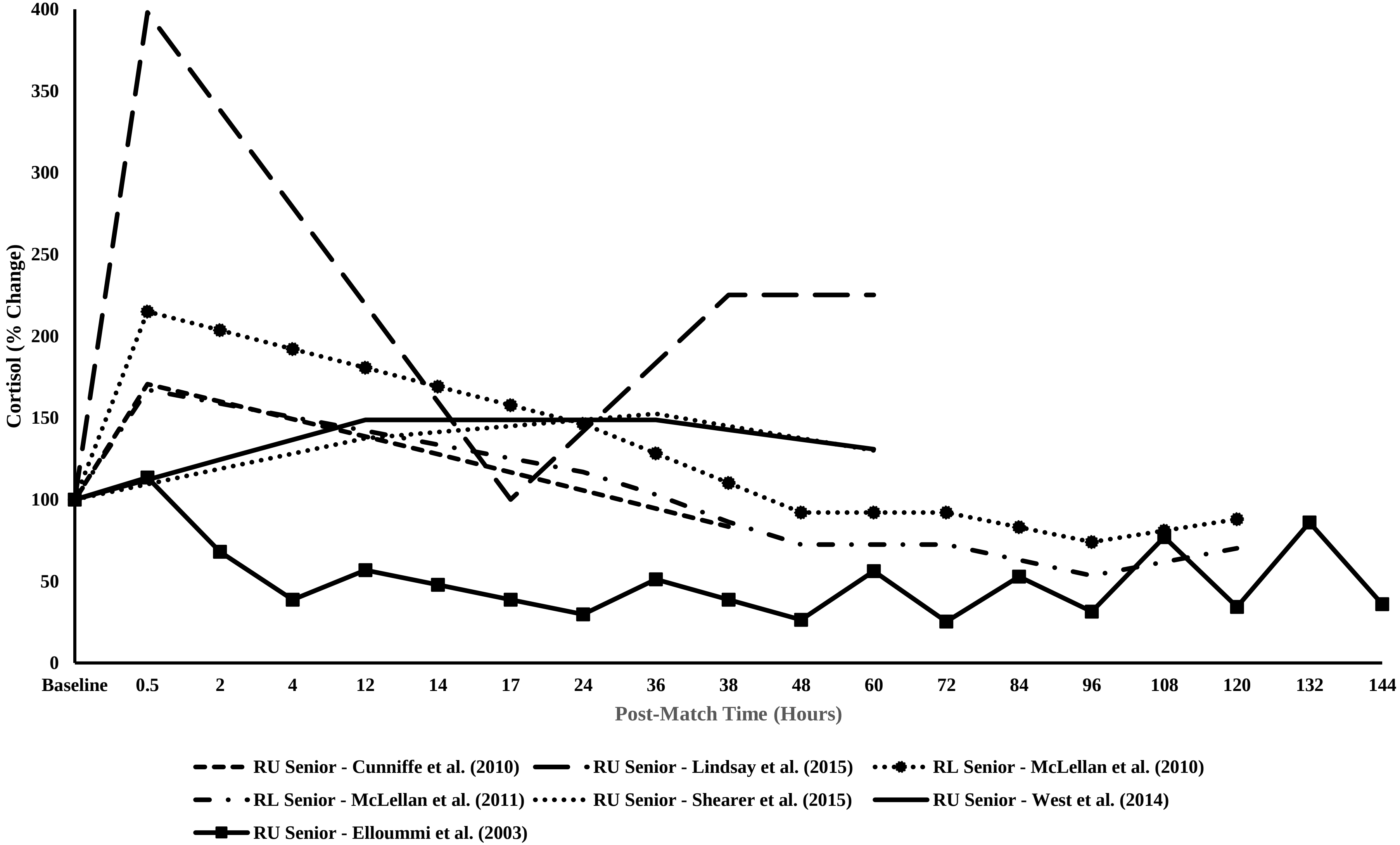

Figure 2.6 Recovery time-course percentage changes in cortisol concentrations following rugby union (RU) and league (RL) match-play

2.4.2.3 Testosterone concentrations

Testosterone is an important psychosocial hormone which may help to regulate emotions and behaviors (e.g., motivation, mood and aggression) (Crewther et al., 2016). Although evidence suggests that the role of T in anabolic processes may be questioned (West & Phillips, 2010), it has been used as a marker of recovery. Changes in T concentrations have been reported to be proportional to the duration and intensity of exercise (i.e., longer and more intense exercise elicits a larger effect in T). Out of the five studies reporting relative T responses (Figure 2.7), three studies reported an acute (i.e., within 60 min following match-play) response, of which two studies observed decreased concentrations ranging from ~14 to ~44% (Cunniffe et al., 2010; Elloumi et al., 2003). When the first post-match measurements were taken at a later time-point (i.e., 12 h), decrements of ~30% were reported (Shearer et al., 2015; West et al., 2014). It could be argued that studies omitting measurements directly post-match underestimated the magnitude of the fatigue response, as a number of studies have identified this as the period in which peak reductions occur. Largely in contrast to the body of literature (Cunniffe et al., 2010; Shearer et al., 2015; West et al., 2014), McLellan et al. (2010) reported an immediate rise in T concentrations post-game. However, this appears to be the result of a sudden decrease in T concentrations 30 min pre-match when compared with measures taken 24 h beforehand.

After an initial post-match decrease, T concentrations typically rise and approached baseline values after 38 (Cunniffe et al., 2010) or 60 (Shearer et al., 2015; West et al., 2014) h, possibly indicating that two or three days are required for T concentrations to recover post-match. In contrast, a single study (Elloumi et al., 2003) reported recovery of T values as early as 12 h post-match. However, because this study applied no exclusion criteria based on playing time, it may be that average responses were affected by potentially minor physiological changes within substitute players who were exposed to fewer minutes of match-play.

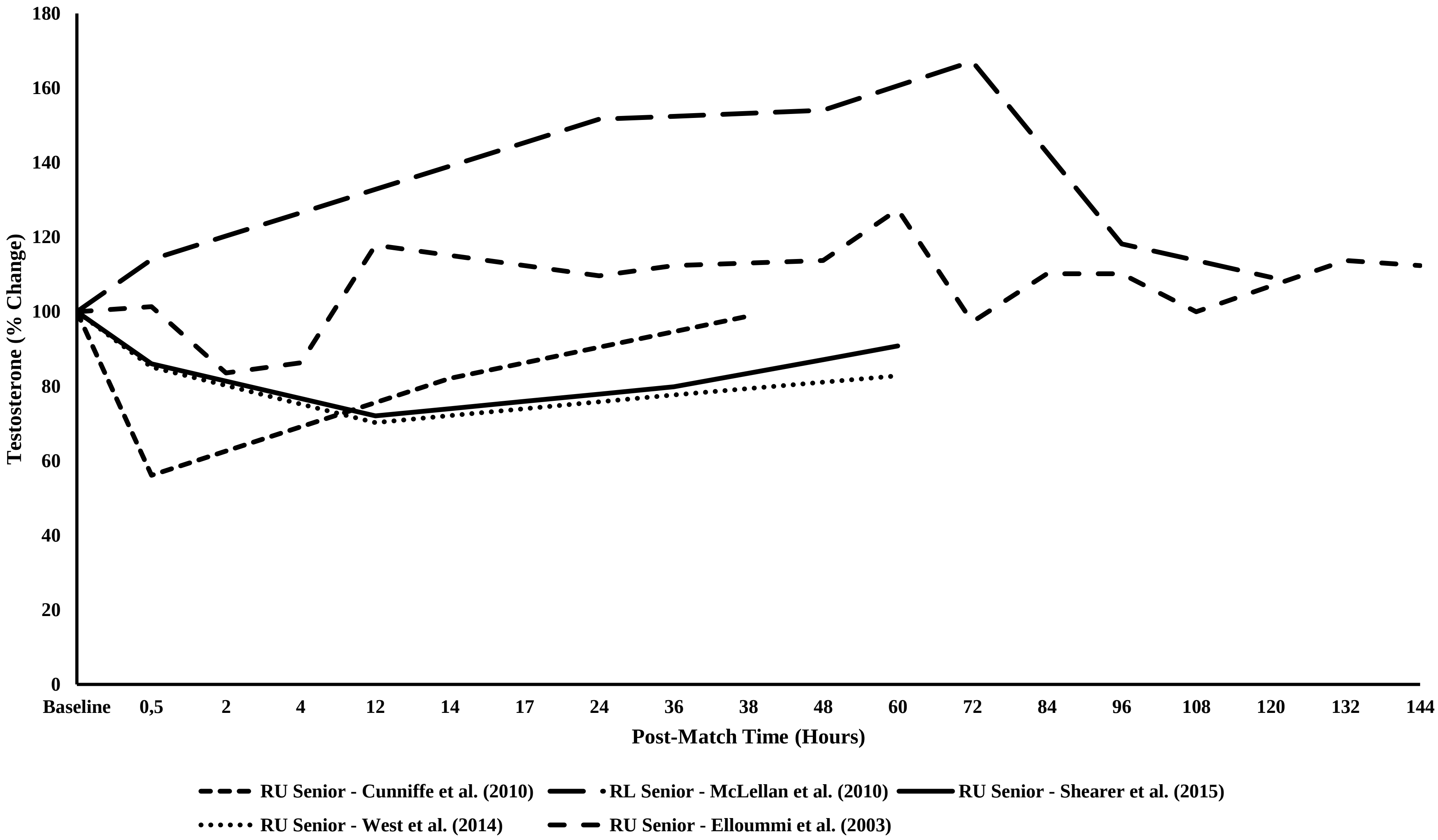

Figure 2.7 Recovery time-course percentage changes in testosterone concentrations following rugby union (RU) and league (RL) match-play

2.4.3 Subjective responses

Six studies (Table 2.3) profiled self-reported wellness responses in a total sample of 92 players (mass 97.8±6.4 kg; height: 1.84±0.01 m). After peaking at 24 h (<65%), mood disturbances required 48-72 h to normalise (Figure 2.8). The average age of the players in the studies profiling subjective responses was ~23 years, while a single study profiled responses in younger athletes (under-20s) (Roe et al., 2016c). Detailed information in relation to activity profiles was reported in three studies (Oxendale et al., 2016; Roe et al., 2016c; Twist et al., 2012), while specific details on recovery strategies have been reported in two studies (Oxendale et al., 2016; Twist et al., 2012). Disturbances in wellness could be caused by a variety of match-related variables (i.e., result of the game, individual match demands, individual performance and feedback on individual performance) and external (i.e., sleep disturbance, family commitments, relationships, work and education) factors (Kellmann et al., 2018). Peak disturbances in wellness (ranging from 24 to 65%) occurred 24 h post-match, before the response stabilised or began a gradual return towards baseline (Figure 2.8). Although complete recovery was not reported in any of the studies, no significant changes in wellness disturbance compared to baseline measures were reported between 48 and 72 h, indicating that responses have returned to near pre-match values.

Table 2.3 Studies investigating the recovery profile of perceptual responses following rugby match-play

Study	Players	Code + Level	Stimulus	Recovery Strategies	Measures taken	Results
(McLean et al., 2010)	Professional players (n: 12; age: 24±4 years; height: 1.85±0.06 m; mass: 101.9±8.4 kg)	RL; NLR team	Match load: Game 1: 421±173 AU Game 2: 411±213 AU Game 3: 411±217 AU	MD+1: Recovery session. No details reported.	Five-item wellness Q on a 5p LS (1: negative outcome,5: positive outcome) + fatigue levels + muscle soreness (Δ from baseline)	Q: +24: ↓ from baseline (*d*: -1.64), +48 h: ↓ (*d*: -1.53), +96 h: ↔ Fatigue: +24 h: ↑ from baseline (*d*: -1.65), +48 h: ↑ (*d*: -1.42), +96 h: ↔ Muscle soreness: +24 h: ↑ from baseline (*d*: -1.57), +48 h: ↑ (*d*: -1.44), +96 h: ↔
(Oxendale et al., 2016)	Professional players (n: 17; age: 25±4 years; stature: 1.84±0.06 m; mass: 98.5±10.3 kg)	RL; SL team	Playing duration: 55±21 min (F), 67±25 min (B); distance: 4675±1678 m (82±7 m/min) (F), 5640±2191 m (83±10 m/min) (B); high-intensity running: 307±194 m (F), 481±262 m (B); #high-intensity accelerations: 5±3 (F), 9±6 (B); #high-intensity decelerations: 8±5 (F), 10±6 (B); #collisions: 54±37 (F), 31±5 (B); #RHIE: 14±10 (F), 10±5 (B)	MD+1: Low-intensity exercise and massage (30 min). MD +2: Players encouraged to rest.	Rating of perceived muscle soreness on a 7p LS (0: extreme soreness – 6: no soreness) (MDif to baseline)	+12 h: -1.1±0.5 ↓ from baseline, +36 h: -0.8±0.5 ↓, +60 h: ↔ (not reported)
(Roe et al., 2016c)	Professional U19 players (n: 14; age 17±1 years; stature: 1.83±0.08 m; mass: 86.2±11.6 kg)	RU; English academy team	Match duration: 73 min; AML: 334±121 AU; distance covered: 4691±878 m (74±6m.min^{-1}) of which 2215±461 m jogging, 663±238 m striding and 41±40 m sprinting; APLTM: 451±102; PLTMs: 187±47	No recovery session	Six-item wellness Q on a 5p LS (1: negative outcome, 5: positive outcome) (%Δ from baseline)	+24 h: -24.0±4.3% ↓ from baseline, +48 h: -8.3±5.9% ↓, +72 h: -3.6±3.7% ↔
(Shearer et al., 2015)	Professional players (n: 12; age: 25±4 years)	RU; professional team in South Wales, UK	Playing duration: 82±11 min.	Participants instructed to follow normal individual recovery strategies. No details reported.	Six-item wellness Q on a 5p LK (BAM) (1: not at all – 5: extremely)	Mood Disturbance: +12 h: 7.67±4.49 ↑ from baseline (4.92±2.27), +36 h: 6.33±2.96 ↑, +60 h: 5.17±3.56 ↔ Energy Index: +12 h: 0.86±0.6 ↓ from baseline (1.52±1.19), +36 h: 0.92±0.6 ↓, +60 h: 1.26±0.7 ↔
(Twist et al., 2012)	Professional players (n: 23; B:10, F:13) (age: 26±5 years; stature: 1.83±0.07; mass: 91.9±11.6 kg (B), 102.0±6.7 kg (F))	RL; SL team	Playing duration: 80±0 min (B), 51±16 min (F); #tot contacts: 25±8 (B), 38±19 (F); #defensive contacts: 14±8 (B), 26±14 (F); #offensive contacts: 12±3 (B), 13±6 (F)	MD+1: Deep-water running & swimming (20 min) MD+1 (PM): Players encouraged to rest.	Rating on muscle soreness, fatigue, and attitude to training on a 5p LS (1: positive outcome -5: negative outcome)	Muscle soreness: (B): +24 h: 3.5±0.7 ↑ from baseline (2.3±0.7), +48 h: 3.2±0.6 ↑ (F): +24 h: 3.2±0.8 ↑ from baseline (2.0±0.4), +48 h: 3.3±0.9 ↑ Fatigue: (B): (2.4±0.5) +24 h: 3.3±0.7 ↑ from baseline, +48 h: 3.0±0.8 ↑; (F): +24 h: 3.0±0.8 ↑ from baseline (2.2±0.4), +48 h: 3.0±0.9 ↑

						Attitude to training: (B): +24 h: 2.4±0.7 ↑ from baseline (1.9±0.8), +48 h: 2.5±1.4 ↔ (F): +24 h: 2.3±1.1 ↑ from baseline (1.4±0.7), +48 h: 2.2±1.2 ↔
(West et al., 2014)	Professional players (n: 14; age: 25±4 years; stature: 1.85±0.10 m; mass: 105.2±12.3 kg)	RU; professional team in South Wales, UK	Not reported	Not reported	Six-item wellness Q on a 5p LS (BAM) (0: not at all – 4: extremely outcome)	Mood disturbance score: +12 h≈ 7.49 (56%) ↑ from baseline (≈4.80), +36 h≈ 6.38 (33%) ↔, +60 h≈ 5.18 (8%) ↔

#: Number of, Δ: Change, ↓: Significant decrease from baseline, ↑: Significant increase from baseline, ↔: No significant change from baseline, 5p LS: 5-point Likert Scale, 7p LS: 7-point Likert Scale AML: Average match load (RPE x time), APLTM: Average PlayerLoad™, AU: Arbitrary units, B: Backs, BAM: Brief Assessment of Mood, *d* :Cohen's d, F: Forwards, MD: Match day, MD +1: First day post-match, MDif: Mean Difference, NRL, National Rugby League, PLTMs: PlayerLoad™ slow, RL: Rugby League, RPE: Rate of perceived exertion, RU: Rugby Union, SL, Super League, Q: Questionnaire.

2.4.3.1 Perceptual questionnaires

A common method by which players provide feedback on wellness is via the use of questionnaires. Although many different questionnaires exist, two short 6-item questionnaires, whereby players indicated their responses on a 5-point Likert-scale have often been used in practice, being, a psychological questionnaire assessing different facets of wellness (McLean et al., 2010; Roe et al., 2016c), and the brief assessment of mood (BAM) (Shearer et al., 2015; West et al., 2014); a brief version of the Profile of Mood States (POMS) (Mcnair et al., 1971) that assesses different mood adjectives. Large variability exists between these two questionnaires; the rated items in each questionnaire assess different facets of the recovery process while ratings also represent reversed responses (i.e., in some studies (McLean et al., 2010; Roe et al., 2016c) a low score represents a negative response and a high score represent a positive response, whereas in other studies (Shearer et al., 2015; West et al., 2014), the opposite was true). This emphasises that although post-match wellness responses appear similar, large methodological differences make direct comparisons between studies challenging. The way questionnaires are used in practice differs as well. Practitioners may either look at individual items on the questionnaire, or only assess the total score of all items. In addition, it is not uncommon for customised wellness questionnaires to be used within individual clubs. However, the lack of validity of those customised questionnaires should be carefully considered.

2.4.3.2 Perceived muscle soreness

Another common method to provide feedback on wellness is via ratings of perceived muscle soreness (Fletcher et al., 2016); for which there is no standardised rating system, with some studies using a 1-5 Likert scale (McLean et al., 2010; Twist et al., 2012), whereas others have used a 0-6 Likert scale . However, a more expansive scale (i.e., 1-10 or 1-100) might be preferable to express a more accurate representation of the response and thus sensitivity of the scales (McLaren et al., 2017). While most studies use a general muscle soreness score, a more expansive approach was adopted in AF (Kinsella et al., 2012), which required a score of soreness of different body parts on a 1-10 Likert scale (both left and right side of calf, hamstring, quadriceps, adductor, hip flexor and glutes) and an average of those ratings was taken for a full body muscle soreness score. This approach may be useful as it gives more specific feedback to the coaches about soreness in different body parts so training could be adapted accordingly. However, it may be useful that this also accounts for upper-body sites. The use of a rating of muscle soreness as opposed to a questionnaire (in which ratings of muscle soreness may also be included (McLean et al., 2010; Roe et al., 2016c)) could both prolong and reduce a return to baseline measures as the sensitivity of the mode of measurement may influence the interpretation of the time-course of recovery observed.

The importance of reporting activity profiles in detail is further highlighted by observations that RHIE and number of collisions (heavy collisions particularly) during match-play displayed strong positive correlations with increased muscle soreness (Oxendale et al., 2016). It is argued that a combination of blunt-force trauma caused by physical collisions and high-intensity eccentric movements have a greater effect on muscle damage and muscle soreness than each factor in isolation (Johnston & Gabbett, 2011). Subsequent positional comparisons may be a useful addition to future research, as the increased number of collisions and RHIE performed by forwards may lead to greater muscle soreness in comparison to backs, which could affect the consequent recovery period (Oxendale et al., 2016).

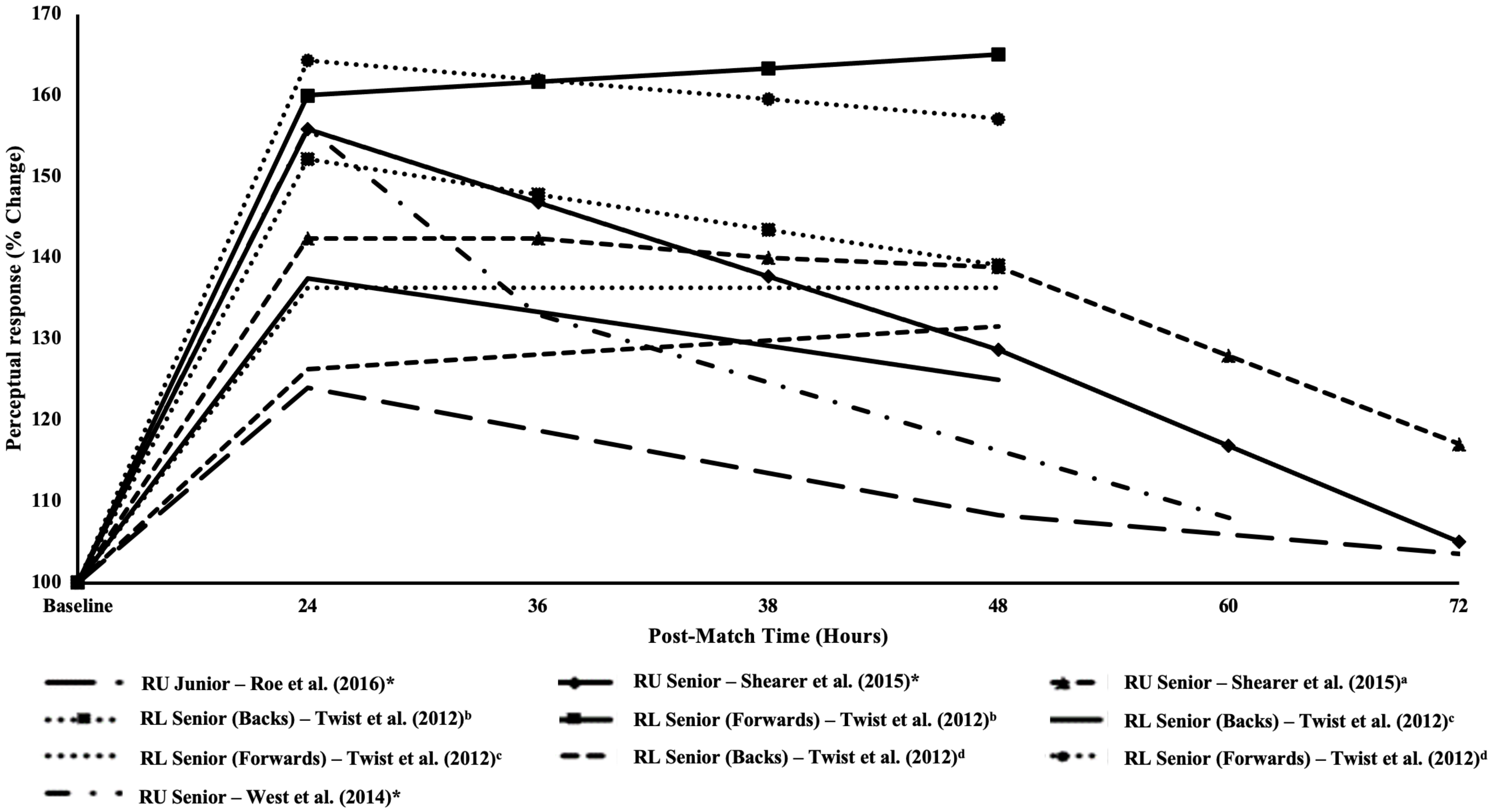

Figure 2.8 Recovery time-course percentage changes in subjective responses following rugby union (RU) and league (RL) match-play. * represents wellness questionnaire, [a] represents energy index measure, [b] represents muscle soreness rating, [c] represents perceived fatigue rating, [d] represents attitude to training rating

2.4.4 Reliability

As highlighted above, various assessments can be used to analyse the extent of muscle damage that has taken place. To draw valid conclusions related to the pre- and post-match-play measurements, and the consequent muscle damage that has occurred, it is important to assess the reliability of a monitoring tool and its specific variables (Cormack et al., 2008c). This is especially true, given that reliability of measures is population-specific (Cormack et al., 2008c). Reliability of recovery makers has sporadically been reported in collision-sports players, with neuromuscular and wellness markers generally showing superior reliability to biochemical or endocrine markers (Cormack et al., 2008c; Roe et al., 2016a; Twist & Highton, 2013). Specifically, in junior RU, five days separated between-day reliability measurements, but no activity (i.e., training) was carried out in the between-day period (Roe et al., 2016a). Although this allows for experimental control, findings may not reflect scenarios in which regular training practices take place. In addition, where studies do report reliability data, it is unclear whether this concerns within- or between-day reliability (Johnston et al., 2015b; Twist et al., 2012). Such information is likely to inform practitioners regarding their use of specific variables during within- or between-day scenarios and should therefore be mentioned.

Arguably, the variability shown in physical qualities amongst academy players, subject to chronological age, maturation status, and training age (Till et al., 2017a; Till et al., 2014a), may also affect the reliability of measures used to assess post-exercise fatigue in this population. For example, assessing lower-body power is commonly done through a CMJ (Till et al., 2017b), while the CMJ is also a popular measure to assess post-match fatigue (Taylor et al., 2012). With increased variability in CMJ performance amongst this age group compared to senior players, reproducibility may be less consistent, consequently affecting reliability. To allow for academy RL practitioners to confidently interpret their data, additional research assessing reliability in recovery markers is required.

2.4.5 Validity

Equally, the validity (i.e., the extent to which a concept is accurately measured) of a tool or variable needs to be considered. It seems logical that a direct measurement of muscle damage is the most valid way of determining the damage caused. However, although direct measurement of muscle damage is possible (i.e., by taking a small piece of muscle tissue through a muscle biopsy) (Chen et al., 2007; Lovering & De Deyne, 2004), such a measure is invasive, time-consuming, and expensive, making it impractical for sporting environments (Tavares et al., 2017). Instead, as highlighted in the sections above, indirect markers of muscle damage may be preferred. As contractile capabilities are reduced significantly due to disrupted sarcomeres and the uncontrollable movement of Ca^{2+} into the sarcoplasm (Peake et al., 2017), force-generating performance tasks (e.g., jumping, sprinting, isometric or isokinetic dynamometry) provide an indirect indication of muscle damage (Twist & Highton, 2013). Membrane permeability allows enzymes and muscle proteins (e.g., CK, myoglobin) to drift into the bloodstream (Markus et al., 2021), whilst, at different stages of the process, muscle damage is also associated with the increase of certain hormones and immune cells (Peake et al., 2017). Measurements of specific concentrations of these markers in the bloodstream or saliva also provides indirect evidence of muscle damage (Twist & Highton, 2013). Finally, taking a score of wellness and/or soreness, either generally or at a specific site of the body, provides a simple subjective manner of assessing muscle damage. As each method of assessing post-exercise responses covers a slightly different aspect of the construct of ‘fatigue’, it is particularly important to consider to what extent an assessment measures this construct.

2.4.6 Considerations around post-match responses

Although, contextual factors meant that considerable variability was observed, recovery timelines have been reported in this section. Neuromuscular responses have been assessed through monitoring CMJ performance (PP and FT), with acute reductions in PP of up to 31.5% being followed by decrements of up to 37% at 24 h post-match. Measurements of PP appear to be a more sensitive marker of fatigue than FT as prolonged decreases are observed beyond 48 h, while any decreases in FT beyond 48 h are mostly found to be trivial or insignificant. With this in mind, practitioners should seek to assess those variables that represent the most sensitive markers of neuromuscular fatigue within their testing battery. That being said, it would be worthwhile to explore additional CMJ variables as well as the utility of other measures of fatigue in response to rugby match-play in order to assess their sensitivity and thus the efficacy of their adoption within both research and practice.

Studies profiling changes in CK concentrations reported peak increases of 120-451% between 12 and 24 h post-match. In contrast, in most studies profiling a C and T response, peak values were reported acutely post-match. However, while biochemical and/or endocrine responses are often reported within rugby literature, it is important to consider that large inter-individual variability exists, and thus findings must be interpreted with caution. Subjective responses to match-play have proven difficult to compare due to the large variability in methodologies (e.g., differences in Likert scales, different 'topics' or 'emotions' that require to be rated and reversed responses). Notwithstanding, all studies that have reported a subjective response have observed peak disturbances in wellness of 24-65% occurring at 24 h post-match, after which near baselines measures are achieved between 48 and 72 h.

Out of the studies reported in this section, only four (Jones et al., 2014; McLellan & Lovell, 2012; Oxendale et al., 2016; Twist et al., 2012) provided detailed information relating to activity profiles (i.e., total distance, high-speed running, number of collisions etc.), training regimes (i.e., type and timing of training sessions) and recovery strategies (i.e., type and timing of specific strategies). Reporting such information is important as these variables may profoundly influence the recovery responses observed. For example, performing intense training within the recovery period could prolong the return to baseline measures, whereas the inclusion of effective recovery strategies is likely to have the opposite effect.

The average age of the participants in studies profiling a fatigue response following match-play was 23 years, with only three studies (of which two worked with the same sample) using younger athletes (under-20 or academy teams), suggesting there is a lack of research that profiles recovery within academy rugby players. As it is reported that correlations exist between match demands and the magnitude of post-match responses (Jones et al., 2014; Oxendale et al., 2016; Twist et al., 2012), it could be argued that recovery timelines in academy players might be different as a result of differing match demands. Additionally, academy players often do not play rugby full-time and as a result face competing lifestyle demands (i.e., education, work), which could influence their recovery profiles. Inferior physical qualities in academy players may also affect their post-exercise responses differently to senior players.

2.5 Physical qualities

To achieve the complex and highly varied physical demands that are required at the highest level, RL players need to develop a broad range of physical qualities (Meir et al., 2001b; Till et al., 2013). Due to the duration of the game (i.e., 80 min), the high distances covered and the need for a rapid recovery following periods of high intensity, well-developed aerobic capacity is important (Johnston et al., 2014a). The most decisive moments of the match, however, are usually decided during (repeated) occurrences of high intensity, which strongly rely on the anaerobic (i.e., phosphagen, glycolytic) energy systems (Gabbett et al., 2008a). High-intensity running in RL is often over a small distance (i.e., <20 m), hence the (repeated) ability to accelerate quickly and efficiently is a key attribute for all players (Gabbett, 2012b). Backs, who are more likely to perform sprints over a longer distance (Gabbett, 2012b), also need to develop top-speed qualities (Johnston et al., 2014a). Altogether, physical characteristics of specific players should also be complemented with appropriate body composition. Due to their increased involvement in collisions (Johnston et al., 2019), forwards are likely to have increased body mass, larger body fat percentage and greater skinfold thickness compared to other positions (Till et al., 2013), but high body mass, and particularly lean mass, is important in all positions (Till et al., 2011).

Except for aerobic capacity, it is generally accepted that physical qualities such as linear speed, change-of-direction speed, muscular strength, and muscular power generally increase as younger players move across age categories (i.e., 13-20 years old) (Baker, 2001, 2002; Gabbett, 2002; Gabbett, 2009; Gabbett et al., 2008b; Till et al., 2010). This is the result of increased training volume, the onset of peak height velocity, and the introduction to resistance training (Till et al., 2015b). Even though physical qualities improve as players get older, these are still known to be inferior to senior professionals (Baker, 2002; Ireton et al., 2019; Till et al., 2017b). Whilst this may not be surprising due to an extended training age and completed maturation in senior players, it is hugely important for young players to develop physically. Notwithstanding the high level of technical skill that is required to progress as a RL player (Johnston et al., 2014a), enhanced physical qualities have been found to play a potentially crucial role in the development of academy players. Specifically, as it has been shown that superior physical qualities are positively correlated to important performance parameters (i.e., tackling ability, high-intensity running) (Gabbett, 2016; Gabbett et al., 2013), general playing ability (Gabbett et al., 2007), increased selection in starting teams and national selection (Gabbett, 2009; Till et al., 2011), as well as long-term career attainment and professional status (Till et al., 2016a; Till et al., 2015a; Till et al., 2016b).

In addition to its positive relationship with important performance parameters, superior physical qualities may also be able to attenuate post-exercise fatigue. As playing standard increases, so does the intensity of the game (Gabbett, 2012a, 2013, 2014; Sirotic et al., 2009). As such, it may be expected that the post-match fatigue response also increases, but well-developed physical qualities may be able to offset these responses. Indeed, neuromuscular fatigue and levels of CK were lower in those players with greater high-speed running ability and high levels of lower-body strength and power, despite having greater internal and external match loads (Johnston et al., 2015a; Johnston et al., 2015b). Equally, increased levels of fatigue have been associated with reduced match performance (i.e., reductions in high-speed running distance and tackling proficiency) during intensified RL competition (Johnston et al., 2013a; Johnston et al., 2013b).

With so many of the damage-inducing mechanisms (i.e., high-speed running, sprinting) relying on the SSC (Douglas et al., 2017), and thus force-producing capabilities, players with higher levels of strength and power will be able to cope better with the forces associated with these movements (Byrne et al., 2004). It is therefore unsurprising that superior physical qualities could indeed minimise the fatigue response. The literature highlights that both the standard and intensity of play, as well as the physical qualities associated with the players differ between academy and senior professionals. Both these parameters also appear to affect post-exercise fatigue, and as such, academy players may experience a different time-course and profile of fatigue compared to their senior counterparts. As this is currently still unclear, better understanding is required regarding the fatigue and recovery processes of academy players.

2.6 Recovery strategies

As highlighted, many contextual factors (e.g., match demands, inclusion of training, physical qualities) should be considered when contextualising post-exercise responses. Finally, the use of specific recovery strategies employed in the time between exercise completion and the post-exercise measurements also warrants consideration (Jones et al., 2014; McLellan & Lovell, 2012; McLellan et al., 2011a). Nutrition, hydration, and sleep are recognised as recovery-modulating factors (Halson, 2008; Peake, 2019). In addition, to facilitate an enhanced restoration of post-match responses back to baseline, it is common practice amongst professional sporting teams to implement a variety of recovery strategies (McLellan & Lovell, 2012; Oxendale et al., 2016; Twist et al., 2012). A plethora of research assessing the efficacy of recovery strategies is available, and this topic has also been extensively reviewed in rugby (Calleja-González et al., 2019; Tavares et al., 2017). Whilst, for this reason, the evidence behind these strategies will not be elaborately discussed in this section of the thesis, explanation will be provided behind some of the mechanisms that potentially manipulate the recovery process.

Specifically, those strategies that are more accessible and ecologically valid in rugby environments will be briefly discussed. Discussion of some of the more recent and advanced technologies (e.g., cryotherapy, phototherapy) (Calleja-González et al., 2019) is beyond the scope of this thesis. The efficacy of recovery-modulating factors and physical interventions is likely dependent on the type, intensity, and duration of the preceding exercise stimulus (Hudson et al., 2019). In sporting environments, it seems more appropriate that a variety of strategies is used in an attempt to enhance the recovery process (Lindsay et al., 2015a). However, the literature predominantly assesses the efficacy of a single modality in isolation (Tavares et al., 2017), thereby limiting its findings to a practical environment.

2.6.1 Nutrition

Players benefit from a daily diet containing high levels of carbohydrates (CHO) and protein to maximise glycogen concentrations whilst supporting recovery and adaptation (Ranchordas et al., 2017). However, the acute phase following high-intensity exercise is known as a particularly important period to 'kick-start' the recovery process. The main aim of post-exercise nutrition is the replenishment of liver and muscle glycogen, which is the primary fuel source during high-intensity exercise (Peake, 2019). To ensure complete muscle glycogen recovery, 24 h of adequate CHO consumption may be required (Burke et al., 2017), but the initial period 2-4 h post-exercise has frequently been highlighted as a 'window of opportunity' due to increased activity of glycogen-synthesising enzymes during this time (Ivy et al., 1988). To optimise CHO intake, players are encouraged to consume between 1-1.5 $g \cdot kg^{-1} \cdot h^{-1}$ to maximise glycogen synthesis, whilst the intake of high glycaemic index (GI) foods may be preferable over moderate or low GI foods, when glycogen restoration needs to occur as quickly as possible (Jentjens & Jeukendrup, 2003). The addition of 0.2-0.5 $g \cdot kg^{-1} \cdot h^{-1}$ of protein is beneficial for tissue repair, and aids in glycogen resynthesis when CHO intake is suboptimal (i.e., $\leq 1.2\ g \cdot kg^{-1} \cdot h^{-1}$) (Ivy et al., 1988). Various other dietary supplements (e.g., protein, β-alanine, creatine) may be beneficial in enhancing post-exercise recovery (Markus et al., 2021), while polyphenols especially have received addition attention in the literature. Exercise is known to cause increased oxidative stress which elicits a rise in the production of free radicals and lipid peroxidation. This may cause cell damage and could consequently impact health and well-being (Bloomer et al., 2005). A diet rich in antioxidants (e.g., polyphenols) may be able to reduce the harmful effects caused by oxidants, which could positively affect recovery (Markus et al., 2021).

2.6.2 Hydration

Total body water represents between 50-70% of body weight, with individual variability mostly accounted for by differences in body composition (Sawka et al., 2015). When exercising at high intensity, specifically in the heat, metabolic heat production causes an increase in core temperature. To limit this rise, evaporative cooling (i.e., sweating) occurs, which, when fluid loss through sweating is superior to fluid intake, may cause a state of hypohydration (i.e., underhydration) (Evans et al., 2017). The loss of water in sweat leads to a state of hypovolemia (i.e., reduced blood volume) which consequently impairs thermoregulatory effects (i.e., blood flow to the skin to release heat) as well as the cardiovascular system (i.e., reduced stroke volume) (Sawka et al., 2001). It is therefore generally accepted that an elongated state of hypohydration may reduce performance, hence a quick return to a state of euhydration following exercise would be beneficial. When doing so, it is recommended to take in moderate volumes of electrolyte-containing fluids over a longer period, whilst the addition of food could assist in achieving a positive fluid balance (Peake, 2019).

2.6.3 Sleep

It is generally accepted that sleep serves a crucial role in recovery from previous wakefulness and to prepare for the subsequent wake period (Halson, 2014b). Sleep induces changes in almost all physiological processes, whilst its restorative relationship is specifically highlighted in the immune, endocrine, and nervous systems, and the vital role it plays in learning and memory (Halson, 2008). The effect of sleep restriction or sleep improvement on consequent performance (i.e., strength and endurance) tasks remain equivocal, largely because of differing sleeping protocols across studies (Walsh et al., 2020). However, it appears that sleep restriction negatively influences skill execution and various physical attributes (e.g., endurance performance, anaerobic power, sprint performance, reaction time (Walsh et al., 2020; Watson, 2017), consequently impairing performance. Even though various sporting and non-sporting factors may cause short-term sleep disturbances (Walsh et al., 2020), athletes should focus on building long-term healthy sleeping habits, incorporating high quality sleep hygiene

(Bird, 2013). Altogether, recommendations suggest that athletes benefit from 7-9 h of sleep per night, whilst regular sleeping routines and the correct sleeping environment will aid in achieving this.

2.6.4 Hydrotherapy

Hydrotherapy includes the use of water as a recovery strategy. The hydrostatic pressure associated with water immersion causes displacement of fluids from the peripheral to the central cavity, which results in the translocation of various waste products away from the muscle as well as increased stroke volume (Bieuzen et al., 2013). Beyond the general effect of water immersion, the temperature and its mechanisms are thought to play a crucial role in the exact mechanisms enhancing recovery (Vaile et al., 2010). Immersion may occur in cold (≤15°C), thermoneutral (>15°C to 36°C), warm (≥36°C), or contrasting (i.e., alternating between warm and cold water) conditions (Sánchez-Ureña et al., 2015).

Cold-water immersion, perhaps the most popular form of hydrotherapy, is associated with reduced oedema following exercise. By restricting the blood flow through cold-induced vasoconstriction, oedema and the associated pain and soreness is reduced, whilst oxygen blood flow (which may be impaired through oedema) is assisted (Ihsan et al., 2016). The combination of vasoconstriction and hydrostatic pressure elicits the movement of extravascular (i.e., intracellular, and interstitial) spaces into intravascular spaces, which is accompanied by the clearance of dead tissue cells and debris that was caused through muscle damage (Ihsan et al., 2016). A reduction in muscle temperature also reduces intramuscular metabolism which minimises inflammatory events. Finally, the reduction in core body temperature is associated with reduced sensation of perceived exertion which is mirrored by reduced central fatigue.

Compared to CWI, warm-water immersion (WWI) is generally found to be more relaxing and pleasurable, which may aid in the players’ perceived effect of this strategy (Becker et al., 2009). Heat causes vasodilation, which allows for increased blood flow and faster recruitment of immune cells and proinflammatory macrophages to the site of damage. It is anticipated that the inflammatory and the consequent anti-inflammatory response occur quicker following WWI (Petrofsky et al., 2015). In addition, the associated rise in tissue temperature is thought to reduce the perception of pain (Petrofsky et al., 2015). Contrast-water therapy (CWT) consists of alternating between immersion in cold and warm water, and consequently combines the beneficial effects of both peripheral vasoconstriction and vasodilation (Dupuy et al., 2018). This causes a 'pumping action', which may lead to reduced oedema, changes in blood blow distribution, and reduced inflammation (Vaile et al., 2010). Notwithstanding some of the other contextual factors (e.g., depth of immersion, duration) that may influence the efficacy of hydrotherapy, CWI and CWT have generally been found more effective than WWI in reducing perception of fatigue and blood markers of muscle damage (Peake, 2019).

2.6.5 Compressions garments

The rationale behind the use of compression garments (CG) in the post-exercise recovery period lies with the external pressure that is created. In theory, this reduces the space for swelling, haemorrhage, and haematoma, while providing mechanical support (Davies et al., 2009). The compression of superficial veins also improves capillary filtration, which results in an increased blood volume through deep veins, consequently aiding in the removal of waste products (Davies et al., 2009). Contrasting findings exist regarding the efficacy of CG, which is likely due to the properties (i.e., fabric type, thermal resistance, elasticity), characterisation (i.e., upper-body, lower-body, full-body) and pressure of the various CG used (MacRae et al., 2011). The effect of CG on muscle damage, inflammation, and performance measures appears modest (Dupuy et al., 2018; Tavares et al., 2017). However, most studies agree that CG reduce perceived fatigue and muscle soreness, and since CG are practical and mostly inexpensive, it would do no harm for players to use them following high-intensity training or competition (Tavares et al., 2017).

2.6.6 Massage

Massage involves the manipulation of tissue, either manually (i.e., with fingers, hands, and elbows) or via the use of foam rollers or pneumatic compression devices (Peake, 2019). It proposes to increase skin and muscle temperature, enhance blood circulation, and improve range of motion, whilst reducing pain that may exist through stiffness or cramps (Guo et al., 2017). Notwithstanding the type and duration of the massage, it is generally accepted that it may cause reductions in muscle soreness and in concentrations of blood markers of muscle damage (e.g., CK levels), whilst some evidence also suggests improved isometric force and peak torque in those that received a massage compared to those that did not (Guo et al., 2017). Even though self-massage is possible and common (e.g., through foam rollers), the clear benefits appear through a given massage, which understandably requires an additional person to undertake.

2.6.7 Stretching and active recovery

Stretching is performed in an attempt to improve range of motion and reduce pain and soreness through stimulation of various anatomical structures (Peake, 2019). The research assessing the effect of stretching on post-exercise recovery predominantly involves static stretching (Calleja-González et al., 2019). Despite this method being used frequently in sporting environments (Vaile et al., 2010), most of the literature is clear in stating that there are no real benefits to static stretching when attempting to reduce DOMS (Dupuy et al., 2018; Herbert & Gabriel, 2002). Some evidence even suggests that the opposite may be true, but detrimental effects to stretching appear unlikely (Vaile et al., 2010).

Active recovery is another strategy which is commonly used by athletes (Vaile et al., 2010). It is generally seen as low-level activity in the form of walking, jogging, cycling, or swimming and aims to enhance blood flow through the muscle, which should result in subsequent removal of waste products (Dupuy et al., 2018). Whilst the evidence is not entirely convincing, research suggests enhanced clearance of lactate and CK (Dupont et al., 2004; Gill et al., 2006), and reduced DOMS (Dupuy et al., 2018) following low-level activity.

2.7 Recovery versus adaptation

Professional sport involves the constant interaction between load (i.e., training, match-play), subsequent fatigue, recovery, and adaptation (Dupuy et al., 2018). Recovery strategies are typically viewed as a means of reducing fatigue to enhance consequent performance in the following training session or match (Kellmann et al., 2018). As highlighted, there is a wide range of recovery strategies that practitioners may choose from, but implementation should be carefully considered in relation to the population, the stimulus, and the scenario that has occurred (Turner & Comfort, 2017). Recovery strategies should not be treated with a one-size-fits-all approach, particularly in a team sport including specific positional demands and training statuses, which are likely to result in differing profiles and time-courses of recovery (Turner & Comfort, 2017). Furthermore, where acute (i.e., within 72 h of exercise) recovery strategies may be beneficial, or at least non-detrimental, for consequent training or match-play, the effect of long-term use should be carefully considered. For example, some evidence shows that chronic exposure to CWI may blunt adaptation following a block of strength training (Roberts et al., 2015; Yamane et al., 2015), which would be specifically detrimental in the current population, given the importance of developing physical qualities (Till et al., 2015a).

Fatigue is considered necessary to elicit an anti-inflammatory response which is thought to be an integral part of the adaptation process (Markus et al., 2021). Acute exposure to recovery strategies and limiting the inflammatory response would be particularly worthwhile in sporting events that require optimal performance on consecutive days (e.g., multi-stage cycling events) or where winning is the primary aim (i.e., in professional senior sport). Arguably, neither of these elements are present in academy RL, and it should therefore be carefully considered if it is worthwhile to emphasise the implementation of recovery strategies, when contact time with players may already be limited.

2.8 Thesis aims

The foregoing information highlights that whilst a plethora of research is available in relation to various aspects of RL, this is predominantly carried out in senior rugby environments, and with high levels of experimental control, making application of findings difficult in real-world academy RL scenarios. In the current system, young RL players only spend a relatively short period (i.e., up to five years) in a professional environment prior to being offered a senior contract or being released. It is therefore essential that academy players are holistically prepared for the demands and environment associated with professional senior RL. Fatigue and recovery are processes that require careful management, but when performed effectively, may allow more training and playing opportunities for junior players. This thesis therefore aimed to better understand and improve practices in relation to player monitoring, post-exercise responses, and the use of recovery strategies in academy RL. It is hoped that the thesis will add to the currently limited information across academy RL environments, which will provide players, practitioners, and researcher with improved understanding and practical recommendations in relation to the fatigue and recovery process in academy RL.

The following objectives were set to achieve this aim:

- To explore the current academy RL environment in relation to player monitoring, training, and the use of recovery strategies, whilst identifying any considerations, barriers, or opportunities for future research.
- To profile post-match and post-training responses in ecologically valid scenarios, using variables with acceptable reliability.
- To assess the efficacy of a multimodal recovery strategy implemented following high-intensity training.

Chapter three: Current practice in relation to monitoring tools, training regimes, and recovery strategies remains unclear in academy RL environments. The aim of this study was to assess the practitioner perceptions regarding applied practices of player monitoring, training, and recovery strategies in academy RL.

- Although it was anticipated that practitioners would value the use of monitoring tools and the implementation of recovery strategies, it was also expected that due to faced restrictions in relation to time and the availability of staff and facilities, such processes may be difficult to prioritise and implement in practice.

Chapter four: When using monitoring tools to assess player readiness to train or play, it is recommended to assess the reliability of these tools and their specific variables in the bespoke population. Those variables that achieved acceptable reliability may thereafter be used in future research. The aim of this study was to examine the within- and between-day reliability of various markers of fatigue.

- It was anticipated that levels of reliability would differ across the specific variables in the different tests and when assessed in within- or between-day scenarios.

Chapter four: As illustrated, post-match responses have frequently been assessed in senior rugby players. Responses to match-play in academy players are currently unclear, especially when profiled in ecologically valid scenarios, implementing common recovery strategies and regular training practices. This aim of this study was to profile responses for 120 h following match-play.

- H_0: No changes relative to baseline measures will be found in performance and wellness responses following match-play.
- H_1: Performance and wellness responses will change transiently following match-play.

Chapter five: Academy RL players are subjected to a part-time contract, which restricts the number of hours they are legally allowed to perform club-related activities. As a result, activities such as field- and gym-based training or video (p)review sessions are often prioritised over the implementation of recovery strategies. The acute post-match period (i.e., 60-90 post-match-play) highlights an opportunity for players to benefit from recovery strategies in a supervised manner. The aim of this study was to assess the efficacy of a multimodal recovery strategy implemented following a high-intensity rugby league training session.

- H_0: There will be no difference in performance and wellness responses following the implementation of a multimodal recovery strategy compared to the control trial after a high-intensity training session.
- H_1: The performance and wellness responses following a high-intensity training session will be reduced less following a multimodal recovery strategy compared to the control trial.

Chapter 3.0 Practitioner perceptions regarding the practices of player monitoring and recovery strategies in academy rugby league

Chapter Summary

- To contextualise the applied world and to better understand any potential barriers and challenges, this chapter used an open and closed question-containing survey to assess practitioner (n = 29) perceptions regarding applied practices related to player monitoring, training, and use of recovery strategies in academy rugby league.
- In 76% of practitioners, monitoring tools, mainly wellness questionnaires, knee-to-wall and adductor squeeze tests, and measures of soreness were used often or all of the time, but findings suggested that monitoring does not often inform practice.
- Notwithstanding the individual variation in the training practices between clubs, most training sessions took place during late afternoon or evening (i.e., 15:00-21:00 h) to allow players and members of staff to finish their education and/or work commitments. Training, both on the field and in the gym, was largely tailored towards areas of improvement in individual players.
- Most practitioners (i.e., 79%) used recovery strategies often or all of the time, with strategies such as stretching, foam rolling and gym-based recovery (i.e., resistance exercise, cardiovascular exercise) being used most frequently. However, only 55% of practitioners agreed or strongly agreed that the recovery process was prioritised and executed well within their organisation.
- This study provides a novel insight into the academy rugby league environment. Specifically, the time-restrictions that are evident amongst both players and staff members affect the application of some of the applied practices. Equally, this requires consideration in future research design.

3.1 Introduction

The intense nature and high frequency of collisions combined with activities requiring eccentric muscle actions occurring during training or match-play, mean that RL players are likely to experience perturbations in neuromuscular, biochemical and endocrine, and/or perceptual responses that are indicative of fatigue in the post-exercise period (Tavares et al., 2017). Monitoring such changes may be useful for practitioners to assess the physical, physiological, and mental state of the players, which underpins selected decisions regarding their subsequent readiness to train or play (Taylor et al., 2012). As a result of monitoring information, practitioners may choose to modify training protocols or implement additional recovery strategies (Quarrie et al., 2017). This may be especially important as recovery of post-exercise perturbations appears individualised to each player (Roe et al., 2016c), while the extent and time-course of such responses being at least partly affected by exercise-specific characteristics such as intensity, duration and mode of exercise, and recovery-modulating factors such as sleep and nutrition (Markus et al., 2021).

As highlighted in chapter two, post-match responses in rugby have primarily been assessed through isolated performance tests (e.g., CMJ), physiological measures (i.e., blood or salivary markers such as CK, C, or T concentrations) or through perceptual markers (i.e., wellness questionnaires or measures of soreness). To enhance the recovery of perturbations back to baseline, recovery strategies are often utilised following match-play or high-intensity training. Although many recovery strategies are available for practitioners to choose from, the evidence underpinning the efficacy of strategies such as CWI, CG, and active recovery remains equivocal (Calleja-González et al., 2019; Tavares et al., 2017). The preceding stimulus (i.e., match-play vs training or simulation), the use of multiple strategies in combination, or the control trial that is paralleled against the recovery strategy may also influence the efficacy of such a strategy. Nevertheless, it is common practice for practitioners to implement a single or a combination of recovery strategies following match-play (McLellan & Lovell, 2012; McLellan et al., 2011a; Twist et al., 2012).

Player monitoring and implementation of recovery strategies are common within senior professional rugby clubs (Taylor et al., 2012). However, much remains unknown regarding the use of such protocols in rugby academies. Unlike their first-team counterparts, academy players and members of staff are usually only contracted on a part-time basis, which is likely to create time-related challenges regarding implementation of player monitoring and recovery strategies. Indeed, limited personnel and financial resources may dictate that player monitoring and recovery strategies are performed in an alternative manner. Regardless, when performed effectively, player monitoring, and implementation of recovery strategies are likely to assist in providing academy players additional opportunities to develop through training or match-play.

Surveying applied practitioners is a useful tool which can be utilised to contextualise the applied world and to better understand any potential barriers and challenges (Harper et al., 2016). Acquired knowledge could be used to formulate future research questions and study designs that are greater in ecological validity and consequently provide information that is directly applicable to the practitioner (Drust & Green, 2013; Harper & McCunn, 2017). In previous research, surveys have been used to assess perceptions of coaches regarding monitoring practices or the use of recovery strategies in rugby (Starling & Lambert, 2018) and other sports (Crowther et al., 2017; Taylor et al., 2012). Including qualitative questions (i.e., open-ended questions) in such questionnaires may be worthwhile to allow a further insight into applied practice. Given the scarcity of information available in relation to the practices of academy RL players, the aim of this chapter was to examine the perceptions of practitioners regarding the applied practices of player monitoring, training, and the use of recovery strategies in academy RL. Such information will be used to contextualise the environment and challenges in which academy RL players and staff operate and to highlight directions of future research and the consequent study design of those studies.

3.2 Methods

Following ethical approval (Appendix 1), an online poster and survey web link were advertised by members of the research team across a number of social media channels. A single survey was created using an online resource (Jisc Online Surveys; Bristol, UK), and all responses were anonymous.

Although some personal information was disclosed (i.e., years of experience working in academy RL, highest level of sport played, and highest level of education completed), this was not able to be linked to an identifiable individual. The survey (Appendix 2) remained open for recruitment for 150 days following initial dissemination in December 2019 and all participants were required to provide informed consent in order to progress to the survey questions. Prior to dissemination, the survey was piloted by the research team and the approximate time of completion was 15 min. Participants were required to be at least 18 years of age and currently working on a full-time or part-time basis in academy RL in a paid or unpaid role.

All participants answered the same 26 core questions while technical practitioners (i.e., technical coaches and heads of youth) and physical practitioners (i.e., strength and conditioning coaches and sport scientists) also answered further questions based on their specific area of expertise. The survey commenced with four general questions in relation to employment (i.e., full-time, or part-time, years of experience working in academy RL, highest level of sport played, and highest level of education completed). Following explanation of certain terminology, participants then answered up to seven questions related to monitoring of player readiness to train/play, with two questions requiring elaboration of answers. Questions were related to the type of monitoring tool (if any) that practitioners used, as well as the timing of use, and their rationale behind this. The next five questions were related to the weekly schedule between matches, whilst elaboration was required for two of those questions. At this point in the survey, technical and physical practitioners answered three and four separate questions respectively regarding training practices throughout the week. Elaboration was required for all but one of the questions for each subgroup. Thereafter, all participants were asked to complete up to eight questions in relation to the type and timing of recovery strategies used within their organisation. The final two questions of the survey were related to areas of further research in the field. Throughout the survey, participants were asked to answer questions based on a six-day between-match period (i.e., match-day on Saturday, next match on the following Saturday). Despite the diverse group of practitioners that were invited to complete the survey (i.e., physical, technical, and medical practitioners), responses were grouped together. This was found appropriate, because enough space was left to provide a rationale for the responses given (through which individual points of view were likely to become evident), whilst exclusive questions were also asked to a specific group of practitioners. Quantitative responses were primarily provided using a multiple-choice, scaled or rank format. Five-point Likert scales were used to determine perceived importance (i.e., ‘not at all important’; ‘not very important’; ‘neither important nor unimportant’; ‘important’; ‘very important’), extent of agreement (i.e., ‘strongly disagree’; ‘disagree’; ‘neither agree nor disagree’; ‘agree’; ‘strongly agree’), and frequency of implementation (i.e., ‘never’; ‘rarely’; ‘sometimes’; ‘often’; ‘all the time’). It was anticipated that a five-point Likert scale would provide participants with sufficient choices without getting overwhelmed or having to spend a large amount of time on reading and choosing an answer. In addition, it was expected that participants from the industry would be more familiar with five-point Likert scales than any larger scales. Where elaboration was required, a sub-question was added to the main question for participants to justify their responses.

3.3 Data analyses

The present study followed a primarily observational design; hence the quantitative data presentation is mostly descriptive in nature. Where participants were asked to provide their response on a Likert scale (i.e., extent of agreement and frequency of implementation), frequency analysis was conducted to assess the percentage of practitioners that provided a given response. Where participants were required to provide their perceived importance to certain influencing factors, responses were ranked from ‘1’ (not at all important) to ‘5’ (extremely important). Accumulated points then facilitated a ranking from highest to lowest importance (Harper et al., 2016). Responses to open-ended questions (i.e., where participants were asked to elaborate on their answers) were read multiple times to gain familiarity of their content (Tracy, 2010). Thereafter, conventional content analysis was used to identify themes and sub-themes by grouping together the phrases used in the responses provided (Hsieh & Shannon, 2005). To achieve rigor and quality in this process, a ‘critical friend’, who was a member of the research team, was drawn on to provide a sounding board to encourage reflection upon interpretations and explanations that emerged from content analysis (Smith & McGannon, 2018). The role of the critical friend was to challenge, question, and develop the interpretations made by the researcher conducting the content analysis. The conversations held between the researcher and the critical friend resulted in the construction of a coherent and theoretically sound argument which supports the case that is being made in relation to the data (Smith & McGannon, 2018).

3.4 Results

In total, 29 participants were recruited of which five were technical coaches/heads of youth, 14 were strength and conditioning coaches/sport scientists and 10 were physiotherapists. Of the respondents, 59% were employed on a full-time basis, 38% worked on a part-time basis and a single respondent (3%) worked as an intern. The total years of experience working in academy RL ranged from <1 year (14%), 1-3 years (31%), 3-5 years (35%), 5-10 years (14%) to >10 years (7%). Further participant characteristics have been described in Table 3.1.

3.4.1 Monitoring

When asked about the frequency of player monitoring throughout the week, 76% of practitioners indicated that monitoring took place ‘often’ (38%) or ‘all of the time’ (38%), 21% responded with ‘sometimes’ or ‘rarely’, whilst a single practitioner (3%) did not use monitoring tool responses at all. The most common methods of monitoring employed were wellness questionnaires (86%), knee-to-wall test (75%), adductor squeeze test (61%), measures of (upper- and lower-body) soreness (57%), sit and reach test (39%) and CMJ (32%). Biochemical or endocrine responses were not reported to be routinely used by any respondent (0%) when monitoring in academy RL. ‘The availability of equipment’ was chosen as the most important factor when selecting a monitoring tool, closely followed by ‘the information derived from’ and ‘the research available in’ that specific tool (Figure 3.1). Although monitoring happened throughout the full week, measurements were predominantly taken during the mid-week stages (i.e., match-day +2, +3 and -3).

Table 3.1 Respondent characteristics

Item	Responses	Number of respondents
Sport played	Rugby league	13
	Football	9
	Rugby union	1
	Hockey	1
	Weightlifting	1
	Cricket	1
	Golf	1
	Athletics	1
	Gaelic football	1
Level of sport played	Amateur	16
	Semi-professional	7
	Professional	6
Highest level of education completed	GSCE	1
	BTEC	1
	Bachelor’s degree	12
	Master’s degree	13
	PhD	2

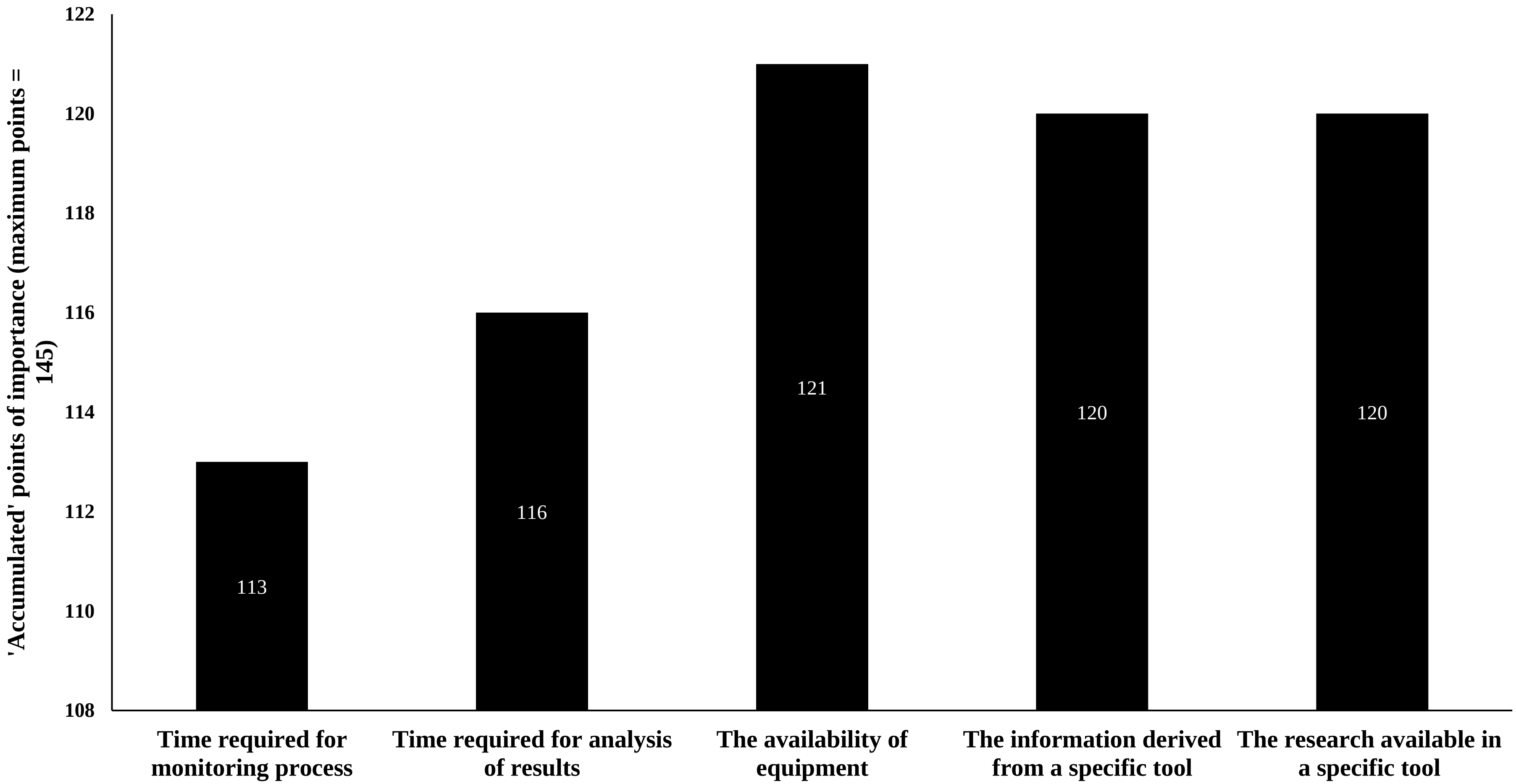

Figure 3.1 Practitioners' perceived importance of different factors associated with choosing a monitoring tool (n = 29)

Table 3.2 highlights the actions that follow the results found through player monitoring in the week following match-play. Practitioners mentioned the need for increased data collection throughout the monitoring process (Table 3.3). Specifically, using more monitoring tools would provide ''*both objective and subjective markers of readiness to train*'', ''*a balance of quantified and qualified data*'', and ''*different insights into a player's recovery*''. Increased data gathered would assist practitioners with ''*making better judgements or amendments to their training/recovery*'', and ''*making decisions during the training/playing process*''. When discussing the requirements of specific monitoring tools, practitioners indicated a preference for tools which ''*have a relationship to predicted injury*'' and those assessing wellness as they provide a ''*perception of fatigue against objective measures*''. Practically, measures were preferred to be ''*reliable*'' and ''*sensitive*'', whilst being ''*easy to administer and analyse data from*''.

When asked about frequency of monitoring throughout the week (Table 3.3), several practitioners would choose to increase monitoring practices to take measurements every day as this would provide ''*an insight into player's soreness and potential injury risk throughout the week*'', ''*a complete process of recovery*'', and ''*a more accurate evaluation of individual traits in recovery*''. Other practitioners, however, mentioned that over-monitoring could ''*muddy the water*'' and could be ''*problematic in that the nature of the game requires mental robustness and players performing whilst not at their physical or mental best*''. Instead, ''*having a day-by-day awareness, and not necessarily testing*'', may be enough. Monitoring on match-day was not found desirable, as this may ''*take away from the player's pre-match routines*'', whilst ''*an honest answer is unlikely*''. Throughout the week, monitoring was used pre-training to assess if ''*adequate recovery post-game has taken place*'' and ''*if it is useful to adjust their training*'', but also post-training to ''*see how well the players had recovered from their two days of training*''.

Table 3.2 Actions undertaken following the results found through player monitoring in the week following match-play

	Never	**Rarely**	**Sometimes**	**Often**	**All of the time**
Training volume/intensity of a training session is adapted for the full team	7%	29%	50%	11%	4%
Training volume/intensity of a training session is adapted for individual members of the team	0%	4%	43%	39%	14%
Recovery strategies are modified for the whole team	7%	21%	32%	32%	7%
Recovery strategies are modified for individual members of the team	0%	18%	14%	46%	21%
Team selection is modified in the following match	18%	36%	36%	7%	4%
Keep a close eye on individual members on the following day(s) in the case of a ‘red flag’	0%	0%	11%	39%	50%

Table 3.3 Content analysis of 'monitoring practices'

Phrase	Sub-Theme	Theme	Subject
• Monitoring protocol already in place **plus creatine kinase testing to assess tissue damage**. **Plus, countermovement jump to help assess neuromuscular fatigue** (p27). • **Countermovement jump has potential to provide extensive insight.** I'm **intrigued by endocrine response**. Believe there is **value with wellness** (p3). • I'm a little undecided to be honest but I would be interested in monitoring **a slow and fast stretch-shortening cycle** (p13). • Having **additional information on how each player is recovering**, will **enable coaches to make better judgement or amendments to their training/recovery** (p10). • I'd ensure that **both objective and subjective markers of readiness to train** were taken into account (p15). • Collectively **more data to analyse to improve overall justification** for return to play (p8). • **The combination** could give **a good indication to levels of fatigue** (p2). • They all provide a **different insight into a player's recovery** (p18). • A **balance of quantified and qualified data** to **help make decisions during the training/playing process** (p28). • I feel these would give me a **well-rounded battery of objective data** (p14). • The **more scientific information we had the more objective we could be** in our solutions to any problems (p4). • Additional ability to purchase equipment for mid-thigh pull and groin squeeze. **Increased accuracy with more scientific testing** (p21). • Would also have **GPS vest to monitor load** and total distance covered within training sessions we do this with load and rep ranges in the gym but struggle to do this when they are on field training (p6).	Having additional objective and subjective information	Monitoring tools	Monitoring practices
• Mainly from **its relation to predicted injury,** I really like the adductor squeeze test and I think it's particularly relevant (p19). • If I could, I would have a baseline for all the players in each test, then **dependent on injury have the correct outcome measure** that could correlate to help determine if a patient was ready to return to play (p23). • Any **injured area** knowing their average leak and peak forces relative to their body weight and opposite side (p26). • **Wellness is key** as ultimately it is about how the athlete feels (p19). • I would also use wellness questionnaires in order to get to know the athlete more to tailor their programme and recovery strategies and to see their **perception of fatigue against objective measures** (p20). • The **correct variables** of the CMJ give some important information related to force and power output of the athlete (p19). • Physical testing measures such as squat jump it could be argued are **not totally reliable** as there is scope for inconsistency around performers effort levels on a week to week basis (p25). • I am **unaware of the evidence behind creatine kinase and testosterone** being used as measurement of readiness and therefore would not automatically choose to test these. However, would be open to these tests if evidence suggested they were worthwhile (p12). • **Sensitive markers** (p1). • I have previously used all of these tests and are **confident with what results they give me** (p5). • The countermovement jump and drop jump can bring about **competition in the group and boost moral** before a game weekend (p20).	Specific requirements of the monitoring tool		

• **Basic testing for the squad**, which is more suitable for the level of athletes working with. Still gives relevant and affective results (p7). • I would always go for the tools that engage the players and **reduce time spent testing** (p20). • **Easy to track and administer** (p1). • The methods I have chosen are **easy to administer and analyse data from**. They're also less time-consuming for athletes to complete (p15).	General requirements of the monitoring tool		Monitoring practices
• **Think players should be monitored every day.** However, I don't see the need to push it straight after the game. No harm waiting till match day+1 (p11). • **I believe checking readiness to play/train daily** is good practice especially at professional level sport (p10). • **I would monitor the complete process of recovery** for each athlete. This would then define further interventions required for that athlete, which creates a better individualized program for that individual (p6). • I would like to **monitor them as much as possible** (p7). • **Regular monitoring and assessment allow for more accurate evaluation of individual traits in recovery** (p8). • Provides an **insight into players soreness throughout the week and potential injury/injury risk** (p2). • If staff/ time available, then **additional screening would be very beneficial** (p24). • **Every day is a chance to gather information** and players respond to games in different ways, so we can see readiness each day between games (p28). • Logistically, I would do their **testing during the training week** (p5). • **Continually monitoring players to best advise rehab/training/playing loads** (p21). • If possible, **every day seems to be the best option** (p9). • I would like to **monitor every day to see fluctuations in performance** (p16).	If possible, monitoring would be done on a daily basis	Timing of monitoring	
• **Over monitoring could be problematic in that the nature of the game requires mental robustness** and often **players performing whilst not at their physical or mental best** (p25). • **Over monitoring may result in players only training/performing when at their physical best** which doesn't represent the demands of the game (p25). • The **danger of over monitoring is we will never create robust performers** if we are unable to push them when they are not feeling their best (p25). • Too much data, if not well collated, can **muddy the water** (p26). • They have the **opportunity to contact us when not on a training day** (p12). • Having a **day by day awareness of a player's injury and rehab, not necessarily testing** on each day (p24).	Too much data can muddy the water		
• However, **we don't automatically do checks pre-game** as these checks and decisions should have already been made (p12). • In an ideal world, the opportunity to check on game day would be good but **may take away from the players pre match routines** (p12). • **Wouldn't see the relevance of match-day -1, as an honest answer is unlikely** (p7). • **Match day would be a general conversation** with the athlete (p20). • **Directly post-match a conversation or visually signs from the team** as a whole is enough to judge how intense a game was (p28). • **Day of the game I don't want the players to have the distraction from the game.** If our preparation heading into the game has caused a lack of readiness, feedback from players would suffice (p28). • **I wouldn't use it on game day** unless we are making a return to play on an injured player. If they aren't ready to play during the week, they are likely not to be selected to play on match day (p5).	Monitoring around match-day		

• I would measure post-match, **those players who have not completed the desired distances covered, sprints made etc will then do a 'top up'** (p20).		Timing of monitoring	Monitoring practices
• Again, the days may change depending on the schedule or the data, but I'd initially be interested in **the days to inform training** (p13). • Match day +3 and -3 would be the two biggest training days, so **having a good idea of where the players are at physically beforehand** would be beneficial (p15). • We **check on our players daily before every session** (p12). • I would then assess +3 as **this is the next time the lads come in for training**, this is when they should be having their strength session but will be tailored if still fatigued from game (p20). • **48 hours post game enables decisions to be made on subsequent training day.** Too early post game does not inform decision making for next training day (p1). • To **assess how effective the club's recovery processes are** post-match (p27). • Post-match I believe players should have emptied the tank so they should be exhausted, but for people that have played limited minutes, **it would be useful to adjust their training** etc (p4). • Testing and monitoring 60 mins post-match and then after 24 and 48 hours, is **enough information to form a picture on individual players** from a recovery perspective (p25). • Also **-1 would allow for me to see how well the players had recovered from their 2 days training** and also where they were going into the game (p15). • **Again on -2 as this is the last time we will see them before the match**. Any potential fatigue should diminish before the game but recovery strategies could be put in place if needed (p20).	Use of monitoring pre- and post-training		

P: Participant number

3.4.2 Training regimes

Whilst large variety exists between clubs regarding their mid-week training schedule (i.e., match-day +2, +3, -3, -2), most practitioners (86%) indicated that players did not attend the club on the day following the match, whereas players predominantly did attend training on the day before the next match (86%). Many respondents (76%) indicated to have specific days throughout the week on which players almost always had a day off, regardless of the day the match took place, and this day was often a Sunday. Throughout the week, training occurred mostly during late afternoon (15:00-18:00 h) or evening (18:00-21:00 h). This time was found most suitable as players and coaches often had commitments outside of rugby (i.e., school, college or work), but was also determined by availability of facilities, due to ''*first team being given priority of training times*''. It was also mentioned that ''*the number of hours in which players can train based on how much they are paid is limited*'' and therefore needs to be carefully considered (Table 3.4).

Whilst different skills (i.e., defensive, attacking, position-specific, and general skills) are practiced throughout the full training week, 60% of technical practitioners highlighted that defensive skills (i.e., contact or wrestle) were often performed earlier in the week, whilst attacking skills occurred later in the week. Mid-week on-field training was often >60 min, whilst the session on the day prior to match-day was usually of shorter duration (i.e., 30-60 min). Figure 3.2 indicates that 'areas of improvement required by individual players' were found most important when prescribing on-field technical and tactical training. This was closely followed by 'areas of improvement required by the team' and 'physical cost of the previous match'.

Table 3.4 Content analysis of 'purpose of training'

Phrase	Sub-Theme	Theme	Subject
• **Sunday's, players generally want this to spend time with families** (p11). • **Sunday as the head coach likes to be off on this day** (p19). • **Our academy players normally have Sunday off.** Unsure of exact rationale. This is normally the day after the game. They will be monitored but it gives them a chance for their own recovery and players that work to at least have 1 full day off per week (p12). • **Wednesday. Lack of facilities** (p22). • **Sunday would generally be a day off.** The lads combine their rugby with work or college, so this is an opportunity for them all the have a full day off. If we play on Saturday, then recovery is done at home (p13). • **Players will always have a Sunday off.** The week of training is manipulated around games which can be played in the week (p6). • **The under 18s have most Wednesdays off as decided by the coaching staff and college** (p24). • **Sunday - unless there's an extremely short turn around.** Coaches decision to have Sunday off (p2). • **Usual to have Sunday as a day of rest.** Historical with coaching staff and funding available for players and staff for unsociable hours (p23). • We normally have **Fridays rota'd off** (p18). • **Thursdays. This is due to their college schedule and it being the day off from college** for most players. For our players studying A levels it is their longest day. So, it makes sense to have no training on that day (p28). • Scheduling for education and travelling commitments. **Wednesday and Sunday are usually off to minimize days travelling** - although open to change if schedule requires (p21). • **Sunday is usually a day off** (p9).	Specific day off during the week	Weekly training schedule	Purpose of training
• **Match day +3** as the first team plays on Sundays (p27). • Players will have the **day after a game off along with a day midweek** (p10). • **Matchday Saturday, recovery day the following day.** Sometimes recovery day will be mid-week on Wednesday dependant on player training load that week (p8). • **Gameday +1 is always off** (usually a Monday) (p14). • **Game day + 4 for recovery for the next game** (p16).	Day off in relation to the game		
• **Facility availability** (p25). • **Availability of training venues** (p27). • This is **due to facilities** (p6). • Not through choice, **just times available** (p7). • **Club time limited due to restrictions with stadium access and first team given priority of training times** (p8). • To **fit around first team schedule/facilities** (p5).	Availability of facilities	Logistical considerations	
• **Players come in after work/college** (p11). • This is the **best time to get all the lads to training who may be at work or college** the remainder of the day (p19). • We tend to be able to get the field at approximately 5 or 6pm, which **gives the players that work a chance to finish work before coming to the club** (p12). • Always **train late afternoon/evening due to work and college commitment of players** (p22).	Commitments outside of rugby (i.e.,		

• We **fit around college commitments**. Timings vary depending on which day is game day (p13). • **Due to players attending college/work, training is late afternoon** (p10). • Timing of the player's **work commitments** (p6). • The training times **allow for players to finish their studies or job** (p15). • **Players/staff have college/work commitments** (p2). • Times available to **train around college/work commitments** (p23). • Players attend college 09:00-13:30, with slight variation during each day. **Our training begins after all education commitments have finished** (p28). • Training times are in the afternoon/night **to cater for the staff and players** (p5). • **Education set up allows for training in afternoon.** Training is usually between 13:00-17:00 (college hours) (p21). • **This is the time most players are available due to work or college** (p9). • **The number of hours in which players can train based on how much they are paid** (p25).	school, college or work)	Logistical considerations	Purpose of training
• With the youth squads still developing, **we do not load as such for games** (p4). • **If they go into a youth game at 85-90%, we can live with that** as we are **after long term development not short-term** • **Don't do captains runs - it's another training session (although reduced load)** and another chance to develop (p21).	Training around games	On-field training (technical practitioners)	
• **The midweek session is when staff are able to get most work done with players ahead of the next game** (p25). • **if players need to get some extra training in which is on the curriculum, we will do it** (p4). • **Game day plus 3 (Tuesday) usually main defensive contact day** (p21). • **Monday's = low level skill, Wednesday = defensive skill, Friday = offensive skill / team skill** (p17). • Age grade rugby so **general skills and positional skills run throughout whole programme** (p21). • Usually **focus on the defensive side of the game early in the week and attacking side later on** (p9). • **Sport science guidance dictates general recovery 48 hours post-match** and a **light session the day prior to a game**	Training throughout the week		
• On a 7-day turn-around we usually have two training days (i.e., MD+3 and MD-3). **We split this in a slower (more acceleration-deceleration) day on +3 and a faster day on -3** (p19). • **Speed training twice a week** when matches are Saturday to Saturday (p22). • **Try to get 2 speed exposures** (p3). • **A speed session at the back end** (p10). • **Any high-speed running, conditioning, max velocity work would be done before a day off to allow for sufficient recovery** (p15). • Given the training schedule, this is the approach we take. **Speed is performed far enough away from both games** (p1). • Players would train off feet conditioning and **any speed work directly on GD-3** (p16). • **On-feet conditioning carried out once a week** (p22). • **High intensity conditioning tends to be early in the week** (p10). • **Will do on field conditioning, alongside tactical training (**p7).	Physical focus during field sessions	On-field training (physical practitioners)	
• **We are quite reactive in season**. Individual conditioning for non-players or injured lads would be individualized (p13). • Match day +3 is dependent on fatigue levels. **There will be some form of speed, agility or conditioning element but to what extent will depend on the athlete's recovery levels**. This day also allows enough time for recovery before competition (p29). • **Based on players and non-players plus any additional needs (**p16). • Trying to **get as much into the athletes whilst still managing fatigue** (p11).	Improving physical capabilities on the field		

• Performing **speed/agility match day - 3 at low volume will provide a presentation effect and not cause soreness for competition** (p29). • Match day -1 no S&C lead sessions are performed **to ensure athletes are not fatigued** (p29). • Tempo running/change of direction/acceleration work would be done the day before **as it wouldn't have too much impact on the athlete's performance in training the day after** (p15). • **Players are at their freshest match-day +3 and match-day -3.** Match-day +2 we may have done a very light field session of low-volume, low-intensity skills. we choose to go high central nervous system, lactic bias on match day +3 as this is when they should be most ready to train with intent. Match day -3 they will have some fatigue from the high central nervous system day previous. So, we will target the aerobic energy system through on-feet conditioning on this day (p28). • This is all dependant on the players and what part of the mesocycle they are **within the season. We use a block periodisation model** (p6). • Usually I have 10 minutes before each session to get the players warmed up. The focus will vary and will **undulate weekly from acceleration, deceleration and change of direction** (p20). • **While maintaining fitness and priming for game at the tail end of the week** (p3).	whilst managing fatigue		Purpose of training
• **MD+3 is more upper body focused whilst MD-3 is lower-body focused**. Legs may need a little longer to recovery post-game (p19). • **Our sessions are generally full body, but the intensity and exercises are adjusted to suit** (p13). • For 'selected players' 3 gym sessions per week **with two specific and one full body.** 'Non-players' two uppers and two lowers (p22). • **Our +3 focuses on upper-body strength, with -3 focusing on lower-body going into a day off** (p16). • **Full body all week** (p7). • **They will then have 2 full body resistance training** as they have a lot to get in over two days of 40-minute sessions (p20). • **Match-day +3 we will do all our lowers except any eccentrics**, this is due to us running the following day. **Match day -3 we will do all our main upper body strength work along with our lowers eccentrics** as we're going into a day off (p28). • **Game day - 3 highest day of the week, speed & strength** (p1). • **Match day +3 is generally our heavy strength day** (p13). • **Early in the week we get the big lifts out the way and tend to taper towards plyometrics at the back end** (p10). • **The players will usually perform a central nervous system priming session on a -1 focusing on jumps and throws** • **Lighter more power-based session the day before a game** (p7). • **Some will do a low volume high intensity power session** (p28). • **Pre-game primer GD-1** (p1). • Once again depends on the mesocycle we are in and the **requirements of the individuals** which can be adapted (p6). • **Anyone who requires** will do a low volume upper body accessory session on match-day -1 (p28).	Weekly periodisation of gym-based training	Off-field delivery (physical practitioners)	
• Again, trying to **get the most from the athletes, whist managing fatigue** (p11). • **Lower body generally takes longer to recover**, so the most intense days are performed on +3 and -3 as athletes are recovered enough to perform the work required and **to allow enough recovery before competition**. **No weights are performed -1 to ensure athletes are not fatigued** (p29). • **Our +2 is usually a lower intensity full body session aimed at getting the players moving again after their recovery day** with some off-feet conditioning (p15).	Adjusting gym-based training to levels of fatigue		

• If little fatigue is present, we will do an upper body session MD+2. **Within the squad the intensity and volume of this will vary depending on fatigue and readiness to train. Players with high fatigue will use this session as recovery**, low minute and non-playing players will use this session as a normal upper body training with the goal of adaptation (p28).			Purpose of training
• **45-60 minutes is likely all that would be available** from technical coaches/head coaches (p11). • **Allocated an hour time slot** (p3). • **Limited time restrictions in the gym** for the whole squad (p7). • **These are the time slots given to us** on the days of training (p20). • **As we only have two proper sessions a week, these will be quite long** (p19). • Gym sessions tend to take around 60 minutes. **The is plenty enough time for the players to complete their program** • **Allows all necessary content to be performed** (p29). • My rule of thumb is from the prehab and warm-up that we only perform **gym-based strength training for no longer than 60 minutes** (p6). • +3 and -3 are our **2 big sessions of the week** focusing on the players individual physical needs (p15). • **Low-med volume in general in season. Match-day +3 lower volume lowers due to being on feet the following day** and on-feet volume having more importance over gym-based volume. **Match-day -3 higher volume due to going into a day off following this** (p28).	Mid-week gym-based training	Duration of off-field training	
• **Short gym** 48 hours post-match (p22). • **Short primer** on match-day-1 (p3). • **For +2 the session is usually shorter** as the players spend more time working on hip/shoulder mobility prior to the session (p15). • -1 is a **short priming session** (p15).	Gym-based training around match-days		

P: Participant number

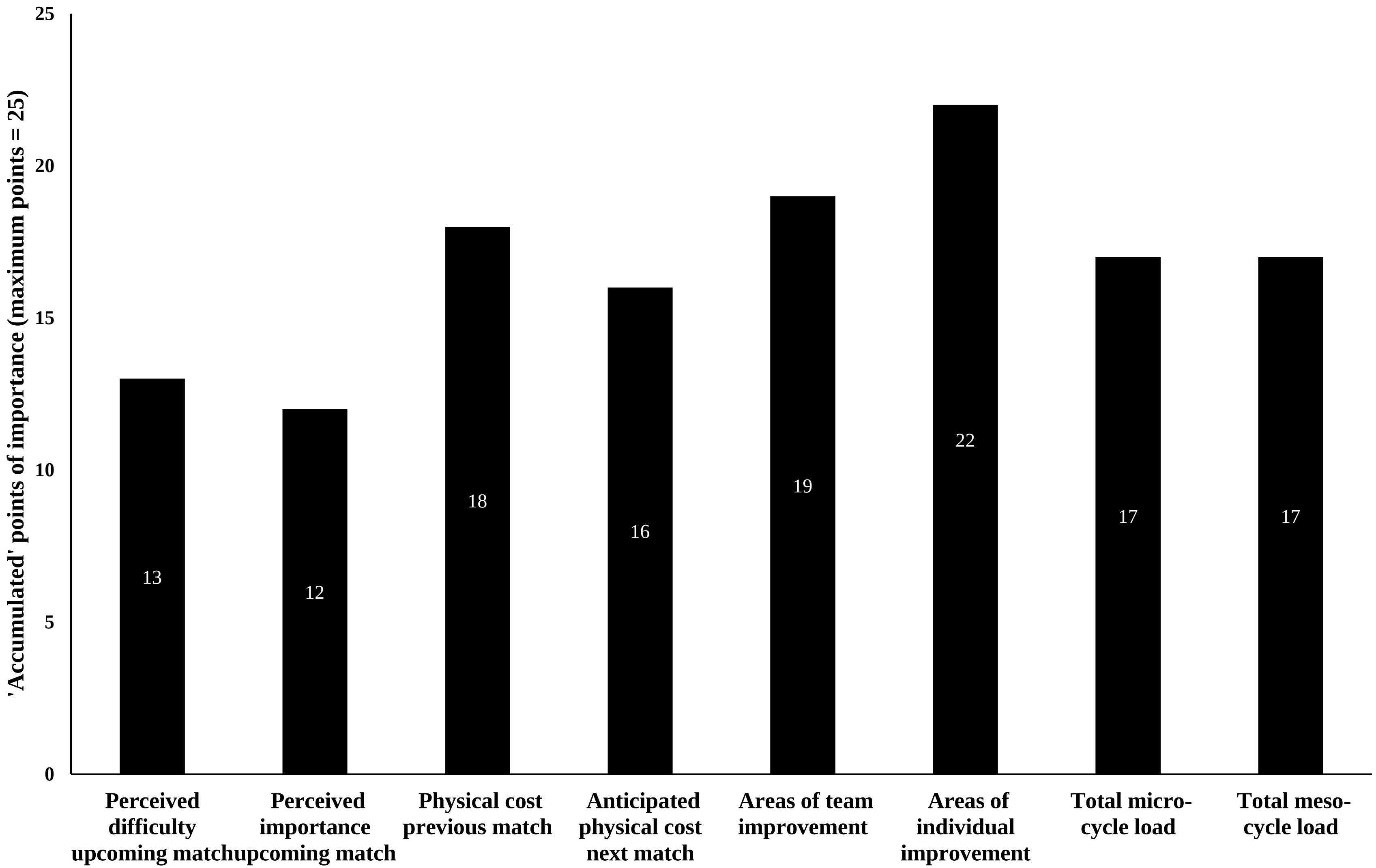

Figure 3.2 Technical practitioners' perceived importance of different factors associated with prescription of training (n = 5)

Physical practitioners had no direct involvement regarding on-field training taking place on match-day -1. Physical field-based elements (i.e., on-feet conditioning, conditioning games, speed, and change of direction/agility training) mostly occurred on match-day +3, -3 and -2. High-speed exposures were often carefully considered, as practitioners indicated that ''*any high-speed running/maximal velocity work would be done before a day off to allow for enough recovery*'', and ''*speed is performed far enough away from both games*''. In-season planning was quite ''*reactive*'', and physical practitioners ''*try to get as much as possible into the athlete whilst managing fatigue*'' (Table 3.4). Physical practitioners implemented different strategies regarding their periodisation of gym-based training. Some chose to separate upper- and lower-body training (e.g., ''*match-day+3 is more upper-body focused whilst match-day-3 is lower-body focused*''). Others chose to have ''*full-body all week*'' whilst ''*intensity and exercises were adjusted to suit*''. It was highlighted that ''*early in the week, we get the big lifts out the way and tend to taper towards plyometrics at the back end*'', whilst ''*a lighter more power-based session is performed the day before the game*'' (Table 3.4). Gym-based training was up to 60 min during mid-week sessions, whilst they were often of shorter duration closer to a previous or upcoming game. Although most practitioners found ''*this to be plenty enough time for the players to complete their program*'', others indicated that ''*45-60 minutes is likely all that would be available*''. 'Athletic needs of individual players' were found most important when prescribing gym-based training (Figure 3.3), followed by the 'the meso-, and micro-cycle training load' and 'the physical cost of the previous match'.

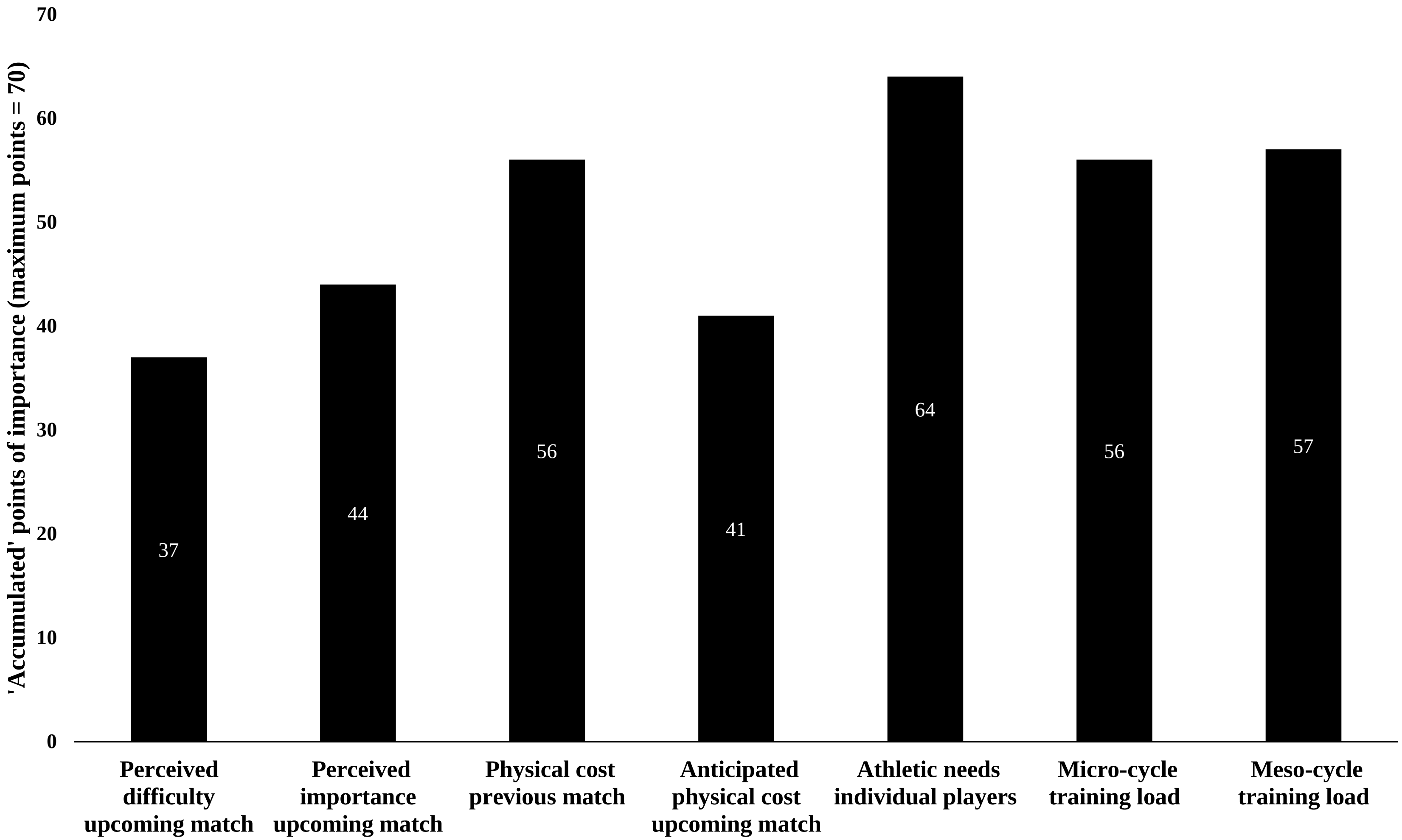

Figure 3.3 Physical practitioners' perceived importance of different factors associated with prescription of gym-based training (n = 14)

3.4.3 Recovery strategies

Of all respondents, 97% agreed or strongly agreed that ‘recovery strategies in academy rugby league were important in order to improve readiness to train and play’. Conversely, only 55% of practitioners agreed or strongly agreed that ‘the recovery process of academy rugby league players is prioritised and executed well within their organisation’ with the remaining 45% disagreeing or providing neutral responses. Recovery strategies were used often or all of the time by 79% of practitioners, whilst 21% used them sometimes or rarely. Table 3.5 describes the frequency at which specific strategies were used, whilst Table 3.6 specifically highlights on which day(s) they were used during an in-season training week. Practitioners indicated that ‘availability of facilities and equipment’ was the most important factor when prescribing a certain recovery strategy, whilst ‘time required to undertake the strategy’ and ‘the research available in support of a specific strategy’ were also found to be of high importance (Figure 3.4).

Practitioners highlighted a desire to increase the number of recovery strategies used, while more frequent use of hydrotherapy (e.g., swimming, cold-water immersion, and contrast bathing) was specifically mentioned (Table 3.7). Where possible, practitioners would like to ‘’*allow the athletes access to whatever strategies they believed work best*’’ and to ‘’*have a more structured approach to player’s individual needs and requests*’’. Various challenges to the practicality of the recovery process also came to light as ‘’*combining recovery with light skills may be useful, as it sometimes feels like a waste of time that is already limited*’’, whilst ‘’*coaching staff want as much time as possible on the training field and do not prioritise recovery of players over this*’’. Instead, ‘’*players are often left to do their own recovery at home*’’. The period directly following match-play (i.e., 60-90 min post-match-play) was highlighted as a window of opportunity to implement strategies ’straight away’. The frequency of use in other recovery-modulating factors (i.e., shower, supplementation, protein- and CHO-rich meal, rehydration, and carbohydrate restoration) is reported in Table 3.8.

Table 3.5 Frequency of use of various recovery strategies

	Never	**Rarely**	**Sometimes**	**Often**	**All of the time**
Cold-water immersion	35%	10%	24%	24%	7%
Hot-water immersion	68%	14%	20%	0%	0%
Contrast-water therapy	69%	7%	14%	7%	3%
Swimming (or recovery taking place in the swimming pool)	24%	17%	31%	24%	3%
Compression garments	17%	10%	21%	41%	10%
Massage	21%	14%	35%	17%	14%
Stretching	0%	7%	10%	45%	38%
Foam rolling	0%	3%	17%	41%	38%
Gym-based recovery (e.g., resistance exercise)	7%	10%	10%	38%	35%
Gym-based recovery (e.g., cardiovascular exercise)	3%	10%	3%	48%	35%

Table 3.6 Weekly timing of various recovery strategies

	Directly post-match (within 60 min)	Match-day +1	Match-day +2	Match-day +3	Match-day -3	Match-day -2	Match-day -1	Match-day (pre-match)	Strategy not used
Cold-water immersion	35%	24%	28%	0%	0%	7%	0%	0%	35%
Hot-water immersion	3%	7%	7%	3%	0%	0%	0%	3%	83%
Contrast-water therapy	10%	10%	7%	0%	0%	3%	0%	3%	76%
Swimming (or recovery taking place in the swimming pool)	3%	59%	24%	0%	3%	0%	0%	0%	24%
Compression garments	61%	39%	36%	18%	18%	18%	21%	14%	18%
Massage	7%	14%	43%	25%	29%	14%	25%	32%	29%
Stretching	17%	48%	79%	35%	28%	35%	48%	24%	0%
Foam rolling	14%	52%	79%	41%	41%	38%	48%	28%	0%
Gym-based recovery (e.g., resistance exercise)	0%	21%	76%	7%	10%	7%	10%	0%	7%
Gym-based recovery (e.g., cardiovascular exercise)	3%	28%	69%	7%	7%	7%	7%	0%	7%

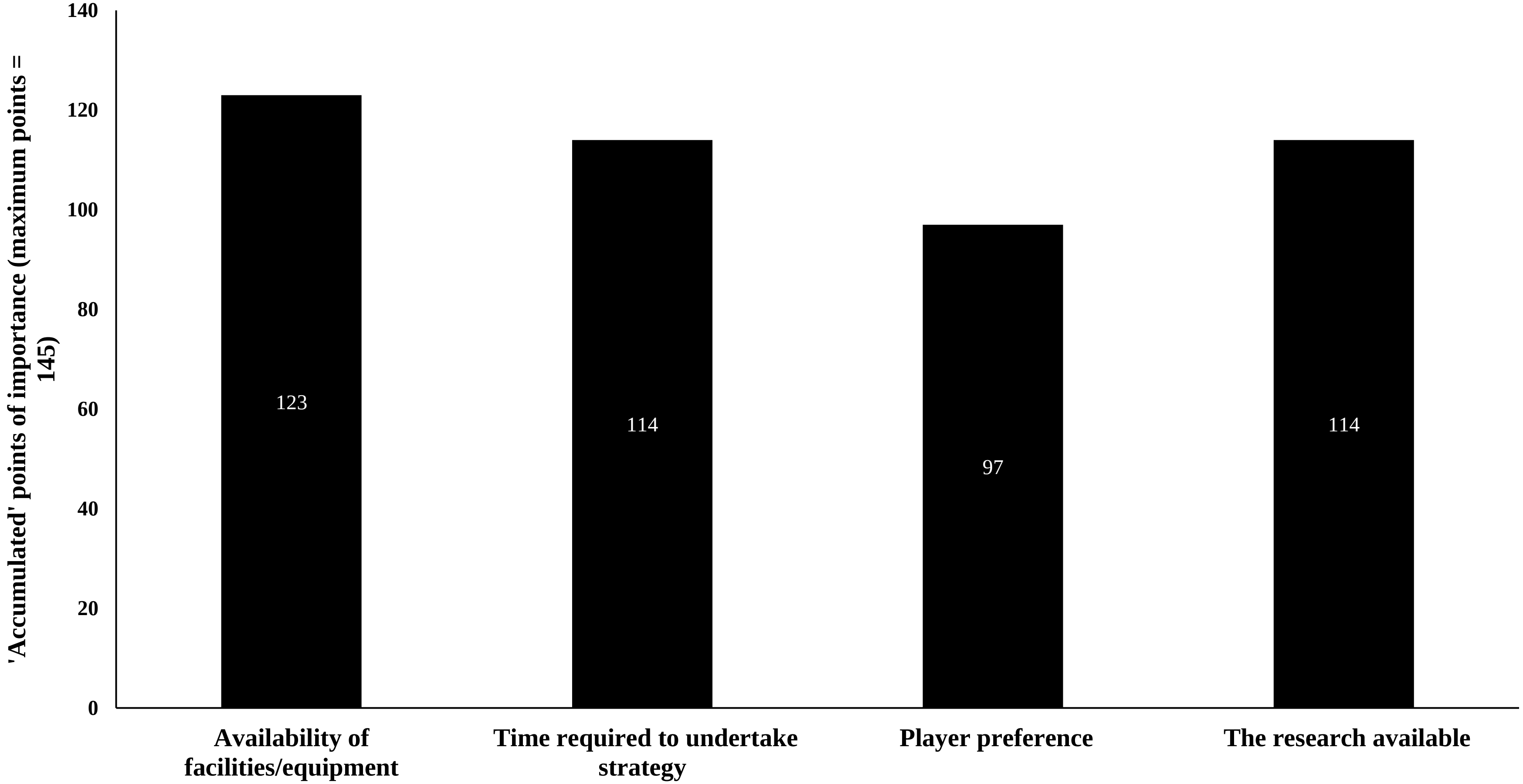

Figure 3.4 Practitioners' perceived importance of different factors associated with prescription of recovery strategies (n = 29)

Table 3.7 Content analysis of 'recovery strategies'

Phrase	Sub-Theme	Theme	Subject
• I'd like us to **combine some recovery work with light skills**- sometimes **it feels like a waste of time that is already limited** • I would want to do more **if facilities allowed** (p4). • Depending on the day of the game, **players are often left to do their own recovery at home**. This wouldn't be preferred and ideally, they would be in on MD+1 to run through a full recovery protocol (involving some form of hydrotherapy as well as a good flush out and foam rolling/stretching) (p19). • If the players have a hot or cold bath, this is **completed in their own homes**. We also have a few players who have bought their own compression garments and go to pools, but this is now compulsory (p12). • **Stretching and foam rolling would be home based** for those who need it (p20). • Barriers provided by coaching staff who **want as much time as possible on the training field and do not prioritize recovery of players over this** (p12).	Optimising time that is already limited	Challenges & opportunities in the recovery process	Recovery strategies
• Also, **direct recovery post-match can be better to provide them with more nutritional strategies and ice baths straight away** (p19). • **Pool recovery 60 mins post-game** and then on the second day after the game (p25). • **Improved nutrition/hydration post game with a chef** (p2). • Yes- **straight after a game I would do a pool session with contrast water sessions** (p4).	Using the acute post-match period		
• Would **allow the athletes access to whatever strategies they believed work best** (p11). • I'd maybe set up smaller groups where **players can select from a range of strategies dependant on what they feel works for them** (p15). • Have more dedicated time to monitor and **guide recovery strategies individually for players** (p8). • Yes, more structured approach to **player's individual specific needs and requests.** e.g. some players prefer pool based, some players prefer to get on a bike (p23). • I would have more options available to the athletes in order **for them to find their preferential recovery method** (p28).	Personal preference	Wider range of strategies for players to choose from	
• **I would take them to a gym with a pool and spa facilities so they could swim and contrast bathe** as well as completing their resistance based and cv based recovery (p12). • **Pool work recovery day after game** (p10). • **I would include swimming as a recovery modality** (p20). • **Availability to use cold-water immersion more regularly** (p2). • **Access to a pool** (p1). • **Contrast bathing facilities at the club** (p21). • **More swimming** (p17). • **Swimming pool for compression** (16).	Hydrotherapy		
• Yes. **Active recovery such as swimming would always be performed, alongside massage and cryotherapy** (p29). • Would like more time, for both stretching and foam rolling, as that eats into gym time. **More access to the pool and more time with physios** (p7). • **All players to be issued with foam rollers too** (p20). • **Provide players with compression garments** (p2).	More strategies		

• **Variety in recovery methods would help players attention and compliance** - so more trips to the pool to recover would be ideal (p5). • **More options and time to educate players** (p14). • Scientific testing. **Increased wellness and sleep monitoring** (p21). • Yes, I would have **more hands-on recovery through massage when players flag up and requiring attention** on wellness (p5). • I would **provide assistance with appropriate nutrition** for players (p27).			

P: Participant number

Table 3.8 Frequency of use of modulating recovery factors

	Never	Rarely	Sometimes	Often	All of the time
Shower post-match	0%	0%	0%	25%	75%
Supplementation (protein shake or equivalent)	3%	3%	3%	35%	55%
Protein- and carbohydrate-rich meal post-match	0%	0%	10%	41%	48%
Rehydration (e.g., water)	0%	0%	3%	31%	66%
Carbohydrate restoration (e.g., sweets or a carbohydrate drink such as a Lucozade)	0%	0%	10%	55%	35%

3.4.4 Future research

All respondents (100%) believed that more research should be conducted in relation to fatigue and recovery in academy RL players. The effect of match-play and field-based training on player 'fatigue' were rated as the most important areas of future research (Figure 3.5).

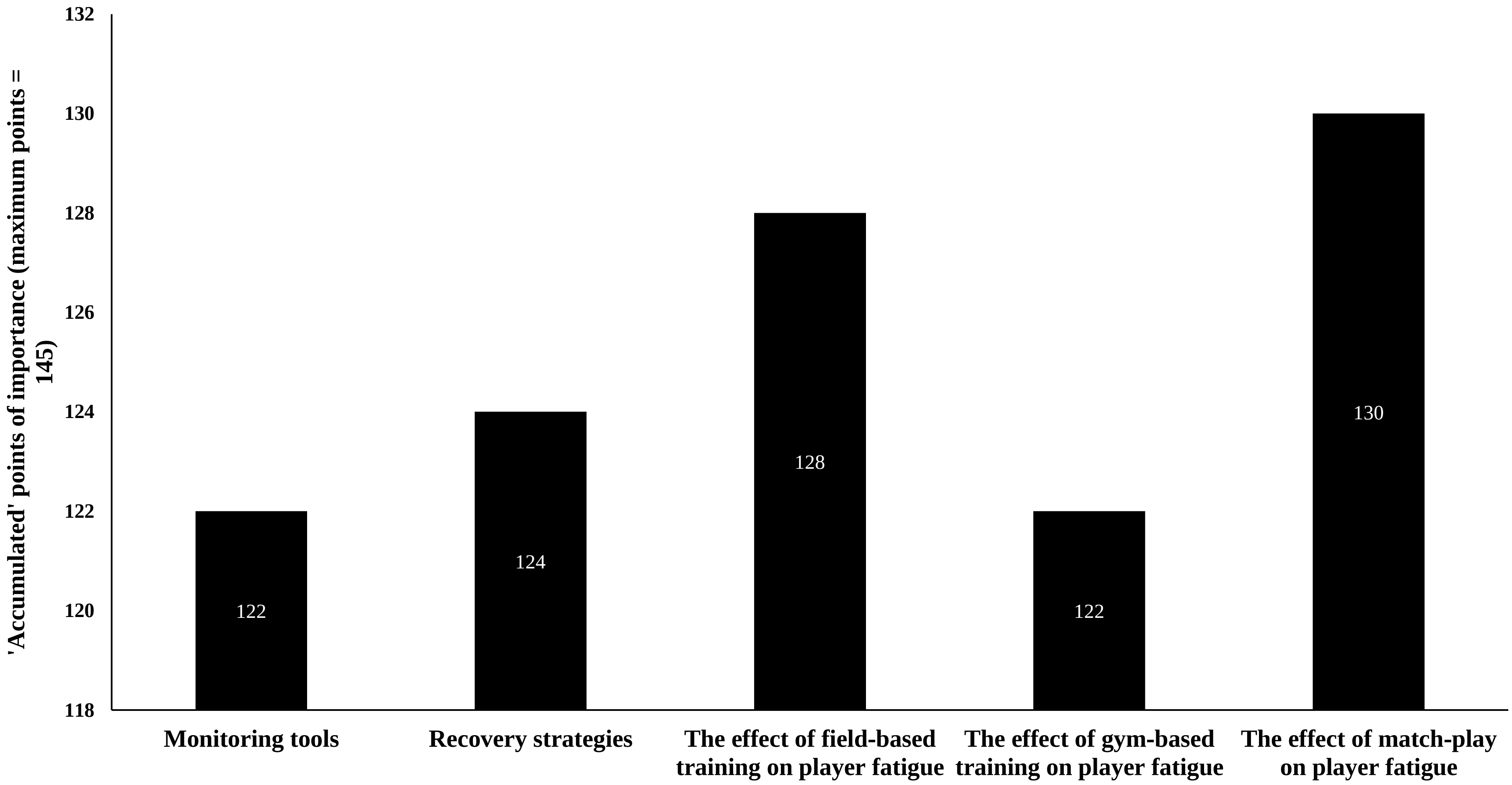

Figure 3.5 Practitioners' perceived importance of different areas of future research (n = 29)

3.5. Discussion

This study assessed the perceptions of practitioners regarding the applied practices of player monitoring, training, and the use of recovery strategies in academy RL. Monitoring player readiness to train predominantly happened mid-week (i.e., match-day +2, +3 and -3) with tools that were generally easy to implement (i.e., wellness questionnaire, knee-to-wall test, adductor squeeze test, and measures of soreness). Training often took place during late afternoon or evening (i.e., 15:00-21:00 h) to allow for players and members of the coaching staff to finish their education and/or work commitments. When prescribing training (i.e., both on the field and in the gym), the areas of improvement in individual players were found to be most important. Notably, trends dictated that earlier in the training week, there was a stronger emphasis on defensive skills and physical contact on the field and strength-based exercises in the gym. In contrast, attacking skills and high-speed running, combined with power-based exercises in the gym, typically occurred later in the training week. Most practitioners (79%) indicated that they were using recovery strategies often or all of the time. Strategies such as stretching, foam rolling, gym-based recovery (i.e., resistance exercise, cardiovascular exercise), and compression garments were used most frequently. Altogether, the present chapter contextualises the academy RL environment and presents novel information regarding the practical challenges and considerations related to the fatigue and recovery process in this population.

Of the monitoring tools identified, a wellness questionnaire was used by 86% of respondents, which is similar to the responses provided by practitioners in a variety of other sports (Taylor et al., 2012). A wellness questionnaire is a relatively quick and reliable way to gain understanding of an athlete's perceptual well-being, which makes its popularity amongst academy RL practitioners unsurprising. In addition to subjective tools, the objective measures used most in academy RL were the adductor squeeze test and the CMJ. The potentially predictive relationship to groin injuries (Moreno-Pérez et al., 2019) would be the likely rationale for practitioners to use the adductor squeeze test. The CMJ, a frequently used tool in other sports also (Taylor et al., 2012), is a well-researched, quick and reliable test, of which certain variables may provide an indication of fatigue following high-intensity exercise. The frequent use of the knee-to-wall (75%) and sit and reach tests (39%) may be explained by the high number of medical practitioners (i.e., n = 10) that completed the survey. The knee-to-wall test assesses range of motion in ankle dorsiflexion, which, when limited, may predispose athletes to anterior cruciate ligament, and patellar tendon injuries (Mason-Mackay et al., 2017). A sit and reach test allows measurements of lower back and hamstring flexibility, but questions remain regarding its validity (López-Miñarro et al., 2009), whilst the effect of hamstring flexibility on hamstring muscle strain injury remains inconsistent (Liu et al., 2012). Altogether, these tools are easy and quick to administer, whilst they require minimal training. Practitioners highlighted these as important requirements of a monitoring tool, and it is therefore unsurprising that they are utilised most within academy RL.

Practitioners indicated that during a competitive training week, monitoring primarily took place mid-week (i.e., match-day +2, +3, and -3). Although players are known to require 48-72 h to recover from match-play, not all training needs to be excluded during this period. Depending on the individual extent and time-course of recovery responses (Markus et al., 2021), as well as positional match demands (Gabbett et al., 2012), some players may benefit from light training on match-day +2 which provides an additional opportunity to develop without eliciting additional fatigue. While it is at this point that monitoring could influence practice the most, results observed here indicate that monitoring did not often inform practice (Table 3.2). Monitoring readiness to train or play should be paralleled with subsequent adjustments to practice where necessary (Taylor et al., 2012). Various methods (i.e., visual identification of trends, arbitrary cut-off values, or a significant drop below average scores) may be used to identify ‘red flags’ in individual players (Taylor et al., 2012), and practitioners need to be clear on the extent of change in the monitored responses which would prompt such adjustments. The findings of the current study highlight that whilst a time investment is allocated to player monitoring, investigating these identified changes, and potentially adjusting practice for individuals appears time-consuming and challenging in practice. Indeed, the training times (i.e., between 15:00-21:00 h) and the part-time nature of most players and almost half the members of staff suggest time-restrictions which may cause conflict (Rothwell et al., 2020), and compromise ‘best practice’. Although strategies such as ‘keeping a close eye on individuals in case of a red flag’ or ‘every-day conversation’ have been found extremely valuable (Taube et al., 2013), practical methods of responding to (a lack of) reported symptoms by adjusting training protocols where necessary may be beneficial (Quarrie et al., 2017). Notably, practitioners rated the effect of match-play and field-based training on player ‘fatigue’ as the most important areas of future research, and further information on this subject may help practitioners when designing and adjusting their training protocols.

The mid-week training period (i.e., match-day +3, -3, and -2) is the period in which most field- and gym-training took place. Acknowledging the variety in training schedules between clubs, and the limited number of technical practitioners that completed the survey, certain trends in relation to training methods were discovered across practitioners. It appears that earlier in the week there is an increased focus on defensive skills and physical contact on the fields whilst there is a large focus on strength exercises in the gym. In contrast, attacking skills and high-speed running are emphasised later in the week, with gym sessions largely focusing on more power-based or plyometric exercises. Such a periodisation may be explained by the extended period of recovery that is required by a velocity component (i.e., PP in CMJ) compared to a force component (i.e., PF in CMJ) following high-intensity exercise (i.e., match-play) (McLellan & Lovell, 2012; Norris et al., 2019). Consequently, any training with a large focus on the velocity component (i.e., high-speed running on the field and power training in the gym) may be considered further away from match-play.

It is common in many senior team sports that the training session on the day prior to match-play (i.e., captain’s run) is of a significantly shorter duration, to avoid it negatively influencing subsequent match performance (Dubois et al., 2017; Malone et al., 2015). The aim of this session is to practice different shapes, formations and set pieces to ‘fine-tune’ these skills in preparation for the upcoming game. Although an optimal and winning performance is sought after in senior sports, this may not be the case in academy players, as the main aim is long-term individual physical, technical and tactical development (Phibbs et al., 2018; Till et al., 2015a). Undoubtedly, some coaches and players may disagree, but winning games may at times be of secondary importance in academy RL (Rothwell et al., 2020). At the same time, winning games also plays an important part in the development of young RL players, especially, when considering their potential final destination, where winning games is considered most important (i.e., first team). Therefore, practitioners should aim to find a balance between player development and winning performances where appropriate. Nevertheless, it may not be surprising that some practitioners indicated not ''*to load players for games*'', and ''*to be okay with players going into a youth game at 85-90%*''. Although this session on match-day -1 was also of a slightly shorter duration than mid-week training (i.e., 30-60 min) in academy players, ''*it is just another training session*''. Such a difference in physical loading prior to match-play between senior and academy environments may also have implications for monitoring practices. Specifically, if an optimal physical state is not necessarily required in academy players, it is unlikely that any potential decrements in performance or wellness variables found through monitoring will influence practice at this time (i.e., close to match-play).

Historically, academy RL matches in the UK are played on a Thursday or a Saturday. Almost all practitioners reported that the day following match-play was a day off. In addition, a Sunday was almost always a day off as well, regardless of the day the game was played that week (unless this was a Sunday). Research assessing post-match recovery responses often include recovery strategies on match-day +1 (McLean et al., 2010; Oxendale et al., 2016; Twist et al., 2012), as this is common practice in senior rugby. The practical application of such research in this population is limited as academy players do not take part in club-led recovery activities on this day. Instead, practitioners indicated that players may at times be left to perform their own recovery at home. This highlights the importance for practitioners to provide players with a structured and guided recovery protocol which they are able to follow on their own. Practitioners also highlighted a window of opportunity to benefit from the quality of supervised recovery strategies. The period directly after the game (i.e., within 90 min post-match) is a practically achievable time where players are still present. Appropriate nutritional strategies (Ranchordas et al., 2017) alongside recovery modalities such as hydrotherapy may be effective to 'kick-start' the recovery process (Tavares et al., 2017). However, whilst the effect of various post-exercise recovery modalities has been researched in isolation (Duffield et al., 2010; Garcia et al., 2016), the efficacy of a holistic approach, combining various aspects of the recovery process (i.e., nutrition, sleep, recovery modalities) remains to be investigated further (Lindsay et al., 2015a).

Despite practically all practitioners (97%) highly valuing the use of recovery strategies in academy RL, only just over half of practitioners (55%) agreed that the recovery process was executed well within their organisation, which is likely due to the time-restrictions present in this population. It appears that, as academy players are only legally allowed to spend a certain amount of time performing club-related duties, other activities such as field- or gym-based training, and video (p)review sessions may be prioritised over the implementation of recovery strategies. It may therefore not be surprising that those strategies most commonly used (i.e., stretching, foam rolling, gym-based recovery, compression garments) are relatively cheap, easy to implement and time efficient. However, their effects on performance and recovery may be relatively minor (Sands et al., 2013; Tavares et al., 2017; Wiewelhove et al., 2019), and the consistent use of such strategies in practice may therefore be questioned. This information highlights once more that ecologically valid protocols in relation to the recovery process are required in this population.

Whilst this chapter presents novel observations regarding academy RL environments and the perceptions of practitioners in relation to monitoring practices and the use of recovery strategies, it is not without limitations. Firstly, to assess weekly practices, questions were standardised to assume a between-match period of six days (i.e., match-day on the Saturday, next match on the Saturday). Naturally, the duration of between-game periods varies significantly throughout the season, and this is likely to impact various aspects of training, as well as the implementation of monitoring and recovery strategies. Other external factors, such as time in-season and individual player circumstances are likely to play a role also. This study provides general trends, but various protocols and training strategies naturally differ between clubs, meaning individual variation exists. As previously highlighted, only 12 or 13 professional academies exist in the UK, many with limited financial resources and personnel. A total of 29 practitioners completed the survey, and whilst this may not be a particularly large number in relation to many larger-scale surveys, it could still be considered a reasonable number considering this survey only targeted academy RL practitioners. All responses were grouped together despite having three different subgroups in technical practitioners (i.e., technical coaches and heads of youth), physical practitioners (i.e., strength and conditioning coaches and sport scientists), and medical practitioners.

Acknowledging that different practitioners may have differing points of view, the survey was not individually made for each subgroup as questions were overall quite general and enough space was provided to explain any specific thoughts and considerations. This way, various themes still emerged through content analysis, which was likely to be linked to the different subgroups. In addition, exclusive questions were also asked to specific subgroups. Nevertheless, this study was only able to recruit a limited number of technical practitioners (i.e., technical coaches, heads of youth), and whilst certain trends emerged from the data provided, future research is needed to investigate technical training practices in more depth. Conventional content analysis was found to appropriately add depth and background information to contextualise the merely quantitative data provided. Altogether, the quantitative and qualitative data provided context to the environment of academy RL, whilst various barriers and opportunities were highlighted by those working in the field, which will aid the design of ecologically valid research in this population.

3.6 Conclusion

Although this survey specifically targeted practitioners working in academy RL, the responses and data collected may be useful for practitioners in other (rugby) academies also, as environments may show similarities. Due to limited time and resources, monitoring player readiness should only occur when results will influence practice. If this is not possible, practitioners should re-consider their rationale underpinning the use of player monitoring. The main aim of academy rugby is long-term holistic development of their players, whilst winning games should be of secondary importance. As a result, optimal preparation for a match-winning performance is not always sought after, and monitoring of performance or wellness variables on the day of, or prior to match-play, is unlikely to influence practice in academy RL environments. To avoid monitoring player readiness when impact to practice is minimal, (i.e., prior to match-play), practitioners are recommended to focus monitoring efforts on the mid-week training period. Any perturbations that players may suffer from (either from match-day or a previous training session) could then be dealt with appropriately. To do so, practitioners are recommended to use both subjective (e.g., well-being questionnaire) and objective tools (e.g., adductor squeeze test, CMJ) that are easily and quickly implemented and analysed. Due to time-restrictions, players may at times, specifically after high-intensity training, be left to perform or follow recovery-enhancing activities and protocols by themselves. It is therefore particularly important for practitioners to educate players regarding the recovery process, whilst enhancing recovery and priming good practice by providing carefully guided and structured recovery protocols which players can follow by themselves. Alongside such protocols, recovery interventions supervised by coaching staff could also take place. The acute period post-match-play (i.e., within 90 minutes of match finishing) was highlighted by practitioners as an important time in the recovery process which could be intervened with, using various nutritional strategies and recovery modalities. Despite facing challenges in relation to time restrictions and the availability of facilities, such a strategy would provide an ecologically valid solution to enhance the recovery process in an academy RL environment.

Chapter 4.0 The reliability of neuromuscular and perceptual measures used to profile recovery, and the time-course of such responses following academy rugby league match-play

Chapter Summary

- During three visits over two days, up to 11 academy rugby league players completed a wellness questionnaire, and three attempts of both the isometric mid-thigh pull (IMTP) and the countermovement jump (CMJ), to assess their within- and between-day reliability.
- Post-match responses were assessed for 120 h (baseline: -3, +24, +48, +72, +96, +120 h) using those variables that showed acceptable (i.e., no between-trial differences and between-day coefficient of variation ≤10% and intraclass correlation coefficient ≥0.8) between-day reliability.
- For the IMTP, acceptable within- and between-day reliability was found in force at 200, and 250 ms, and peak force. Most variables in the CMJ achieved acceptable within-day reliability, whilst six (i.e., flight-time, peak force, peak power, relative peak power, velocity at take-off, jump-height) variables demonstrated acceptable between-day reliability. Only total wellness demonstrated acceptable between-day reliability in the wellness questionnaire.
- Reductions of 4.75% and 9.23% (vs baseline; 2.54 $m \cdot s^{-1}$; 0.33 m) occurred at +24 h for CMJ velocity at take-off and jump-height, respectively. Despite moderate and large effect sizes in the post-match period, no significant changes were found across IMPT variables and total wellness.
- Practitioners should be mindful of the influence that the choice of recovery monitoring tool and variables may have upon the practical interpretation of the data.

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4.1 Introduction

Largely due to the frequency and intensity of eccentric muscle actions and physical contacts (Oxendale et al., 2016; Twist et al., 2012), the demands of match-play may cause post-match perturbations in the hormonal milieu (Johnston et al., 2015b; Twist et al., 2012), indices of neuromuscular function (McLellan & Lovell, 2012; McLellan et al., 2011a; Oxendale et al., 2016), perceptual responses (McLean et al., 2010; Twist et al., 2012), and muscle soreness (Oxendale et al., 2016). Knowing the influence of match-play on specific recovery and preparedness to train markers is valuable for practitioners when seeking to modulate training intensity and/or volume thereafter in order to avoid accumulation of fatigue and subsequent injury, illness and/or underperformance (Kellmann et al., 2018).

Up to 120 h may be required to facilitate full post-match recovery (McLellan et al., 2011a), however most observations from adult players have reported durations of 48-72 h (McLellan & Lovell, 2012; West et al., 2014) when profiling the restoration of neuromuscular, biochemical or endocrine, and perceptual responses (chapter two). These inconsistencies may reflect methodological differences between studies, such as the reliability of the specific variables being examined (Roe et al., 2016a), between-study differences in match-play demands, as well as discrepancies in training regimes (McLellan et al., 2011a; Roe et al., 2016c) and recovery strategies (McLellan & Lovell, 2012; West et al., 2014) implemented in the post-match period; all of which are known to modulate post-match recovery. Literature reporting the reliability of the various recovery markers used in collision-sports players is limited, in both senior (Cormack et al., 2008c), and academy (Roe et al., 2016a) playing standards. Furthermore, whilst some investigations have reported reliability data, it is unclear whether these relate to within- or between-day assessments (Johnston et al., 2015b; Twist et al., 2012). Such information may be important, especially when considering the repeated use of certain measurements in either within- or between-day scenarios. Because the reliability of measures may be population-specific (Cormack et al., 2008c), it is important for practitioners to know the reproducibility of tests and variables in their target population. This was confirmed by academy RL practitioners, who mentioned the importance of acceptable sensitivity and reliability in their monitoring tools (Table 3.3).

As highlighted in chapter two, previous studies that have profiled post-match responses in RL, have often recruited senior age players (McLean et al., 2010; McLellan & Lovell, 2012; Oxendale et al., 2016; Twist et al., 2012), and typically neglected those in the later stages of adolescence (i.e., 16-19 years). Notably, investigations assessing responses to match-play in academy RU (Roe et al., 2016c; Roe et al., 2016d) or RL (Johnston et al., 2015b) players remain limited. Differing activity profiles during match-play (Johnston et al., 2015a; McLellan & Lovell, 2013), and differences in certain physical capabilities associated with specific age groups (i.e., reduced fitness levels and maximal strength) (Gabbett, 2002; Till et al., 2014b) appear to influence post-match recovery responses (Johnston et al., 2015a; Johnston et al., 2015b). For this reason, there remains a need for practitioners to understand the magnitude and time-scale of post-match responses in academy players as this is likely to affect the implementation of recovery strategies and training regimes in the post-match period. This statement is especially true given that professional academy players often have additional commitments outside of their rugby careers in the form of school, college or additional employment, which may cause further restrictions and challenges when seeking to maximise recovery (Hendricks et al., 2019). Finally, survey findings (chapter three) highlighted match-play and field-based training on player ‘fatigue’ as the most important areas of future research. Collectively, differential post-match responses may be elicited in academy versus senior players when methods that incorporate greater ecological validity are employed. Therefore, in academy RL players, the aim of this chapter was to A) assess the within- and between-day reliability of neuromuscular and perceptual measures, before B) profiling the time-course of recovery of variables deemed reliable for 120 h post-match

4.2 Methods

4.2.1 Testing considerations

Chapter two highlights some of many measures that may be used to assess post-exercise responses. Prior to data collection for the current study, various measures were considered above the ones that were ultimately profiled. Specifically, a drop jump (DJ), a PPU, and a maximal power effort on the Wattbike were all considered, but ultimately excluded. Acknowledging that each of these measures provides a unique insight into a specific element of fatigue, assessing the reliability and post-match responses for all these measures would have been taken up considerably more time, and would have been practically challenging.

A DJ, which requires stepping of a box, and upon landing, subsequently jumping as quick and high as possible, is a measure commonly used to assess reactive strength index (RSI) (i.e., the ability of completing a fast SSC action), by dividing jump-height (JH) by ground contact time (McMahon et al., 2021). Alternatively, RSI modified (RSI_{mod}) is calculated in a CMJ by dividing JH by time to take off. Such a measure is very similar to FT:CT ratio, originally proposed by (Cormack et al., 2008b), and these two variables indeed share an almost perfect positive relationship (McMahon et al., 2018). Acknowledging the differences between these two jumps (i.e., a DJ is a fast SSC task, whereas the CMJ is a slow SSC task), a large relationship exists between RSI and RSI_{mod} (McMahon et al., 2021). Given this relationship, and the more frequent use of the CMJ in academy RL (chapter two), the CMJ was preferred over the DJ.

The Wattbike is an air-braked ergometer, which calculates power output via a load cell located next to the chain (Hopker et al., 2010). Reliability data of PP on the Wattbike suggests a Coefficient of Variation (CV) of 3.0% in professional AF players (Wehbe et al., 2015b), while extra caution should be taken when assessing test-retest reliability at lower power outputs (Hopker et al., 2010). An 'all-out' PP test, completed over six s, may provide an alternative way of monitoring neuromuscular fatigue, with the non-weight aspect of the test being the obvious benefit (Roe et al., 2017a). However, when profiled following match-play, the Wattbike PP test appears to be lacking sensitivity to fatigue (Roe et al., 2017a; Wehbe et al., 2015a). This may be due to most fatigue-inducing elements being the result of eccentric muscle actions, whilst the PP test on the Wattbike only quantifies the concentric component of the experienced fatigue. For this reason, the PP test on the Wattbike was not included in any further measurements.

Finally, the PPU, which may provide an indication of upper-body neuromuscular fatigue, was considered. A PPU requires the hands to be on a force platform with elbows extended, after which a push-up is performed as quickly as possible with the aim of the hands leaving the platform (Roe et al., 2016a). Indeed, match-play or training involving frequent collisions are known to elicit perturbations in upper-body neuromuscular function (Roe et al., 2017b), which may consequently be profiled using the PPU (Roe et al., 2016c). However, due to the anticipated difficulty of consistently performing a plyometric push-up, a subjective measure of upper-body responses was preferred.

4.2.2 Experimental overview

Figure 4.1 outlines the methods used in this study. In part A, this study assessed the reliability of isometric mid-thigh pull (IMTP), CMJ, and wellness questionnaire measures in academy RL players. Within- (i.e., morning; AM vs afternoon; PM in week 2) and between-day (i.e., PM measures week 1 vs week 2) reliability was assessed during three visits over two days (i.e., week 1 day 1 PM, week 2 day 2 AM, week 2 day 2 PM). Each day was one week apart with the PM measure from the second day also serving as a baseline time-point for part B; occurring approximately 3 h before match-play commenced. Thereafter, in part B, the influence of match-play on variables deemed eligible (based on acceptable between-day reliability) was assessed for 120 h following a competitive RL match. After completion of the match, players were assessed at +24, +48, +72, +96 and +120 h.

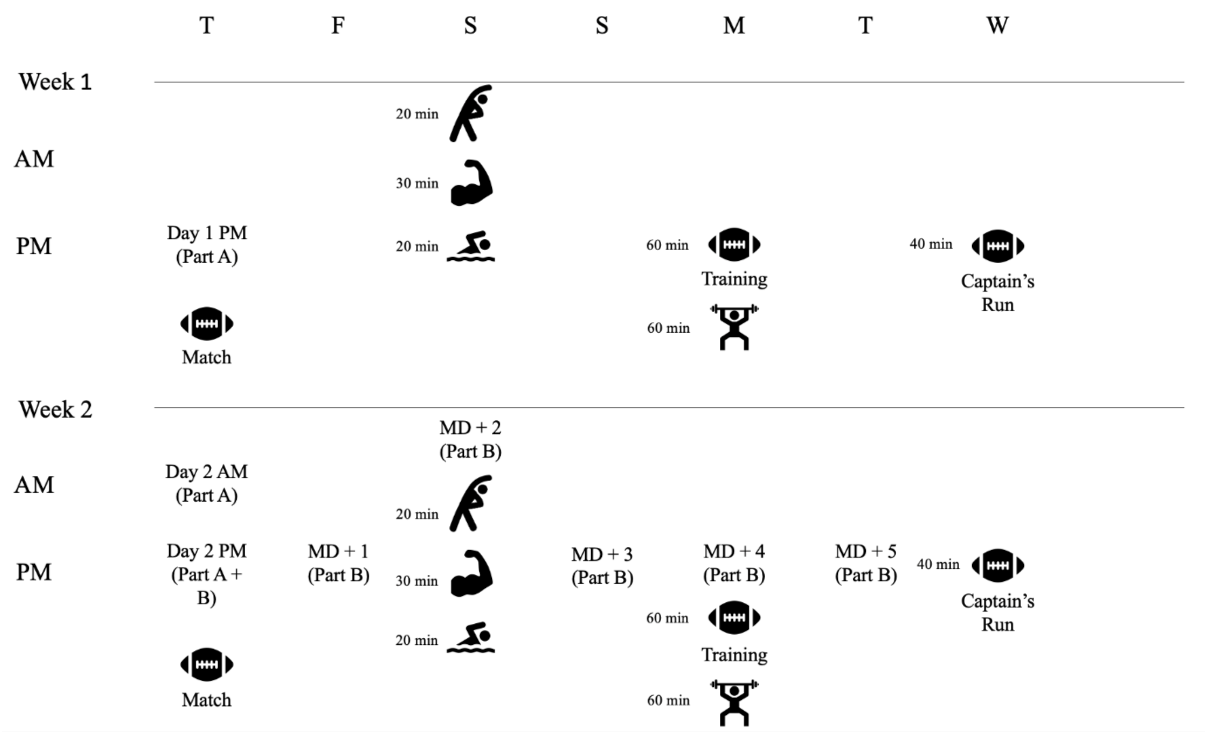

Figure 4.1 Study Protocol. Match: Match-play; Training: The primary focus of this training session is development of specific skills and the tactical aspects of the game; Captain's run: The final training session leading up to the game. This session predominantly focuses on the tactical and game-specific elements of the game; : Static and dynamic stretching as well as full body foam rolling in order to restore range of motion and general movement function; : An upper-body hypertrophy-based training session; : Pool session mostly taking place in the shallow end of the pool in which players perform a variety of dynamic movements (e.g., lunges, squats, calf raises, high knees); : Individual gym-based program including a variety of full-body movements designed to improve strength, power and/or hypertrophy (e.g., bilateral squat variation, knee- and or hamstring-dominant hamstring exercises, lower-body unilateral exercises, horizontal and/or vertical push and pull exercises).

4.2.3 Participants

Following institutional ethical approval (Appendix 3), 11 male RL players (age: 18 ± 1 years, mass: 92 ± 9 kg, stature: 1.83 ± 0.04 m, years spent in professional playing and training: 4 ± 1 years, three repetition maximum back squat: 141 ± 11 kg, three repetition maximum bench press: 93 ± 7 kg) from the same SL academy volunteered to take part in the study. Players represented a range of positions, but six played as forwards (i.e., three prop forwards, one back row forward, one loose forward, and one hooker) with the remaining five players being backs (i.e., two wingers, two centres and one fullback). One player was unable to participate in visit one of the between-day component of part A; therefore, between-day comparisons, and part B responses represent ten players. Player absences were due to reasons unrelated to the study (i.e., injuries from previous matches, lack of availability for testing). Players were given full details of the study procedures and were informed of the risks and benefits of the study prior to the start of data collection. Retrospective power analysis was performed using G*Power and indicated that >80% statistical power had been achieved for the statistically significant differences observed relative to baseline in JH of the CMJ. Upon agreeing to participate in the study, players then provided written informed consent prior to the start of data collection. Although players had historically sustained a range of lower and upper body injuries, all were declared fit and free of illness or injury by the club's medical staff at the time of testing.

4.2.4 Procedures

All testing took place in the gym of the SL club, which players were accustomed to following their regular training taking place in this environment. Players arrived for testing in groups of three or four, to limit any distraction as much as possible during testing procedures. Upon arrival for testing, players first completed a wellness questionnaire, followed by a standard dynamic warm-up (including lunges, sweeps, hip openers, heel flicks, high knees and leg swings) and two submaximal attempts of the IMTP and the CMJ, before commencing the testing protocols. Match-play took place mid-season and locomotor activities were profiled using MEMS devices. During the post-match period, players continued to participate in club activities (i.e., recovery strategies, training) as well as regular lifestyle commitments (e.g., college, school, work) as normal (Figure 4.1). Throughout the entire period of data collection, players were encouraged to maintain normal dietary intake, as advised by the club's nutritionist.

4.2.5 Subjective wellness

A wellness questionnaire was used by 86% of academy RL practitioners (chapter three). Therefore, players completed a short wellness questionnaire adapted from McLean and colleagues (McLean et al., 2010). This questionnaire, which players were accustomed to completing as part of routine monitoring practices at the club, required a rating of perceived fatigue, sleep quality, muscle soreness (separate ratings for upper- and lower-body soreness), stress levels and mood on a five-point Likert scale. The aggregate sum of all six scores also provided a total wellness score. Lower values indicated a negative response whilst higher values indicated a positive response. Players completed the questionnaire separated from other individuals in order to minimise the influence from other players and/or coaching staff. The between-day reliability (CV: 7.1%) of this questionnaire has previously been reported in academy RU players during a non-training week (Roe et al., 2016a).

4.2.6 Isometric mid-thigh pull

In preparation for testing, participants took part in three habituation trials in the week prior to data collection. During the first habituation trial, players placed themselves in their preferred position whilst adhering to the prescribed guidelines as well as adhering to the range of joint angles (knee and hip angle of 120-135° and 140-150°, respectively) previously recommended (Beckham et al., 2018). Once the pulling position was established, starting positions were replicated between testing sessions to ensure repeatability of measures. Players were asked to stand on the force plate (type: FP4060-05-PT, dimensions: 600 mm x 400 mm, sampling: 1000 Hz, Bertec Corporation, Columbus, OH, USA) and to strap themselves to the bar using lifting straps (XXR Sports, Mitcham, UK) whilst achieving the correct body position that was previously determined during habituation. In this position, which replicated their second pull of the power clean, feet were roughly centered under the bar and hip-width apart. Knees were slightly flexed underneath and in front of the bar, whilst the torso was upright and shoulders retracted and depressed, above or slightly behind the vertical plane of the bar (Beckham et al., 2018). Using a goniometer (66fit, Spalding, UK), measurements were taken of both hip- and knee-angles to ensure players were in the correct position. Players were allowed minimal pre-tension to avoid any slack in the body prior to pull initiation (Mangine et al., 2016). In order to achieve optimal results, players were instructed to 'push their feet into the floor' and to 'pull as hard and fast as possible' (Halperin et al., 2016). Once stabilised (verified by watching the player and the force trace), a countdown was given, followed by a maximal effort of the IMTP.

Visual inspection of the force-time curves during testing determined acceptability for inclusion. Trials were disregarded if an attempt included an unstable initial weighing period (i.e., clear fluctuation in the force-time data), if a clear countermovement (i.e., >50 N) took place prior to the pull, if PF occurred at the end of the trial or if prior tension was applied before commencement of the pull (i.e., >50 N over body weight). Trials were also deemed invalid if PF was separated by >250 N between attempts or when a large change in body position was observed during the trial (Comfort et al., 2019; Dos' Santos et al., 2017). When incorrect trials took place, players were asked to repeat the test to ensure each participant achieving three valid attempts. Players rested for a minimum of two min after each effort to ensure sufficient rest (Thomas et al., 2017). The IMTP testing was conducted as per the recommendations of Comfort et al. (2019).

Based on the IMTP attempt during which PF was achieved, raw vertical force-time data were saved and exported into a Microsoft Excel file (Version 2019, Microsoft Corporation) which was later analysed. Data remained unfiltered, as there are minimal differences between values in unfiltered or filtered (e.g., fourth-order Butterworth) conditions (Dos' Santos et al., 2018a). To identify the onset of the pull, a threshold of five standard deviations (SD) of bodyweight, identified during one second of quiet standing immediately prior to commencing the pull (i.e., the weighing period), was used, as per (Comfort et al., 2019). The between-day reliability of PF, time-specific forces, and values elicited during IMTP timebands have been found to be reliable (Intraclass Correlation Coefficient (ICC) $\geq$ 0.7, CV $\leq$ 15%), irrespective of body posture and barbell position (Guppy et al., 2018).

4.2.7 Countermovement jump

For the CMJ, an objective monitoring tool frequently used in academy RL (chapter three), players were instructed to stand on the force plate with their knees extended and feet in their preferred positions of slightly wider than shoulder-width apart whilst their hands remained on the hips. Following instruction to ‘jump as high and fast as they can,’ players dropped to a depth of their discretion and performed a jump for maximal height (McMahon et al., 2017a). A specific depth was not prescribed as it was anticipated that this may be hard to control for, whilst this may also negatively affect the primary aim of the jump, which was to jump as high and fast as possible. If, at any point during the jump, visual inspection deemed the hands to have come off the hips or legs being tucked in, the attempt was classified as invalid and the trial was repeated until three valid attempts were achieved. Players rested for a minimum of 60 s between trials (Thomas et al., 2017).

Following a successful attempt, raw vertical force-time data were saved from the jump that elicited the greatest JH within a trial before being exported into a Microsoft Excel file which was later analysed. The start of the jump was identified as the time-point at which force deviated by five SD’s of bodyweight (measured during one second of quiet standing) (West et al., 2011). Instances of take-off and touchdown were identified as the time-point whereby force deviated in excess of five times the SD during a 300 ms period of flight phase of the jump (i.e., when the platform was unloaded) (Moir, 2008). This timeframe was taken at the end of the flight phase to avoid the unstable period of force-time data at the start of this phase. The between-day reliability of the CMJ has previously been reported in academy RU players during a non-training week (CV% <5.0%) (Roe et al., 2016a).

4.2.8 Match-play activity profiles

A competitive home fixture took place during the mid-season (19:00 h kick off). Subjective internal match load was obtained by a session rating of perceived exertion (sRPE) within 30 min of the match finishing (Borg, 1998). Players provided their individual score in isolation from others in order to minimise the influence of other players or coaches. The locomotive demands of the game were measured using portable MEMS units sampling at 10 Hz (Optimeye S5, Catapult Innovations, Melbourne, Australia). Units were worn in a pouch on the upper back of the playing shirt positioned between the shoulder blades. Devices were turned on just before the warm-up and turned off after the match. Following match completion, data were downloaded using proprietary software (Openfield Version 2.3.3, Catapult Innovations). Raw data files were trimmed on an individual player basis to ensure that only data pertaining to time spent on pitch was exported for analysis. The MEMS units used throughout this thesis provide numerous parameters that could give an indication of the external load of match-play. The parameters selected were (relative) distance covered, high-speed distance, RHIE, and PlayerLoad.

Total distance is an external load parameter commonly reported but given the various ways in which total distance can be accumulated, more contextual information is required. Indeed, relative distance (i.e., match intensity) may be calculated by dividing total distance by minutes played. The 10 Hz units provide a valid measure of distance covered, with a margin of error smaller than 1% (Johnston et al., 2014b). Distance covered at high speed (i.e., ≥ 5.5 $m \cdot min^{-1}$) is of particular importance also, both for match performance (Johnston et al., 2014a) and the high involvement of eccentric muscle actions (Douglas et al., 2017). In addition, RHIE were selected due to its positive relationship with increased muscle soreness (Oxendale et al., 2016).

PlayerLoad describes an accumulation of the tri-axial accelerometers (i.e., anterior-posterior, medial-lateral, and vertical), sampling at 100Hz (Nicolella et al., 2018), and is used to measure accelerometer-derived activities such as accelerations, decelerations, changes of direction, jumps, or collisions. Acknowledging that PlayerLoad slow, which only measures accelerometer data when velocity is < 0.2 $m \cdot min^{-1}$, has an even greater correlation with collisions, PlayerLoad displays a very large relationship with collisions also (Roe et al., 2016b). Superior levels of intradevice compared to interdevice reliability have previously been reported (Nicolella et al., 2018), and for this reason, the same device was always used by the same player. The formula used for this parameter is described below.

$$\sum_{t=0}^{t=n} \sqrt{(fwd_{t=i+l} - fwd_{t=i})^2 + (side_{t=i+l} - side_{t=i})^2 + (up_{t=i+l} - up_{t=i})^2}$$

for t = 0, 0.01, 0.02, 0.03….n

4.2.9 Statistical analyses

For part A of the study, the within- and between-day reliability of variables was examined using mean changes between visits (assessed via paired samples t-tests), typical error (TE: SD of the differences score divided by √2), CV (TE expressed as a percentage of the subject's mean score), limits of agreement (LOA: mean bias ± 1.96 SD) and ICC (two-way mixed method, absolute agreement) values. Providing no significant differences existed, variables were deemed to have acceptable reliability in either component (i.e., on a within- or between-day basis) if both CV% was ≤10% (15) and ICC was ≥0.8 (Comfort et al., 2015). These thresholds for acceptable reliability were chosen as they have typically been used in recent related research (Comfort et al., 2015; Fitzpatrick et al., 2019). To evaluate the internal consistency of the wellness questionnaire, Cronbach's Alpha (α) was calculated (Cronbach, 1951). The threshold for an acceptable α was set at >0.7 (Bland & Altman, 1997), whilst inter-item correlations were also considered. Only those variables that met the criteria for between-day reliability, were eligible thereafter in part B of the study. For part B, initial assessments of normality were performed, before changes in post-match measures were analysed, using a repeated-measures analysis of variance (ANOVA) in statistical software (SPSS version 21, Chicago, ILL, USA). Assumptions of sphericity were explored, and where necessary the Greenhouse-Geisser adjustment was used. If significant main effects were detected, data were compared using Bonferroni corrected pairwise comparisons. The criterion level of statistical significance was set at p ≤0.05. The magnitude of differences between all time-points was also expressed as a standardised mean difference (Cohen's d effect size: ES). Classifications for ES were set as trivial (ES < 0.2), small (0.2 ≤ ES < 0.5), moderate (0.5 ≤ ES < 0.8) and large (ES ≥ 0.8) (Fritz et al., 2012). Data presented as mean ± SD unless otherwise stated.

4.3 Results – Part A

4.3.1 Isometric mid-thigh pull reliability

Reliability statistics for the IMTP are shown in Tables 4.1 and 4.2. Acceptable within-day reliability was observed for PF, and force at 30 (F30), 150 (F150), 200 (F200), and 250 (F250) ms (CV%: 3.67-9.76%; ICC: 0.83-0.93). Acceptable between-day reliability values were observed for F200, F250 and PF (CV%: 4.34-8.62%; ICC: 0.87-0.92). Although no significant differences existed between repeated measurements, no other variables demonstrated acceptable reliability on either a within- or between-day basis.

4.3.2 Countermovement jump reliability

Reliability statistics for the CMJ are shown in Tables 4.3 and 4.4**.** All variables, except for PP, relative PP, and velocity at take-off (VTO), which were omitted due to the presence of significant differences between trials, showed acceptable levels of within-day reliability (CV%: 3.03-7.34%; ICC: 0.82-0.98). Six variables (i.e., FT, PF, PP, relative PP, VTO and JH) met the thresholds for acceptable between-day reliability (CV%: 2.56-6.79%; ICC: 0.83-0.91). The remaining five variables (i.e., movement-time (MT), FT:MT ratio, relative PF, time to PF, time to PP) did not meet the criteria for between-day reliability.

4.3.3 Subjective wellness reliability

Reliability statistics for the wellness questionnaire are shown in Tables 4.5 and 4.6. Whilst some individual components of the questionnaire (i.e., sleep quality, lower body soreness, mood, and total wellness) met the criteria of within-day reliability (CV%: 7.66-9.52%; ICC: 0.83-0.96), acceptable levels for between-day reliability were only found in the total wellness score (CV%: 7.05%; ICC: 0.90). The additional measure of Cronbach's Alpha resulted in $\alpha = 0.89$, meaning that acceptable internal consistency was achieved by the items in the wellness questionnaire. Inter-item correlations are shown in Table 4.7.

Table 4.1 Mean (± standard deviation) responses and the within-day reliability statistics for the isometric mid-thigh pull (*n*=11)

Variable	Timing		Mean change	TE (95% CI)	ICC (95% CI)	CV (95% CI)	LoA (95% CI)	Acceptable Reliability?
	Week 2 AM	Week 2 PM						
F30 (N)	1027.28 (71.72)	1053.19 (88.34)	25.91	42.27 (29.54, 74.18)	0.83 (0.40, 0.95)	3.91 (2.71, 6.96)	-143.08 (-244.05, -97.15) to 91.26 (45.33, 192.23)	✓
F50 (N)	1107.71 (110.67)	1146.77 (158.21)	39.06	91.89 (64.20, 161.26)	0.71 (-0.04, 0.92)	7.91 (5.46, 14.30)	-293.76 (-513.24, -193.92) to 215.64 (115.80, 435.12)	✗
F100 (N)	1365.07 (242.26)	1420.24 (314.18)	55.16	174.83 (122.15, 306.81)	0.77 (0.14, 0.94)	11.58 (7.96, 21.20)	-539.76 (-957.34, -349.80) to 429.43 (239, 47, 847.01)	✗
F150 (N)	1623.64 (321.37)	1670.13 (344.87)	46.49	159.27 (111.28, 279.50)	0.88 (0.55, 0.97)	9.76 (6.73, 17.76)	-487.96 (-868.38, -314.90) to 394.98 (221.92, 775.40)	✓
F200 (N)	1858.82 (349.72)	1901.68 (351.99)	42.86	154.58 (108.01, 271.28)	0.90 (0.63, 0.97)	8.41 (5.81, 15.23)	-471.33 (-840.56, -303.37) to 385.62 (217.66, 754.85)	✓
F250 (N)	2022.65 (331.77)	2075.84 (326.60)	53.19	145.61 (101.74, 255.53)	0.89 (0.62, 0.97)	7.17 (4.96, 12.93)	-456.79 (-804.58, -298.58) to 350.41 (192.20, 698.20)	✓
PF (N)	2577.09 (279.00)	2628.41 (264.70)	51.32	97.36 (68.03, 170.87)	0.93 (0.74, 0.98)	3.67 (2.55, 6.53)	-321.20 (-553.754, -215.40) to 218.56 (112.77, 451.12)	✓

AM: Morning; CI: Confidence interval; CV%: Coefficient of variation; F30: Force at 30 ms; F50: Force at 50 ms; F100: Force at 100 ms; F150: Force at 150 ms; F200: Force at 200 ms; F250: Force at 250 ms; ICC: Intraclass correlation coefficient; LoA: Limits of agreement; PF: Peak force; PM: Afternoon; TE: Typical error. Acceptable reliability was defined as no between-trial differences and CV ≤10% and ICC ≥0.8.

Table 4.2 Mean (± standard deviation) responses and the between-day reliability statistics for the isometric mid-thigh pull (*n*=10)

Variable	Timing		Mean change	TE (95% CI)	ICC (95% CI)	CV (95% CI)	LoA (95% CI)	Acceptable Reliability?
	Week 1 PM	Week 2 PM						
F30 (N)	1040.80 (59.00)	1051.26 (92.87)	10.46	61.40 (42.24, 112.10)	0.57 (-0.95, 0.90)	6.07 (4.14, 11.36)	-180.65 (-340.38, -111.40) to 159.75 (90.49, 319.47)	✗
F50 (N)	1127.46 (94.04)	1150.87 (166.15)	23.41	109.39 (75.24, 199.69)	0.53 (-1.10, 0.89)	9.86 (6.68, 18.73)	-326.61 (-611.15, -203.24) to 279.79 (156.42, 564.32)	✗
F100 (N)	1404.13 (215.80)	1429.48 (329.59)	25.35	200.08 (137.62, 365.26)	0.67 (-0.45, 0.92)	14.20 (9.56, 27.43)	-579.93 (-1100.37, -354.27) to 529.23 (303.57, 1049.67)	✗
F150 (N)	1677.54 (281.51)	1670.28 (363.52)	7.26	170.75 (117.45, 311.72)	0.85 (0.38, 0.96)	10.91 (7.38, 20.82)	-466.03 (-910.18, -273.44) to 480.56 (287.97, 924.71)	✗
F200 (N)	1921.20 (297.20)	1895.69 (370.44)	25.51	154.48 (106.26, 282.02)	0.89 (0.55, 0.97)	8.62 (5.58, 16.29)	-402.68 (-804.52, -228.45) to 453.71 (279.48, 855.55)	✓*
F250 (N)	2078.98 (288.99)	2073.48 (344.17)	5.50	158.55 (109.06, 289.45)	0.87 (0.45, 0.97)	8.01 (5.44, 15.11)	-433.98 (-846.40, -255.16) to 444.98 (266.15, 857.40)	✓*
PF (N)	2593.47 (288.46)	2627.58 (279.00)	34.11	112.46 (82.02, 185.01)	0.92 (0.68, 0.98)	4.34 (3.15, 7.24)	-345.82 (-638.34, -218.98) to 277.61 (150.78, 570.14)	✓*

CI: Confidence interval; CV%: Coefficient of variation; F30: Force at 30 ms; F50: Force at 50 ms; F100: Force at 100 ms; F150: Force at 150 ms; F200: Force at 200 ms; F250: Force at 250 ms; ICC: Intraclass correlation coefficient; LoA: Limits of agreement; PF: Peak force; PM: Afternoon; TE: Typical error. Acceptable reliability was defined as no between-trial differences and CV ≤10% and ICC ≥0.8. * Variable met the criteria for between-day reliability and was therefore eligible for Part B of the study.

Table 4.3 Mean (± standard deviation) responses and the within-day reliability statistics for the countermovement jump (*n*=11)

Variable	Timing		Mean change	TE (95% CI)	ICC (95% CI)	CV (95% CI)	LoA (95% CI)	Acceptable Reliability?
	Week 2 AM	Week 2 PM						
MT (s)	0.74 (0.12)	0.71 (0.10)	0.03	0.04 (0.03, 0.07)	0.91 (0.64, 0.98)	5.97 (4.07, 11.17)	-0.09 (-0.20, -0.04) to 0.15 (0.10, 0.26)	✓
FT (s)	0.51 (0.03)	0.52 (0.04)	0.01	0.02 (0.01, 0.03)	0.88 (0.45, 0.97)	3.03 (2.07, 5.60)	-0.06 (-0.10, -0.04) to 0.03 (0.01, 0.07)	✓
FT:MT ratio	0.69 (0.10)	0.74 (0.10)	0.05	0.05 (0.03, 0.09)	0.82 (0. 26, 0.96)	7.34 (4.99, 13.80)	-0.19 (-0.32, -0.13) to 0.09 (0.31, 0.22)	✓
PF (N)	2362.00 (367.12)	2411.32 (369.62)	49.32	77.33 (53.19, 141.18)	0.98 (0.90, 0.99)	3.15 (2.15, 5.82)	-263.67 (-464.82, -176.45) to 165.03 (77.81, 366.18)	✓
Relative PF (N·kg^{-1} BW)	25.54 (2.85)	25.88 (2.98)	0.34	0.89 (0.61, 1.62)	0.95 (0.82, 0.98)	3.34 (2.29, 6.19)	-2.79 (-5.10, -1.80) to 2.12 (1.12, 4.42)	✓
Time to PF (s)	0.55 (0.10)	0.52 (0.08)	0.03	0.04 (0.02, 0.07)	0.89 (0.54, 0.97)	7.09 (4.83, 13.33)	-0.07 (-0.16, -0.03) to 0.13 (0.09, 0.23)	✓
PP (W)	4644.38 (453.47)	4939.47** (507.11)	295.09	132.89 (91.41, 242.61)	0.88 (-0.13, 0.98)	2.75 (1.88, 5.07)	-263.67 (-464.82, -176.45) to 165.03 (77.81, 366.18)	✗
Relative PP (W·kg^{-1} BW)	50.42 (3.78)	53.22 (4.73)**	2.80	1.61 (1.11, 2.93)	0.84 (-0.091, 0.97)	2.94 (2.02, 5.44)	-7.25 (-11.43, -5.44) to 1.66 (-0.16, 5.84)	✗
Time to PP (s)	0.68 (0.12)	0.64 (0.10)	0.04	0.04 (0.03, 0.08)	0.92 (0.67, 0.98)	6.29 (4.29, 11.79)	-0.08 (-0.19, -0.04) to 0.15 (0.10, 0.26)	✓
VTO (m·s^{-1})	2.46 (0.16)	2.54 (0.18)**	0.08	0.06 (0.04, 0.12)	0.87 (0.24, 0.97)	2.58 (1.77, 4.77)	-0.26 (-0.43, -0.19) to 0.09 (0.02, 0.26)	✗
JH (m)	0.31 (0.04)	0.33 (0.05)	0.02	0.02 (0.01, 0.03)	0.89 (0.62, 0.97)	5.23 (3.57, 9.76)	-0.07 (-0.11, -0.05) to 0.02 (0.01, 0.07)	✓

AM: Morning; BW: Body weight; CI: Confidence interval; CV%: Coefficient of variation; F30: Force at 30 ms; F50: Force at 50 ms; F100: Force at 100 ms; F150: Force at 150 ms; F200: Force at 200 ms; F250: Force at 250 ms; FT: Flight time; ICC: Intraclass correlation coefficient; JH: Jump height; LoA: Limits of agreement; MT: Movement time; PF: Peak force; PM: Afternoon; PP: Peak power; TE: Typical error; VTO: Velocity at take-off; **: Significantly different ($p \leq 0.05$) from week 2 AM. Acceptable reliability was defined as no between-trial differences and CV ≤10% and ICC ≥0.8.

Table 4.4 Mean (± standard deviation) responses and the between-day reliability statistics for the countermovement jump (*n*=10)

Variable	Timing		Mean change	TE (95% CI)	ICC (95% CI)	CV (95% CI)	LoA (95% CI)	Acceptable Reliability?
	Week 1 PM	Week 2 PM						
MT (s)	0.75 (0.10)	0.71 (0.11)	0.04	0.08 (0.05, 0.15)	0.63 (-0.42, 0.91)	10.5 (6.97, 21.07)	-0.16 (-0.38, -0.08) to 0.26 (0.17, 0.47)	✗
FT (s)	0.52 (0.03)	0.53 (0.04)	0.01	0.02 (0.01, 0.03)	0.89 (0.57, 0.98)	3.08 (2.07, 5.98)	-0.05 (-0.10, -0.04) to 0.03 (0.02, 0.08)	✓ *
FT:MT ratio	0.70 (0.09)	0.76 (0.10)	0.06	0.07 (0.05, 0.13)	0.59 (-0.36, 0.90)	10.11 (6.72, 20.26)	-0.25 (-0.45, -0.17) to 0.13 (0.05, 0.32)	✗
PF (N)	2346.17 (301.12)	2437.74 (381.90)	91.57	146.96 (99.26, 281.53)	0.89 (0.56, 0.98)	6.79 (4.54, 13.41)	-498.91 (-920.82, -326.24) to 315.77 (143.10, 737.67)	✓ *
Relative PF ($N \cdot kg^{-1}$ BW)	25.43 (2.19)	26.23 (2.93)	0.80	1.71 (1.15, 3.28)	0.72 (-0.15, 0.94)	7.02 (4.69, 13.88)	-5.54 (-10.45, -3.53) to 3.94 (1.93, 8.84)	✗
Time to PF (s)	0.58 (0.11)	0.51 (0.08)**	0.07	0.07 (0.04, 0.13)	0.60 (-0.29, 0.91)	11.19 (7.43, 22.54)	-0.11 (-0.30, -0.03) to 0.26 (0.18, 0.44)	✗
PP (W)	4898.03 (465.94)	5020.36 (464.44)	122.33	208.63 (140.92, 399.68)	0.88 (0.52, 0.97)	4.56 (3.05, 8.91)	-700.61 (-1299.58, -455.48) to 455.95 (210.82, 1054.92)	✓ *
Relative PP ($W \cdot kg^{-1}$ BW)	53.30 (5.01)	54.25 (3.66)	0.95	2.38 (1.61, 4.55)	0.83 (0.29, 0.96)	4.73 (3.17, 9.25)	-7.54 (-14.36, -4.74) to 5.64 (2.85, 12.46)	✓ *
Time to PP (s)	0.69 (0.10)	0.64 (0.11)	0.05	0.08 (0.05, 0.15)	0.63 (-0.42, 0.91)	11.59 (7.69, 23.39)	-0.17 (-0.39, -0.08) to 0.26 (0.17, 0.48)	✗
VTO ($m \cdot s^{-1}$)	2.54 (0.15)	2.57 (0.17)	0.03	0.06 (0.04, 0.12)	0.91 (0.64, 0.98)	2.56 (1.72, 4.97)	-0.21 (-0.39, -0.13) to 0.15 (0.07, 0.33)	✓ *
JH (m)	0.33 (0.04)	0.34 (0.04)	0.01	0.02 (0.01, 0.03)	0.91 (0.65, 0.98)	5.19 (3.48, 10.18)	-0.05 (-0.10, -0.03) to 0.04 (0.02, 0.09)	✓ *

BW: Body weight; CI: Confidence interval; CV%: Coefficient of variation; F30: Force at 30 ms; F50: Force at 50 ms; F100: Force at 100 ms; F150: Force at 150 ms; F200: Force at 200 ms; F250: Force at 250 ms; FT: Flight time; ICC: Intraclass correlation coefficient; JH: Jump height; LoA: Limits of agreement; MT: Movement time; PF: Peak force; PM: Afternoon; PP: Peak power; TE: Typical error; VTO: Velocity at take-off. * Variable met the criteria for between-day reliability and was therefore eligible for Part B of the study; **: Significantly different ($p \leq 0.05$) from week 1 PM;. Acceptable reliability was defined as no between-trial differences and CV ≤10% and ICC ≥0.8.

Table 4.5 Mean (± standard deviation) responses and the within-day reliability statistics for the wellness questionnaire (*n*=11)

Variable	Timing		Mean change	TE (95% CI)	ICC (95% CI)	CV (95% CI)	LoA (95% CI)	Acceptable Reliability?
	Week 2 AM	Week 2 PM						
Fatigue	3.36 (0.81)	3.91 (0.83)	0.55	0.73 (0.51, 1.29)	0.30 (-0.93, 0.79)	24.85 (16.77, 47.62)	-2.58 (-4.33, -1.78) to 1.48 (0.69, 3.23)	✗
Sleep quality	3.73 (0.79)	3.91 (0.83)	0.18	0.29 (0.20, 0.50)	0.93 (0.74, 0.98)	7.66 (5.29, 13.82)	-0.97 (-1.66, -0.66) to 0.61 (0.30, 1.29)	✓
General upper body soreness	3.18 (0.60)	3.64 (0.81)**	0.45	0.37 (0.26, 0.65)	0.77 (0.04, 0.94)	10.77 (7.41, 19.66)	-1.48 (-2.36, -1.08) to 0.57 (0.17, 1.45)	✗
General lower body soreness	3.00 (1.10)	3.00 (1.10)	0.00	0.32 (0.22, 0.55)	0.96 (0.85, 0.99)	9.52 (6.56, 17.31)	-0.88 (-1.63, -0.53) to 0.88 (0.53, 1.63)	✓
Stress level	4.09 (0.54)	3.82 (0.87)	0.27	0.56 (0.39, 0.98)	0.58 (-0.45, 0.88)	19.61 (13.33, 36.92)	-1.27 (-2.60, -0.66) to 1.81 (1.20, 3.14)	✗
Mood	4.27 (0.65)	4.27 (0.47)	0.00	0.32 (0.22, 0.55)	0.83 (0.33, 0.95)	8.47 (5.84, 15.33)	-0.88 (-1.63, -0.53) to 0.88 (0.53, 1.63)	✓
Total wellness score	21.64 (2.98)	22.55 (3.78)	0.91	1.80 (1.26, 3.16)	0.83 (0.42, 0.95)	9.20 (6.35, 16.71)	-5.90 (-10.21, -3.95) to 4.08 (2.13, 8.39)	✓

AM; Morning; CI: Confidence interval; CV%: Coefficient of variation; ICC: Intraclass correlation coefficient; LoA: Limits of agreement; PM: Afternoon; TE: Typical error; **: Significantly different ($p \leq 0.05$) from week 2 AM. Acceptable reliability was defined as no between-trial differences and CV ≤10% and ICC ≥0.8.

Table 4.6 Mean (± standard deviation) responses and the between-day reliability statistics for the wellness questionnaire (n=10)

Variable	Timing		Mean change	TE (95% CI)	ICC (95% CI)	CV (95% CI)	LoA (95% CI)	Acceptable Reliability?
	Week 1 PM	Week 2 PM						
Fatigue	3.30 (0.95)	3.80 (0.79)	0.50	0.60 (0.41, 1.10)	0.64 (-0.18, 0.91)	20.36 (13.59, 40.25)	-2.17 (-3.73, -1.49) to 1.17 (0.49, 2.73)	✗
Sleep quality	3.80 (0.42)	3.90 (0.88)	0.10	0.40 (0.28, 0.73)	0.81 (0.21, 0.95)	12.87 (8.68, 24.73)	-1.21 (-2.26, -0.76) to 1.01 (0.56, 2.06)	✗
General upper body soreness	3.40 (0.52)	3.60 (0.84)	0.20	0.65 (0.45, 1.19)	0.25 (-2.40, 0.82)	22.86 (15.21, 45.63)	-2.00 (-3.69, -1.27) to 1.60 (0.87, 3.29)	✗
General lower body soreness	3.00 (1.05)	3.10 (1.10)	0.10	0.62 (0.43, 1.13)	0.82 (0.23, 0.96)	23.14 (15.39, 46.22)	-1.82 (-3.43, -1.12) to 1.62 (0.92, 3.23)	✗
Stress level	3.90 (0.74)	3.80 (0.92)	0.10	0.40 (0.28, 0.73)	0.88 (0.51, 0.97)	14.11 (9.50, 27.24)	-1.01 (-2.06, -0.56) to 1.21 (0.76, 2.26)	✗
Mood	4.10 (0.57)	4.30 (0.48)	0.20	0.30 (0.21, 0.54)	0.79 (0.24, 0.95)	7.99 (5.43, 15.07)	-1.03 (-1.80, -0.69) to 0.63 (0.29, 1.40)	✗
Total wellness score	21.50 (3.31)	22.50 (3.98)	1.00	1.53 (1.05, 2.97)	0.90 (0.60, 0.97)	7.05 (4.80, 13.24)	-5.23 (-9.21, -3.51) to 3.23 (1.51, 7.21)	✓ *

CI: Confidence interval; CV%: Coefficient of variation; ICC: Intraclass correlation coefficient; LoA: Limits of agreement; PM: Afternoon; TE: Typical error. Acceptable reliability was defined as no between-trial differences and CV ≤10% and ICC ≥0.8. * Variable met the criteria for between-day reliability and was therefore eligible for Part B of the study.

Table 4.7 Subjective wellness inter-item correlation matrix

	Sleep Quality	Upper Body Soreness	Lower Body Soreness	Stress Level	Mood
Fatigue	0.29	0.80	0.74	0.71	0.67
Sleep Quality	-	0.69	0.48	0.21	0.22
Upper Body Soreness	-	-	0.85	0.56	0.67
Lower Body Soreness	-	-	-	0.83	0.81
Stress Level	-	-	-	-	0.71
Mood	-	-	-	-	-

4.3.4 Eligibility for Part B

Based on meeting the criteria for acceptable between-day reliability in Part A, the following variables were deemed eligible for part B: F200, F250 and PF in the IMTP; FT, PF, PP, relative PP, VTO and JH in the CMJ; and the total wellness score in the wellness questionnaire.

4.3 Results – Part B

4.3.5 Match demands

The average internal match load (i.e., sRPE x time played) was 950 (±378) AU. Full locomotive match profiles are presented in Table 4.8.

4.3.6 Isometric mid-thigh pull response

Match-play did not affect F200 ($F_{(2, 19)}$= 1.532, p= 0.240) or F250 ($F_{(5, 40)}$= 1.790, p= 0.137). Although match-play did show a significant time-effect for PF ($F_{(5, 40)}$= 2.782, p= 0.030), post-hoc measurements were unable to detect significance between time-points. Moderate (0.66) and large (0.90; 0.95) ES were observed at +24 h compared to baseline values for F200, F250 and PF, respectively. Trivial and small ES (≤0.37) were found at all other time-points thereafter compared to baseline values in PF, but moderate and large ES (≥0.67) were observed throughout the complete post-match period for F250.

4.3.7 Countermovement jump response

Match-play influenced FT ($F_{(5, 40)}$= 5.638, p= 0.001) and although no changes relative to baseline were observed, values increased by 3.78% and 6.19% at +48 and +96 h, respectively, when compared to +24 h (0.502 s) values. Match-play also affected PF ($F_{(2, 19)}$= 4.627, p= 0.019) as values were increased by 11.84% at +96 h versus +24 h (2245 N). Although match-play influenced PP ($F_{(5, 40)}$= 4.992, p= 0.001), and relative PP ($F_{(5, 40)}$= 4.515, p= 0.002), no significant changes were detected between any of the time-points. Match-play influenced VTO ($F_{(5, 40)}$= 6.600, p< 0.001) and JH ($F_{(5, 40)}$= 6.527, p< 0.001) as values were decreased at +24 h compared to baseline (Figures 4.2a and 4.2b). Moderate and large ES (≥0.63) were reported at +24 h for all variables compared to baseline values. Trivial and small ES (≤0.41) compared to baseline values were then reported at +48 h for all variables except PP in which a moderate ES (0.70) existed.

4.3.8 Wellness response

The total wellness score was found to be influenced by match-play ($F_{(5.40)}$= 5.962, p< 0.001). Although no post-match changes were found relative to baseline (23.55 points), values at +24 h were reduced by 8.99% versus +72 h values (21.00 points, p= 0.01). Large ES (0.86) compared to baseline values were reported at +24 h whilst moderate ES (≥0.56) were evident at +48 and +72 h.

Table 4.8 Mean (± standard deviation) locomotive match profiles (n=10)

Timing	Duration (min)	Total distance		High-speed ($\geq$5.5 m·s^{-1}) running (m)	Player load (AU)	Repeated high-intensity efforts (n)
		Absolute (m)	Relative (m·min^{-1})			
Warm-Up	24:21 (00:00)	1648 (230)	68 (9)	50 (49)	174 (21)	9 (2)
First Half	31:36 (14:35)	2756 (1215)	91 (12)	111 (86)	275 (119)	15 (6)
Second Half	37:33 (13:23)	2938 (1046)	80 (10)	58 (46)	283 (99)	15 (5)

AU: Arbitrary units

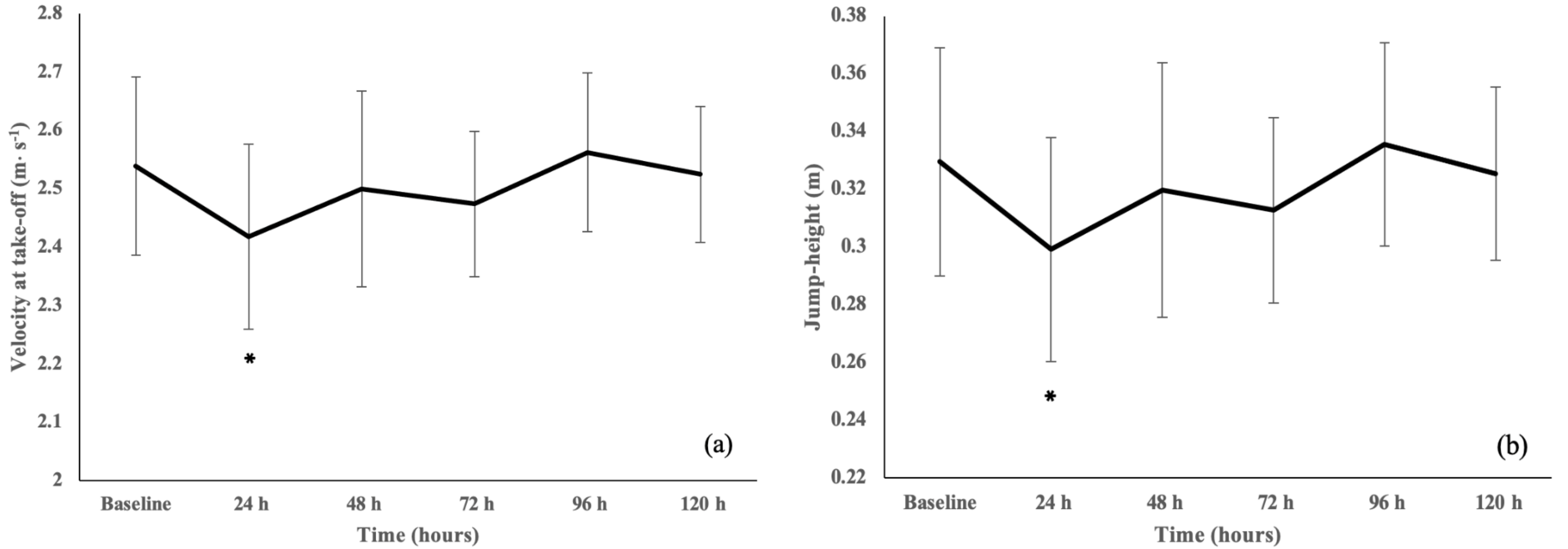

Figure 4.2 Mean (± standard deviation) countermovement jump velocity at take-off (panel a) and jump-height (panel b) before (baseline) and after (+24, +48, +72, +96, +120 h) rugby league match-play. * represents difference ($p \leq 0.05$) relative to baseline.

4.4 Discussion

In professional academy RL players, the aims of this chapter were to assess the reliability of neuromuscular and wellness measures (part A) and to profile the time-course of such responses following match-play (part B). Acceptable within- and between-day reliability (i.e., no between-trial differences, CV% ≤10% and ICC ≥0.8) was achieved by F200, F250 and PF in the IMTP. Most CMJ variables demonstrated acceptable within-day reliability, whilst FT, PF, PP, relative PP, VTO and JH exhibited acceptable between-day reliability. From the wellness questionnaire, only the accumulated total wellness score met the threshold for between-day reliability, whereas four individual components of the wellness questionnaire (i.e., sleep quality, general lower body soreness, mood, and total wellness) produced acceptable within-day reliability. The variables demonstrating acceptable between-day reliability were then eligible for use in part B of the study where match-play did not elicit statistically significant post-hoc differences relative to baseline values for IMPT performance or total wellness. However, VTO and JH in the CMJ were depressed at +24 h versus baseline. Collectively, these findings indicate that the reliability of specific variables may differ when assessed on a within- or between-day basis. Similarly, the magnitude of the post-match response appeared to depend on the assessment and variables used. Such findings warrant consideration by practitioners when considering the type of measurements to be used in practice – especially when normal recovery, lifestyle, and training activities are implemented by academy RL players in the post-match period.

Existing research indicated high within- and between-day reliability for IMTP forces elicited at earlier time-points (i.e., F30, F50, F90) in a variety of sporting populations (Dos' Santos et al., 2018b; Haff et al., 2015). These results are not reflected in the current study where force production at 30, 50, and 100 ms generally did not meet acceptable reliability thresholds. As dynamic tasks such as sprinting typically involve ground-contact times of between 50 and 250 ms (Aagaard et al., 2002), exposures to tasks that involve force production within <50 ms are limited in team sport players. It is plausible that this fact may explain the limited reliability of the F30 and F50 values in the present study. Across different sporting populations, the highest levels of reliability are typically found in forces produced at 200 and

250 ms and in PF (Haff et al., 2015); findings which are in agreement with the results of the present study.

Those CMJ variables demonstrating acceptable levels of within-, as well as between-day reliability (i.e., FT, PF, and JH) are consistent across a number of sporting populations (Cormack et al., 2008c; McMahon et al., 2017a). Time-related variables such as time to PF, time to PP, MT and consequently FT:MT ratio did not meet the threshold for acceptable between-day reliability in the present study; findings which partly reflect those of previous research (Hori et al., 2009; McMahon et al., 2017a). As the present study did not control for CMJ depth, players may have adopted an altered jump strategy when seeking to maximise jump height on each attempt (McMahon et al., 2017b); especially in part B of the study. Allowing players to implement their preferred jump strategy may have inconsistently influenced displacement of their center of mass during the eccentric and concentric phases across different jumps (McMahon et al., 2017b). As a result, time-related variables may have been influenced by modification of the time spent in the eccentric and concentric parts of the movement with a view to maintaining the primary instruction of the jump, being to achieve maximal height. When taking (relative) PP measurements on different days, it should be considered by practitioners to test at the same time of day where possible. This is because PP measures did not achieve acceptable levels of within-day reliability, whilst between-day reliability was achieved. Whilst unproven, this may be due to circadian rhythm influences, which are also known to affect endocrine responses throughout the day (REF).

The monitoring questionnaire used here observed comparable reliability data to a similar questionnaire (i.e., one in which a 1-10 rating is required on soreness across a variety of sites), which was completed throughout the season by elite AF players (Montgomery & Hopkins, 2013). Although greater reliability (i.e., CV being 7.1%) has been reported in a study of academy RU players (Roe et al., 2016a), such scores may have reflected the absence of any physical activity undertaken between testing days. Akin to the methods of Montgomery & Hopkins (2013), the present study was carried out whilst regular training activities were performed; a methodological issue which may influence different elements of the wellness questionnaire. Nevertheless, as the reliability of this type of questionnaire may be questioned when used in more ecologically valid scenarios (i.e., including regular training activities) (Fitzpatrick et al., 2019), the current study may provide a more accurate representation of its within- and between-day reliability during the in-season period, and thus have implications for practitioners using such methods in similar scenarios. Notably, contrary to previous research (Fitzpatrick et al., 2019), the internal consistency of the questionnaire (calculated via Cronbach's Alpha) was deemed acceptable in the present study; a finding which may reflect the absence of negative values for inter-item correlations given that each question was aligned directionally (i.e., negative responses were always categorised as lower numerical values).

Whilst responses to rugby match-play have been profiled using different measures, such as a CMJ (McLellan & Lovell, 2012; Oxendale et al., 2016; West et al., 2014), a PPU (Roe et al., 2016c), and an adductor squeeze test (Roe et al., 2016d), the present study is amongst the first to profile the effects of match-play on IMTP responses (Norris et al., 2019). Although match-play did not influence PF during the IMTP, a large ES (0.95) was reported at +24 h following match-play compared to baseline measures, whilst small and trivial ES were observed thereafter. No significant changes were observed in F200 or F250 following match-play, but a large ES (0.9) in F250 was reported at +24 h versus baseline measures, whilst moderate and large ES ($\geq$0.67) were still evident throughout the full post-match period. Prolonged perturbations seen in some (i.e., F250), but not other (i.e., PF) variables suggest that maximal force may be less sensitive to the influence of match-play when compared to those measures that include a velocity-component. This finding supports observations following AF match-play, in which RFD was found to be more sensitive to recovery of neuromuscular function than PF (Norris et al., 2019). When performing sporting actions such as sprinting, jumping and changing direction, ground contact occurs in time intervals between 50-250 ms, hence it may be more important to apply force quickly as opposed to producing maximal force (Dos'Santos et al., 2017). Any reductions in F250 occurring post-match could therefore have implications on athletic performance throughout the training week.

Jump performance was reduced at +24 h following match-play, as indicated by significant differences ($p \leq 0.039$) and large ($\geq$1.44) ES in VTO and JH as well as moderate to large ($\geq$0.63) ES compared to baseline values in FT, PP and PF. Small or trivial ($\leq$0.41) ES were reported at +48 h after match-play compared to baseline values in FT, PF, VTO and JH, whilst ES observed in PP were still moderate (0.7) at this time-point. Accordingly, when using the CMJ to profile post-match responses, the magnitude of change may differ according to the variable selected; implications which could influence the interpretation of data derived, and thus prescription of training thereafter. Notably, a delayed recovery of PP compared to PF has previously been reported (McLellan et al., 2011a), with the present study supporting this observation. As the nature of RL includes a large frequency of sprinting, jumping and high-speed changes of direction, there is a large reliance on the ability to produce force rapidly (McLellan et al., 2011a). For this reason, and because of its increased sensitivity to match-play, it may be more appropriate for practitioners to assess the velocity-components of CMJ testing rather than the force-components when seeking to profile post-exercise responses. Recovery of CMJ performance in this study was comparable to changes reported following competitive matches in academy rugby players (Johnston et al., 2015b; Roe et al., 2016c). However, prolonged reductions of larger magnitude were reported following competitive matches in senior players (McLellan & Lovell, 2012; Oxendale et al., 2016; Twist et al., 2012; West et al., 2014), which may be the result of differing peak movement and collision demands in this age group (Johnston et al., 2019; Whitehead et al., 2019).

Even though match-play did not affect total wellness, large and moderate ES were found at +24 (0.86) and +48 h (0.76) compared to baseline measures, respectively. Disturbances in wellness in this study were similar to responses observed following competitive rugby matches in both senior and academy players (Oxendale et al., 2016; Roe et al., 2016c; Twist et al., 2012), in which perturbations were present for up to +48 h. Even though acceptable internal consistency was found in the questionnaire, between-day criteria were only met by total wellness. A more expansive scale (i.e., 0-10 or 0-100) may be useful to improve the reliability of all elements in this tool and enhance its practical application (McLaren et al., 2017).

4.5 Conclusion

In conclusion, this chapter observed acceptable within- and between-day reliability in a variety of variables of the IMTP (i.e., F200, F250 and PF) and the CMJ (i.e., FT, PF, and JH). Independent components of the wellness questionnaire should be interpreted with caution as acceptable between-day reliability was reported in total wellness only. Although match-play did not elicit significant post-hoc differences for the majority of variables analysed (excluding VTO and JH), a large ES was observed in the post-match period for most variables (i.e., F200, F250 and PF of the IMTP, FT, PP of the CMJ, and in the total wellness score) when compared to baseline measures. These results indicate that the magnitude and time-course of post-match responses may differ depending on the test and individual variables used. To avoid underestimation of the post-match response, it may be worthwhile to assess both objective (i.e., indices of neuromuscular fatigue) and subjective (i.e., total wellness) measures post-match-play.

When taking IMTP measurements, practitioners working in RL are recommended to use F200, F250 and PF over forces elicited at earlier time-points due to their higher levels of within- and between-day reliability demonstrated in the present study. Likewise, because of its increased sensitivity to match-play, as well as the importance of rapid force application in sport, practitioners may consider the use of F250 over PF when profiling post-exercise responses. For the CMJ, analysis of variables such as FT, PF, PP, relative PP, VTO and JH may be preferred over a variety of other variables as a result of their greater between-day reliability. Assessing the velocity components of the CMJ may also assist in the interpretation of post-match responses. As individual components of the questionnaire lacked acceptable levels of between-day reliability, the use of total wellness is recommended when profiling post-exercise responses; especially given that this was the only element meeting the criteria for between-day reliability in this study. It should however be acknowledged that those variables excluded because of their larger between-day variance, may still be considered if their signal (i.e., response) was greater than the noise (i.e., the variance) and consequently act in a dose-response manner. Collectively, post-match responses require at least 48 h to recover in academy RL players. During this time, practitioners may encourage the effective use of recovery modalities and recognised recovery-enhancing activities relating to sleep, nutrition, and hydration to their players. Strenuous physical activity should be avoided in this time-period as this could prolong a return to baseline values.

Chapter 5.0 The efficacy of a multimodal recovery strategy implemented after a high-intensity rugby league training session

Chapter Summary

- The efficacy of a multimodal recovery strategy implemented within 4 h of academy rugby league training was investigated using a balanced repeated measures randomised cross-over design.
- Following standardised training (5383 m covered, 350 m high-speed running, 28 repeated high-intensity efforts, 24 collisions), players (n = 10) completed a multimodal recovery strategy (i.e., ~639 Kcal meal + ~1276 Kcal snacks, cold-water immersion, sleep hygiene recommendations) or control (i.e., ~639 Kcal meal) practices.
- Apart from peak force in the isometric mid-thigh pull (IMTP), no other between-trial effects (all $p>0.05$) were seen for the IMTP, countermovement jump (CMJ) or wellness variables.
- Transient changes in CMJ performance (i.e., peak power) and wellness variables (i.e., fatigue and lower body soreness) may have implications for practitioners when planning consecutive training sessions that include a high frequency and intensity of eccentric muscle actions.
- When training included limited collisions, a balanced post-exercise meal appeared equally effective relative to a multimodal recovery strategy. Speculatively, the use of a similar multimodal recovery strategy could be more effective when preceded by a greater exercise stimulus (i.e., match-play).
- Practitioners are recommended to implement appropriate post-training nutrition, or, at the very least, provide players with education around this subject to prime good practice and allow players to make the correct decisions when responsible for their own post-exercise nutrition.

5.1 Introduction

Due to the number and the nature of the impacts and the intensity and frequency of eccentric muscle actions that are associated with high-intensity activities, RL match-play is likely to cause post-match perturbations in neuromuscular (Johnston et al., 2015b; McLellan et al., 2011a), biochemical or endocrine (Oxendale et al., 2016; Twist et al., 2012), or perceptual responses (McLean et al., 2010). Acknowledging the largely individual nature of recovery time-courses, these responses typically require between 48-72 h to facilitate restoration back to baseline values, with nutrition, hydration and sleep being recognised as modulating factors contributing to post-match recovery (Halson, 2008, 2014b).

To enhance readiness to train or play, it is common for athletes to implement a number of post-exercise recovery strategies (i.e., up to 72 h following match-play) (McLellan & Lovell, 2012; Oxendale et al., 2016; Twist et al., 2012). It is well-established that planned nutritional and hydration protocols following exercise can facilitate replenishment of glycogen stores, acceleration of muscle-damage repair and enhanced rehydration (Ranchordas et al., 2017). Notably, ingestion of 1-1.5 $g{\cdot}kg^{-1}{\cdot}h^{-1}$ of CHO has been shown to benefit maximal glycogen re-synthesis in the first 4 h following exercise (Burke et al., 2004), whilst adding 0.2-0.5 $g{\cdot}kg^{-1}{\cdot}h^{-1}$ of protein has aided glycogen re-synthesis and enhanced muscle tissue repair, when CHO intake was sub-optimal (i.e., $\leq$1.2 $g{\cdot}kg^{-1}{\cdot}h^{-1}$) (Ivy et al., 2002). The recuperative effects of sleep have also been suggested to benefit recovery as a result of a restorative relationship with the immune, endocrine and nervous systems (Halson, 2008) with general recommendations supporting 7-9 h of sleep per night (Halson, 2014b). Implementing CWI has elicited contrasting findings with some authors observing no benefits following exercise (Higgins et al., 2013; Lindsay et al., 2015a), whereas others disagree (Garcia et al., 2016; Pointon & Duffield, 2012).

While the effects of various recovery modalities have been widely researched within rugby players (Tavares et al., 2017), study designs often include interventions in isolation (i.e., a single strategy implemented on its own) (Caia et al., 2018; Duffield et al., 2010; Garcia et al., 2016; Pointon & Duffield, 2012; Suzuki et al., 2004). Acknowledging that such an approach may allow for greater experimental control and could arguably better determine the efficacy of individual strategies, the limited ecological validity of such studies relative to applied practices may compromise the generalisability of findings in real-world scenarios. Notably, a more holistic approach, including multiple recovery strategies, enhanced psychophysiological post-match responses (Lindsay et al., 2015a). Furthermore, methodological differences persist when assessing the effects of recovery strategies following rugby-specific exercise, with some studies implementing strategies following training (Duffield et al., 2010; Garcia et al., 2016; Pointon & Duffield, 2012), simulated matches (Barber et al., 2020; Higgins et al., 2013) or actual match-play (Gill et al., 2006; Nunes et al., 2019; Suzuki et al., 2004). It is therefore possible that the variability in the context and nature of the preceding exercise bout, especially in relation to the collision aspect, can influence recovery (Hudson et al., 2019).

Implementing recovery strategies is common practice for full-time professional RL players. However, academy players, who are employed by the club on a part-time basis and have commitments elsewhere (i.e., school, college or work), are limited by employment law in the amount of time spent performing club-related activities. Chapter three highlighted that coaching staff may choose to prioritise other activities (e.g., field- or gym-based training, video (p)review sessions) over implementation of recovery strategies as they are perceived to be of greater benefit. Indeed, when prioritised against other activities and when contact time with players is already limited, recovery-related activities may not be perceived as worthwhile. Instead, players may be afforded some time off during the immediate days following match-play. Indeed, across survey responses (chapter three), 86% of practitioners indicated that the day following match-day is a day off. Acknowledging that clubs utilise different training schedules, players often return to the club for training on match-day +2 or +3.

Whilst performing recovery modalities on the days following match-play may not always be practical in academy rugby, the initial post-exercise period, as proposed by academy RL practitioners (chapter three), may pose a realistic alternative for academy players to still benefit from acute implementation of recovery strategies under supervision of the coaching staff. A post-exercise protocol aiming to enhance different elements of recovery (i.e., nutrition, hydration, sleep) in addition to a bout of CWI may be beneficial for player recovery (Lindsay et al., 2015a). Cold-water immersion was previously highlighted as one of the most used strategies in the acute post-match period (see Table 3.6) and was therefore selected as part of the intervention. Therefore, this study investigated the efficacy of a multimodal recovery strategy, implemented within 4 h of high-intensity training, on post-training recovery responses in academy RL players.

5.2 Methods

5.2.1 Experimental overview

Players took part in two standardised field-based training sessions which occurred seven days apart. The initial training session took place approximately ten days after the 2019 academy season finished (i.e., September); a period in which players were only exposed to gym-based resistance training to enhance physical capabilities in preparation for the upcoming season. A counterbalanced repeated measures design was used whereby players were randomly assigned to undertake control (CONT) or recovery (REC) interventions during the first week; an order which was reversed in the second week. Players attended baseline testing (subjective wellness questionnaire, IMTP, CMJ) 3 h before each training session and follow-up assessments were performed at +24 and +48 h. Trial interventions (i.e., REC, CONT) were implemented after training.

5.2.2 Participants

Following institutional ethical approval (Appendix 4), 10 male RL players (age: 17 ± 1 years, body mass: 92 ± 10 kg, stature: 1.83 ± 0.06 m, years spent in professional playing and training: 3 ± 1 years, three repetition maximum back squat: 137 ± 20 kg, three repetition maximum bench press: 96 ± 14 kg) from the same SL academy volunteered to take part in this study. Players represented a range of positions, but seven played as forwards (i.e., five prop forwards, one back row forward, and one loose forward) with the remaining three players being backs (i.e., two wingers and one fullback). The number of participants was based on previous power calculations, performed with G*Power, which highlighted that >80% statistical power had been achieved for the statistically significant differences observed relative to baseline in JH of the CMJ (chapter four)..Prior to participation, players were provided with full details of the study procedures and were informed regarding the risks and benefits involved with the study. Upon agreeing to participate in the study, players then provided written informed consent before data collection began. All players were declared fit to train by the club's medical staff and completed both training sessions as well as all six assessments before and after the training sessions.

5.2.3 Procedures

Upon arrival for testing, players first completed the wellness questionnaire, followed by a standard dynamic warm-up (including various dynamic movements such as jogging, high knees, heel flicks, lunges, sweeps, and side shuffles). Players then performed two submaximal attempts of the IMTP and CMJ, before commencing the testing protocol. Throughout the study duration, players continued to participate in regular lifestyle commitments (i.e., college, school, work) and were encouraged to maintain their normal dietary intake outside of the intervention. In the week prior to the study commencing, players completed a 'standard' sleep and diet diary as well as a sleep hygiene questionnaire (LeBourgeois et al., 2005), representing their 'regular' sleep and diet routines. Players were encouraged to adhere to these routines when exposed to the control trial. Throughout the full duration of the study, players reported their diet for a total of six days whilst a sleep diary and the sleep hygiene questionnaire were completed for each of the four nights during the study.

5.2.4 Subjective wellness

Players completed a modified wellness questionnaire adapted from McLean et al. (2010), which they were accustomed to following its completion in various habituation trials. This questionnaire required a rating of perceived fatigue, sleep quality, upper- and lower-body soreness, stress levels and mood, where higher scores represent less fatigue, soreness, stress and better sleep quality and mood. The aggregate sum of all six scores also provided a total wellness score. Although this questionnaire has often been used with responses recorded on a five-point Likert scale (McLean et al., 2010; Roe et al., 2016c), the reliability and therefore the practicality of such small scales is questioned, especially in academy RL players where acceptable between-day reliability was only achieved in the total wellness score and not by its individual components (chapter four). For this reason, the questionnaire was adapted to include a 100-point Likert scale.

5.2.5 Isometric mid-thigh pull

To prepare for testing and to identify the correct pulling position (i.e., knee and hip angle of 120°-135° and 140°-150°, respectively) for each player (Beckham et al., 2018), players took part in three habituation trials in the week prior to the study commencing. The identified position, replicating the second pull of the power clean, was then repeated between trials. Players were asked to take the required position on the force plate (type: FP4060-05-PT, dimensions: 600 mm x 400 mm, sampling: 1000 Hz, Bertec Corporation, Columbus, OH, USA) and to 'strap themselves' to the bar using lifting straps (XXR Sports, Mitcham, UK) (Beckham et al., 2018). Following measurements taken with a goniometer (66fit, Spalding, UK) of both hip- and knee-angles to ensure the correct pulling position, players were instructed to take the slack out of the bar and to 'push their feet into the floor' whilst 'pulling as hard and fast as possible' (Halperin et al., 2016). Once the player and force trace were stabilised, a maximal effort of the IMTP was performed. Players were asked to perform three valid attempts, whilst invalid efforts, as explained in chapter four, were excluded (Comfort et al., 2019). Raw vertical force-time data were exported into a Microsoft Excel file (Version 2019, Microsoft Corporation), which was later analysed. The onset of the pull was identified as the point at which force deviated by five SD's of bodyweight (measured during one second of quiet standing) (Comfort et al., 2019). The IMTP attempt during which PF was achieved, was used for analysis. Acknowledging the different variables of the IMTP that may be used to assess neuromuscular function, those variables in which acceptable between-day reliability i.e., CV $\leq$10%, ICC $\geq$0.8) was found (i.e., F200, F250, PF; see chapter four), were used to profile post-training IMTP responses.

5.2.6. Countermovement jump

Due to being part of their regular training regimes, players were already familiar with the CMJ. Players were instructed to take place on the force plate with their feet shoulder-width apart and hands akimbo. Following the instruction to 'jump as high and fast as possible', players dipped to a depth of their preference, followed by a jump for maximal height (McMahon et al., 2017a). If hands were taken off the hips or knees were tucked in at any point during the jump, the attempt was classified as invalid. Players performed three valid attempts, after which raw vertical force-time data were exported into a Microsoft Excel file. The start of the jump was identified as the point at which force decreased by five SD's of bodyweight (measured during one second of quiet standing) (West et al., 2011). Take-off and touchdown were identified as the times at which force deviated by five SD's during 300 ms of the flight-phase (i.e., when the force plate is unloaded) (Moir, 2008). The jump during which maximal JH was achieved, was used for analysis. Whilst a plethora of variables in the CMJ may provide an indication of neuromuscular status, certain variables in the CMJ (i.e., FT, PF, PP, relative PP, VTO, and JH) displayed acceptable levels of between-day reliability in academy RL players (chapter four) and were therefore used to profile the post-training response.

5.2.7 Training session design

Training replicated a regular in-season session whereby players performed an athletic warm-up, a skill-based warm-up, team skills and several conditioning games (Figure 5.1). Both sessions followed the same session plan in order to replicate locomotive demands as well as possible between visits. Players were also exposed to a block of RHIE's at the end of each training session (Johnston et al., 2016b). These bouts of RHIE's, previously used as part of a stimulus in fatigue-related research (Johnston et al., 2016b), consisted of six efforts performed within one minute with a 1:1 work-to-rest ratio (i.e., each effort was performed in 5 s). Players rested for 30 s following a single bout and performed eight bouts in total. Each bout involved different combinations of collisions and/or running efforts. Collisions involved a hit on each shoulder, utilising over- and under-hook grips (i.e., pummelling) whilst the running included a 20 m sprint. The combinations of RHIE’s were either all collisions, all running, mainly collisions (i.e., four collisions and two 20 m sprints) or mainly running (i.e., four 20 m sprints and two collisions). Each combination was used twice in a randomised order to ensure comparability between both sessions (Johnston et al., 2016b).

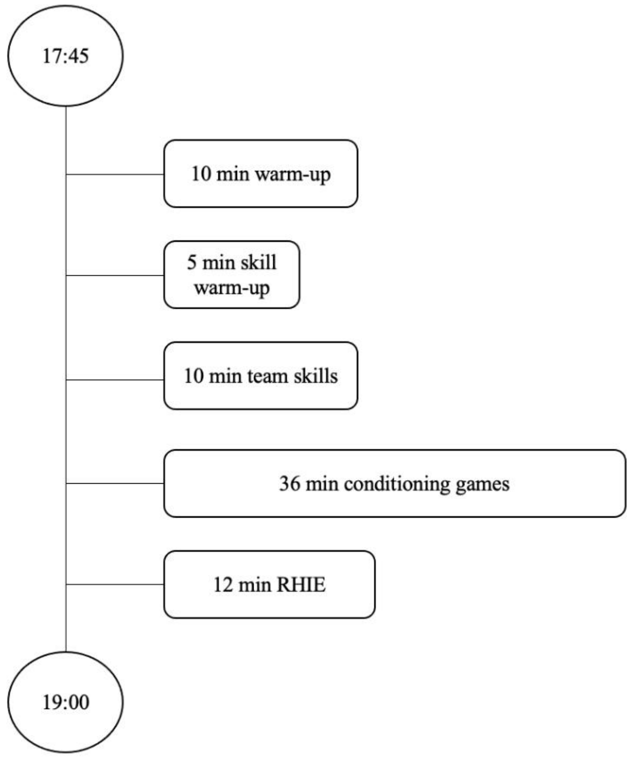

Figure 5.1 Training session design
RHIE: Repeated high-intensity efforts

5.2.8 Training activity profiles

Locomotive demands of the training sessions were measured using portable MEMS units sampling at 10 Hz (Optimeye S5, Catapult Innovations, Melbourne, Australia). Players wore these units in a pouch of a vest positioned between the shoulder blades. Units were turned on just before the warm-up and switched off after the training session. Using proprietary software (Openfield Version 2.3.3., Catapult Innovations), data were then downloaded and trimmed to ensure only data pertaining to time spent performing drills was exported for analysis (i.e., any breaks in training were excluded). In addition, subjective internal training load was obtained by a sRPE score, on a scale from 6 (no exertion) to 20 (maximal exertion) (Borg, 1998).

5.2.9 Interventions

In REC, players implemented a balanced post-training meal containing ~639 Kcal (i.e., 72 g CHO, 38 g protein, 22 g fat), additional snacks and shakes containing ~1276 Kcal (i.e., 207 g CHO, 76 g protein, 16 g fat), CWI (10 min, 10-12 °C, immersed up to the neck), and were given recommendations regarding their sleeping times and sleep hygiene. Players could drink additional water and/or sugar-free juice ad libitum. A detailed outline of these strategies is shown in Figure 5.2. In the CONT trial, which is reflective of 'normal practice' at the club, players received the same meal as those in REC, whilst sugar-free water and/or juice was also readily available.

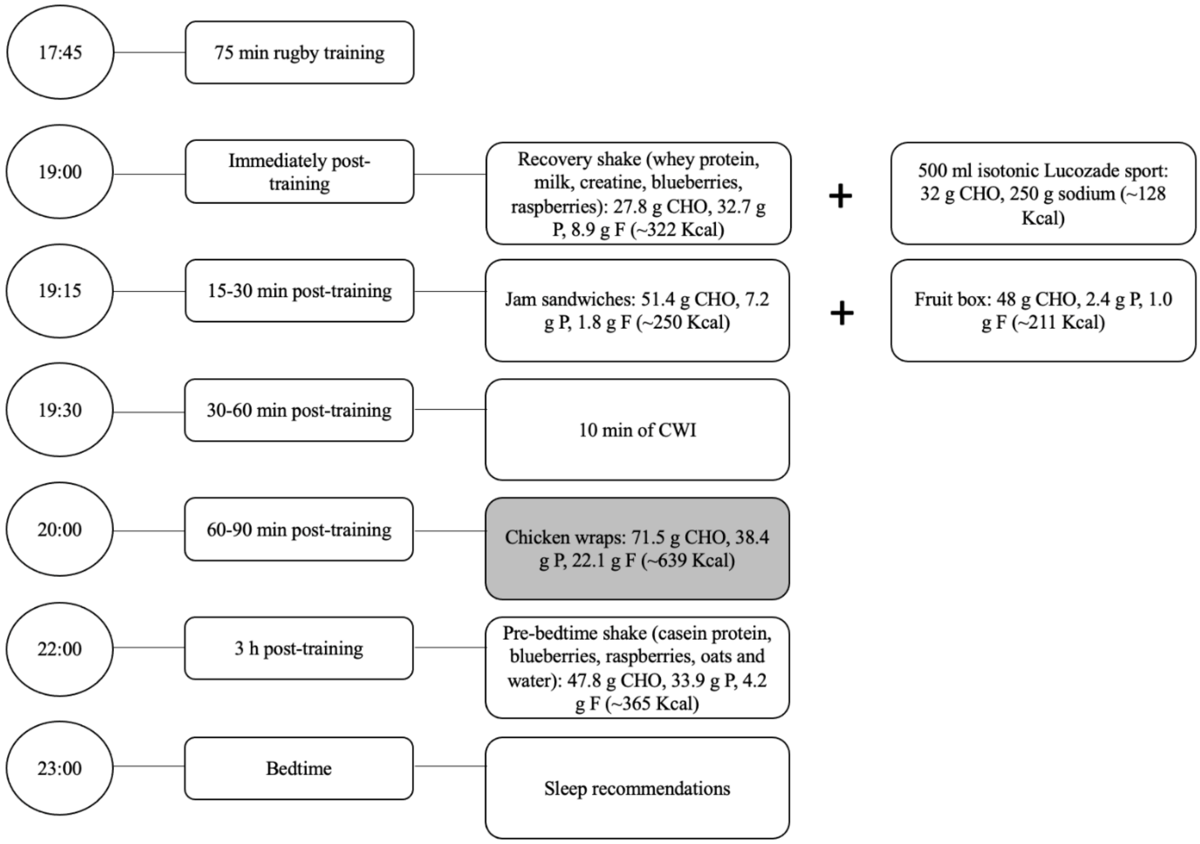

Figure 5.2 Recovery protocol which players are exposed to when in the recovery (REC) trial. The grey box highlights the meal which was consumed in the control (CONT) trial also.
CHO: Carbohydrate; CWI: Cold-water immersion; F: Fat; P: Protein.

5.2.10 Statistical analyses

All statistical analyses were carried out using statistical software (SPSS version 21, Chicago, IL, USA). Following initial assessments of normality through the Kolmogorov-Smirnov test, two-way repeated-measures ANOVA (within-participant factors: trial x time of sample) were used to assess between-trial differences (i.e., REC and CONT) over the three time-points. Mauchly's test of sphericity was consulted, and if found statistically significant ($p \leq 0.05$), the null hypothesis was rejected (i.e., sphericity has been violated), and the Greenhouse-Geisser correction was applied. Where significant p-values were identified for interaction effects, the recovery method was deemed to have influenced the post-training response and between-trial differences were assessed using a paired samples t-test. Significant main effects of time were further investigated using pairwise comparisons with Bonferroni adjustment. Statistical significance was set at ($p \leq 0.05$). Cohen's ES were also used with classifications set at ES<0.2, 0.2≤ ES <0.5, 0.5≤ ES <0.8 and ≥0.8 for trivial, small, moderate and large ES, respectively (Fritz et al., 2012).

5.3 Results

5.3.1 Training activity profiles

Table 5.1 displays the physical activity profiles of both training sessions. Sessions required an average total distance of 5383 ± 410 m, of which 350 ± 85 m high-speed running, with a total number of 28 ± 6 RHIE. PlayerLoad and sRPE values were 596 ± 50 and 15 ± 2 units, respectively. No significant between-session differences existed (Table 5.1).

Table 5.1 Mean (± standard deviation) training activity profiles and internal load (n=10)

Timing	Total distance (m)	High-speed (≥ 5.5 $m \cdot s^{-1}$) running (m)	Player load (AU)	Repeated high-intensity efforts (n)	Rate of perceived exertion (RPE)
Session 1	5244 (388)	354 (81)	587 (57)	27 (6)	14 (3)
Session 2	5523 (401)	345 (93)	605 (43)	29 (6)	15 (2)

AU: Arbitrary units
The absence of symbols denotes no between-session differences

5.3.2 Isometric mid-thigh pull response

In the IMTP, trial influenced PF (trial x time interaction: ($F_{(2,18)}$= 4.524, p = 0.026), but no significant between-trial differences were detected through post-hoc testing at any time-point (Figure 5.3). The recovery protocol had no influence on F200 ($F_{(1,11)}$= 0.649, p = 0.467) or F250 ($F_{(1,11)}$= 0.483, p = 0.545). Training did not influence any of the analysed variables in the IMTP (i.e., PF, F200, F250).

5.3.3 Countermovement jump response

In the CMJ, the recovery protocol did not significantly alter any of the variables in comparison to the control condition, as FT ($F_{(2,18)}$= 0.723, p = 0.499), PF ($F_{(2,18)}$= 0.540, p = 0.592), PP ($F_{(2,18)}$= 0.264, p = 0.771), relative PP ($F_{(2,18)}$= 0.332, p = 0.722), VTO ($F_{(1,12)}$= 0.007, p = 0.967) and JH ($F_{(2,18)}$= 0.012, p = 0.988) all remained unaffected. The training session influenced PP ($F_{(2,18)}$= 5.223, p = 0.016), as +24 h values were reduced by 4 ± 6% compared to baseline across both REC and CONT (Figure 5.4). Relative PP was also influenced by training ($F_{(2,18)}$= 4.426, p = 0.027), but post-hoc analyses showed no significant differences between time-points.

5.3.4. Wellness response

Fatigue ($F_{(2,18)}$= 2.673, p = 0.096), sleep quality ($F_{(2,18)}$= 1.320, p = 0.292), upper- ($F_{(2,18)}$= 1.651, p = 0.220) and lower-body soreness ($F_{(2,18)}$= 2.972, p = 0.077), and total wellness ($F_{(2,18)}$= 1.152, p = 0.338) remained similar between trials over time. As a result of training, fatigue and lower body soreness improved by 16 ± 19% (p = 0.010) and 31 ± 44% (p = 0.024) respectively at +48 h when compared to +24 h values (Figure 5.4). Total wellness increased by 8 ± 9% (p = 0.008) at +48 h compared to baseline values (Figure 5.5).

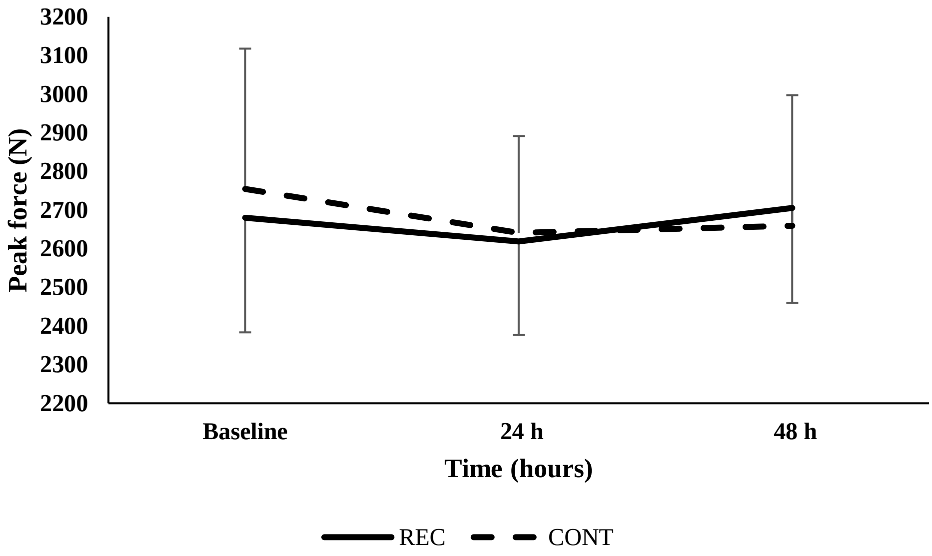

Figure 5.3 Mean peak force in the isometric mid-thigh pull before (baseline) and after (+24 and +48 h) high-intensity rugby league training (p = 0.026).

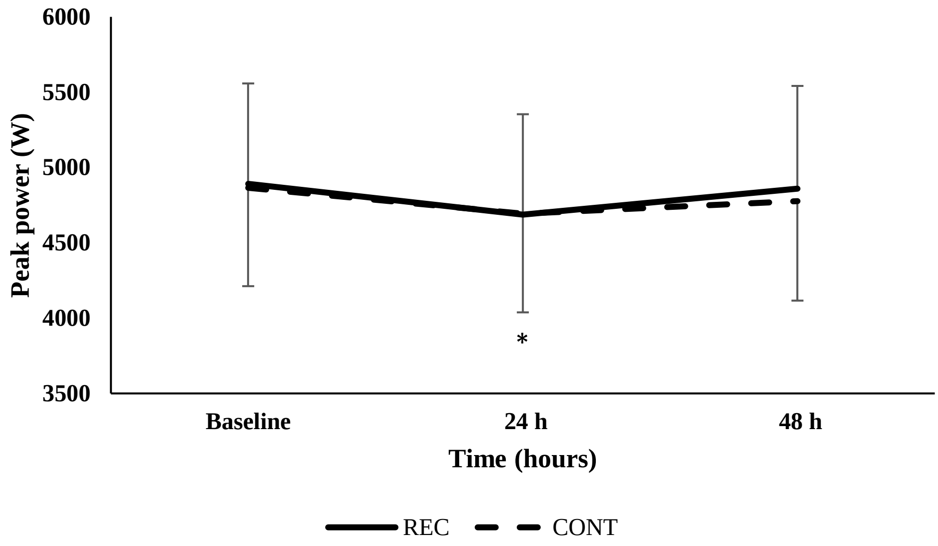

Figure 5.4 Mean peak power in the countermovement jump before (baseline) and after (+24 and +48 h) high-intensity rugby league training. * represents significant main effect difference ($p \leq 0.05$) to baseline.

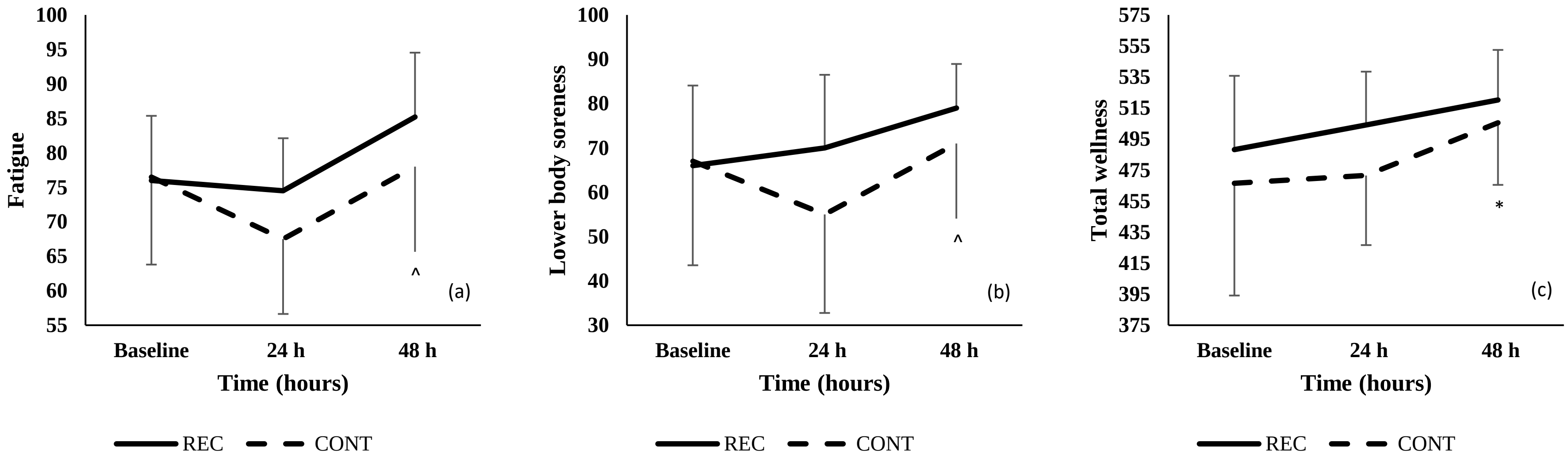

Figure 5.5 Mean fatigue (a), lower body soreness (b) and total wellness (c) before (baseline) and after (+24 and +48 h) rugby league training. * represents significant main effect difference (p≤0.05) to baseline. ^ represents significant main effect difference (p≤0.05) to +24 h.

5.4 Discussion

This chapter sought to assess the effect of a multimodal recovery strategy on objective and subjective responses to training that included both high-intensity running and collisions in academy RL players. Although the exercise stress elicited post-training perturbations that persisted for 24 h, the effects of the intervention (i.e., a balanced meal, additional snacks, CWI, sleep hygiene recommendations) were minimal relative to the control trial (i.e., a balanced meal only) as all but one of between-trial comparisons were similar post-exercise. Therefore, when a post-exercise meal containing ~639 Kcal (i.e., 72 g CHO, 38 g protein, 22 g fat) was consumed shortly after training (i.e., 60-90 min), recovery responses were not significantly benefitted further by the addition of the multimodal strategy. As responses in REC were similar to CONT and acknowledging the likely differences between training and match-play responses, this data supports the consumption of a balanced meal by academy RL players post-training, while highlighting the limited additional benefits of also performing the multimodal recovery strategy following training similar in session-design to that presented here.

Excluding IMTP PF, REC did not significantly influence markers of neuromuscular and perceptual recovery over and above those seen in CONT. Due to acute logistical constraints specific to academy RL (i.e., often limited time for recovery methods), the recovery strategy implemented in the present study only focused on the acute post-exercise window (i.e., within 4 h post-training). Nutritional strategies were targeted to shortly after the training session, and although this strategy aligns to post-exercise nutritional recommendations (Heaton et al., 2017; Ranchordas et al., 2017), next-day dietary intake was not considered. Likewise, whilst logistically practical, CWI was implemented for a single bout of 10 min, and despite such a strategy having been reported as efficacious previously (Lindsay et al., 2015a), the accumulated benefits of repeated CWI exposures have also been observed (Garcia et al., 2016; Pointon & Duffield, 2012). Additionally, sleep (hygiene) recommendations were implemented on a one-off basis, but in contrast to short-term benefits found previously (Caia et al., 2018), no sleep-related improvements were demonstrated in the current study. Therefore, even though recovery strategies were implemented in an ecologically valid and time-efficient manner, the efficacy of such an acute intervention following a rugby training session may be questionable when considered against the control condition of a balanced meal only.

Recovery strategies implemented following match-play appear more effective (Gill et al., 2006; Nunes et al., 2019; Suzuki et al., 2004) than when preceded by a training session or simulated game (Barber et al., 2020; Duffield et al., 2010; Higgins et al., 2012). Notwithstanding the influence of other confounding variables (e.g., timing, duration and type of recovery strategy used), it is sensible to suggest that the efficacy of recovery interventions is somewhat dependent on the magnitude of muscle damage caused by the preceding stimulus. However, further investigation is necessary to confirm these claims. This may be especially true for the present study, as although training sessions were based around conditioning games which, despite being high in relative distance covered and high-speed running, were relatively limited, though not void of, collisions; especially when considering the number and intensity of collisions compared to match-play. Indeed, Hudson et al. (2019) highlighted that significantly increased muscle damage was found following elite RU match-play, whilst high-intensity training, albeit eliciting the same physical load (including high-speed running and sprinting metrics), but omitting collisions, resulted in a reduced (i.e., less damaging) response. Speculatively, the collisions encountered on match-day are less controlled and of a higher intensity than those that occurred in training, therefore potentially eliciting increased muscle damage, resulting in a more prolonged recovery time-course (Hudson et al., 2019) than observed here. Upper body soreness in the current study remained unaffected, suggesting that physical collisions did not elicit the increased soreness that usually occurs through match-play (Johnston et al., 2013b; Roe et al., 2016c). Indeed, when considered alongside the single application of recovery modalities, together with a dampened (relative to match-play), albeit ecologically valid, training stimulus, it may not be surprising that the REC trial was unable to significantly improve recovery relative to provision of immediate post-exercise nutrition (i.e., ~639 Kcal; 72 g CHO, 38 g protein, 22 g fat) that adhered to authoritative nutritional recovery recommendations (Ranchordas et al., 2017). However, chapter three highlighted that such a balanced meal, consumed post-match or post-training may take place at some, but not all rugby league clubs, especially when in an academy environment. Practitioners are therefore recommended to consider implementing adequate post-exercise nutrition, or, at the very least, provide appropriate education in order to prime good practice and provide players with the correct knowledge to make sensible decisions regarding post-exercise nutrition when required to do so by themselves.

Training-induced decrements in PP at +24 h reflected reductions observed post-match-play (McLellan & Lovell, 2012; McLellan et al., 2011a). These responses support the notion that the session did indeed elicit a damaging stimulus given the reduction in selected markers of neuromuscular function observed. From a recovery research perspective, this may offer a surrogate method of eliciting rugby-specific post-exercise perturbations. Whilst it appears that the muscle damage caused plays an important role in the post-training fatigue response, other factors are also worth acknowledgement. Indeed, as highlighted, recovery is multifaceted and involves the integration of a variety of biological systems. For this reason, other factors related to for example the psychological system (e.g., desire to train, motivation) (i.e., mental fatigue) or to nutritional factors (e.g., fuel depletion) may play a role in post-exercise responses. That said, other analysed variables of the CMJ (i.e., FT, PF, VTO and JH) remained unchanged, possibly indicating that they were less sensitive to the training stimulus than PP. Differential sensitivity in recovery markers was also seen in chapter four when responses were profiled following match-play. Notably, increased sensitivity to fatigue in PP relative to those variables primarily assessing force components (i.e., PF) was found in chapter four and elsewhere (McLellan et al., 2011a), and the findings of the current chapter again support such observations in professional academy RL players. Although upper body soreness remained unchanged, likely due to the lack of intensity and frequency in physical collisions, further perturbations as a result of the training session were found in subjective responses. Whilst acknowledging their absence of acceptable between-day reliability (chapter four) on a five-point Likert scale, lower body soreness and fatigue were decreased (i.e., less sore/fatigued) at +48 h compared to +24 h. Total wellness was increased at +48 h compared to baseline values. These time-effects indicate that high-intensity training sessions may elicit reductions in CMJ PP and subjective responses that last for at least 24 h.

It is well documented that post-match perturbations in neuromuscular, biochemical, or endocrine, or perceptual responses may take between 48-72 h to recover (chapter two). During this period, rugby players are unlikely to participate in any high-intensity activity which may prolong their recovery. Whilst this is common practice following match-play, the same principle may not apply to training as survey findings (chapter three) highlighted that consecutive training-days are not uncommon within academy rugby environments. This is despite the fact that locomotor activities of training sessions (such as those reported here) may at times be similar or greater than the average activities occurring in academy RL match-play (chapter four). Reductions in PP at +24 h, which are comparable to some responses post-match-play (Johnston et al., 2015b; McLellan et al., 2011a), indicate that fatigue occurred as a result of the prior training session, and player performance may be reduced during this time. Acknowledging that the type and intensity of the training session likely dictate the responses that were elicited (Roe et al., 2017b), practitioners should be mindful when implementing training sessions on consecutive days. This would be especially true when an accumulation of fatigue may not be the preferred outcome of training (i.e., during the competitive season). Training sessions that are high in frequency and intensity of eccentric muscle actions, and/or in physical impacts are likely to cause perturbations that require at least 24 h to recover. Following such a session, players are encouraged to consume adequate post-exercise nutrition to facilitate the recovery from training. Equally, it may be worthwhile for practitioners to avoid further high-intensity activity focusing on the same musculature in their players on the following day. If optimal match performance is desired, such sessions should not be performed near match-play as players may go into a game in a 'fatigued' state.

5.5 Conclusion

When adequate post-exercise nutrition adhering to authoritative nutritional recovery guidelines is implemented following training, additional recovery strategies as used in the present chapter may not be clearly beneficial, especially if time is restricted to undertake recovery practices. However, it remains unclear whether similar recovery strategies to those used in the current study would benefit players over repeated days of training, interspersed with the increased demands of match-play. Practitioners should therefore implement appropriate post-training nutrition, or, at the very least, provide players with education around this subject to prime good practice and allow players to make the correct decisions when responsible for their own post-exercise nutrition. This is especially true, given that only 48% of practitioners highlighted that a carbohydrate- and protein-rich meal was always consumed following match-play (Table 3.8). Considering the large emphasis that is placed on match-play, this is likely to be even less following training. Although high in relative distance covered and high-speed running, training in the current study included limited physical collisions, especially compared to the amount and intensity observed in match-play. Speculatively, the use of a similar multimodal recovery strategy could be more effective when preceded by a greater exercise stimulus (i.e., match-play), a statement that remains to be evaluated in future research in academy RL players. However, this protocol does offer practitioners a time-efficient and ecologically valid method of implementing various recovery strategies. This may be especially true as academy RL players are often employed by their clubs on a part-time basis and as a result spend a limited amount of time performing club-related activities. Furthermore, the high-intensity training session caused transient changes in performance and wellness variables in the post-exercise period, particularly at +24 h. These findings are particularly important for practitioners who should be mindful of these effects when planning their weekly training schedule if similar sessions feature in the competitive week, especially if the accumulation of fatigue is not desired. Accordingly, consecutive training sessions focusing on the same musculature that encompass a high frequency and intensity of eccentric muscle actions and include a large amount of high-speed running and RHIE should be carefully considered. Furthermore, to limit the effects of fatigue, such sessions should not be scheduled within 24 h of match-play given the potential for impaired recovery, which may potentially compromise optimal match performance thereafter.

Chapter 6.0 General discussion, practical applications, and directions for future research

This thesis aimed to better understand and improve practices in relation to player monitoring, post-exercise responses, and the use of recovery strategies in academy RL. Academy RL is the final level prior to professional senior RL, which highlights the importance of holistically preparing academy players for the professional senior level. The knowledge and recommendations provided here will hopefully help to do so. This thesis specifically aimed to 1) explore the current academy RL environment in relation to player monitoring practices, training, and the use of recovery strategies, 2) profile post-match and post-training responses in ecologically valid scenarios, using variables with acceptable reliability, and 3) assess the efficacy of a multimodal recovery strategy implemented following high-intensity training.

Chapter three investigated practitioner perceptions and practices in relation to player monitoring, training regimes, and recovery strategies. The contextual information gathered in this chapter in relation to academy RL environments helped to inform the study design of the studies in chapter four and five. Specifically, attempting to modify and enhance the recovery process, the effect of an ecologically valid multimodal recovery strategy was assessed following a high-intensity training session (chapter five), using measures previously found to be reliable (chapter four). This approach, roughly aligned with the model proposed by Drust & Green (2013), whereby acquired knowledge from applied practitioners is used to formulate research questions, significantly adds to the ecological validity and application of the studies. Altogether, it is hoped that the findings from this thesis provide some solutions and practical recommendations to the challenges that may occur in relation to the fatigue and recovery process in academy RL players. The current chapter aimed to summarise the findings of the previous chapters. Areas of future research are identified to progress the understanding and practical application of the topic in the bespoke population. An overview is provided in Figure 6.1.

Thesis aims	Study aims	Key findings	Practical applications	Directions of future research
To better understand and improve practices in relation to player monitoring, post-exercise responses, and the use of recovery strategies in academy RL	To assess the practitioner perceptions regarding applied practices of player monitoring, training, and recovery strategies in academy RL	• Practitioners frequently use monitoring tools, but findings do not often inform practice. • Only 55% of practitioners agree that the recovery process is prioritised and executed well within their organisation.	• Subjective tools may be implemented throughout the week, but objective tools should only be used where it may influence practice (e.g., MD+2). • Practitioners are encouraged to focus on providing guidance and education in relation to recovery-modulating factors such as nutrition, hydration, and sleep.	• Determine the extent of change in monitoring results leading to a decrease in performance or increased injury risk. Such a change may prompt modification of practice (e.g., reduced training load). • Investigate the guidance and education currently provided to academy RL players. This may highlight areas of strength and improvement.
	To examine the within- and between-day reliability of various markers of fatigue in academy RL players	• Acceptable between-day reliability was achieved by PF, F200, and F200 in the IMTP, by FT, PF, PP, rPP, VTO, and JH in the CMJ, and by total wellness in the wellness questionnaire.	• Practitioners should use those variables that achieve acceptable reliability in their population.	• Assess test-retest reliability in the fatigue responses following match-play.
	To profile responses for 120 h following academy RL match-play	• Academy players suffer from post-match perturbations that last at least 48 h.	• High-intensity activity should be avoided 48 h following match-play. Whilst considering match demands and individual recovery responses, light activity on MD+2 may provide additional opportunities for players to train and develop.	• Assess the responses experienced following a light training session on MD+2.
	To assess the efficacy of a multimodal recovery strategy implemented following an academy RL training session	• When consuming a balanced meal following a training session high in frequency and intensity of eccentric muscle actions, there are limited additional benefits of performing a multimodal recovery strategy. • High-intensity training, incorporating a high frequency and intensity of eccentric muscle actions, is likely to cause perturbations that last at least 24 h.	• Where possible, practitioners should provide appropriate post-exercise nutrition, or, at the very least, provide education to prime good practice and allow player to make corrects decisions when responsible for their own nutrition. • When accumulation of fatigue is not the desired outcome, an overload of high frequency and intensity of eccentric muscle actions and/or collisions during consecutive training days should be avoided.	• Investigate the effect of appropriate nutrition on post-exercise responses over repeated days of training, interspersed with the demands of match-play. • Assess the responses experienced following field-based and gym-based training sessions.

Figure 6.1 Overview of thesis aims, study aims, key findings, practical applications, and directions of future research.

CMJ: Countermovement jump; F200: Force at 200 ms; F250: Force at 250 ms; FT: Flight-time; IMTP: Isometric mid-thigh pull; JH: Jump-height; MD: Match-day; PF: Peak force; PP: Peak power; RL: Rugby league; rPP: Relative peak power; VTO: Velocity at take-off;

6.1 Realisation of thesis aims

Chapter three aimed to assess the perceptions of practitioners in relation to player monitoring practices, training regimes, and the implementation of recovery strategies. Such information is important to contextualise and understand the environment in which academy RL players and staff operate. It also allows for study design to be directly influenced by the experiences and knowledge of practitioners, which enhances the practical application of the consequent findings. Monitoring of player readiness was done by most practitioners in academy RL, primarily during the mid-week period (i.e., match-day +2, +3 and -3), but time-restrictions often prevented monitoring to inform practice. Due to staff and players having other commitments (i.e., education or work), and limited facility availability, most training sessions took place during late afternoon or evening (i.e., 15:00-21:00 h). Although almost all practitioners highlighted that they used recovery strategies to enhance readiness in their players, 45% was unhappy with the way those strategies were carried out. Because of time restrictions, it is understandable that other activities (i.e., field- or gym-based training, video (p)review sessions) take up most of the available time. Although some time at least was dedicated to player monitoring and the implementation of recovery strategies, it is likely that due to the scarcity of time and resources, these practices were not performed optimally.

When asked about the requirements of a monitoring tool, some practitioners highlighted the importance of tools being reliable. Indeed, when taking measurements, it is recommended to use those variables that achieved acceptable reliability. Chapter four therefore aimed to assess the within- and between-day reliability in different variables of the IMPT, CMJ and wellness questionnaire. Notably, between-day reliability was assessed through two measurements that were separated by seven days, whilst 'regular' practice still occurred in relation to match-play, training, and recovery strategies. The design of this test-retest reliability study adds robustness and practical application to the findings. When taking IMTP measurements, practitioners are recommended to use PF, F250 or F200 over forces elicited at earlier time-points due to the higher levels of within-and between day reliability. Similarly, the use of FT, PF, PP, relative PP, VTO and JH would be preferred over a variety of other variables in the CMJ. Individual components of the questionnaire failed to meet the requirements of acceptable between-day reliability (i.e., CV ≤10%, ICC ≥0.8), hence the use of total wellness would be recommended when profiling post-exercise responses.

Using those measures that elicited acceptable levels of between-day reliability, chapter four also aimed to profile post-match responses. Because post-match perturbations were previously recorded up to 120 h (McLellan et al., 2011a), this study also assessed responses over this period, whilst including regular training activities and recovery strategies. The ecological validity of profiling post-match responses in this manner is a strength of the study. It appears that the magnitude and time-course of post-match responses is dependent on the test and variables used. Notably, match-play did not elicit any significant reductions in IMTP performance or total wellness, despite the presence of large and moderate ES (≥0.76) up to +48 h. In contrast, jump performance was reduced at +24 h, as highlighted by reductions of 4.75% and 9.23% in VTO and JH of the CMJ, respectively.

In an attempt to enhance post-exercise recovery in an ecologically valid way for academy RL players, chapter five aimed to assess the efficacy of a multimodal recovery strategy following high-intensity training. Indeed, the recovery strategies implemented were easily accessible, relatively cheap, and performed directly post-training to avoid taking up too much time, which makes it a practically valid strategy for the bespoke population. Despite being implemented in a time-efficient manner, this recovery strategy, which included modified nutrition, CWI, and recommendations regarding sleep hygiene, appeared no more beneficial when compared to the consumption of a balanced post-training meal. Some evidence suggests however, that when preceded by a stimulus including a higher frequency and intensity of collisions (i.e., match-play), the strategy may be more effective. The training session, which was high in high-intensity running, and thus eccentric muscle actions, did elicit perturbations in the post-training period. More specifically, PP in the CMJ was reduced by 4% at +24 h compared to baseline, whilst measures of wellness (i.e., fatigue and lower body soreness) were reduced (i.e., less fatigued/sore) at +48 h compared to +24 h.

6.2 Monitoring practices

Chapter three highlighted that monitoring of player readiness is common in academy RL as 76% of practitioners indicated that they employed such practices ‘often’ or ‘all of the time’. A wellness questionnaire, knee to wall test, adductor squeeze test, and measures of soreness were used most frequently. The popularity of these tools amongst academy RL practitioners may not be surprising as they are generally quick and easy to undertake, which is useful when time is restricted. Specifically, the use of subjective measures (i.e., a wellness questionnaire or measures of soreness) may be particularly practical when working with academy RL players. Indeed, as players arrive for training from school or work, it may be assumed that both undertaking and analysing results of objective measures, could require longer than the time that is available. Instead, subjective measures may be collected throughout the day as players could provide such responses through answering questions on an online platform. Practitioners will have access to this information prior to players arriving for training and could make informed decisions based on the subjective responses of their players.

However, arguably because of restrictions on time and/or personnel, practice was not often influenced by the information derived from player monitoring. Specifically, if practitioners would spend a considerable amount of time taking objective measurements, it is important that those results are subsequently used to affect practice where necessary. If this is not the case, taking those measurements does not appear worthwhile in relation to the time invested. Practitioners should therefore strongly consider their rationale for using monitoring tools. When doing so, it may help to understand the extent of change in the monitored responses which would negatively influence playing performance or cause increased risk of injury. Acknowledging that various technical and tactical factors also influence playing performance, physical performance (i.e., high-speed running, relative distance covered) during match-play was previously reduced when in a fatigued state compared to a game played under non-fatigued conditions (Johnston et al., 2013a). Whilst it is generally understood and accepted that players suffer from perturbations following high-intensity training or match-play, it is less clear how prolonged reductions may influence practice (e.g., training load modification) and when they may risk causing significant underperformance or injury. Such implications require further investigation.

In addition to the lack of time and/or personnel available, there are other contextual factors that should be considered in relation to the information derived from player monitoring. Indeed, chapter three highlighted that throughout the training week, individual player development is prioritised, and as a result, players are not prepared to be in an optimal physical state during matches, as winning performances are not necessarily sought after. Any reductions in performance or wellness variables throughout the training week or near match-play may therefore not affect practice, because an optimal physical state is not required. Nevertheless, it may still be useful to take objective measures at least once a week where possible. Specifically, match-day +2 may be a suitable day as this is a critical period of post-match recovery where individual recovery time-courses and match demands may allow for additional training opportunities for certain players.

Regardless of using objective or subjective measures, it is highly desirable for practitioners to use those variables that are most reliable (Cormack et al., 2008c). Chapter four assessed test-retest reliability of 25 variables across the IMTP, CMJ and wellness questionnaire. Based on levels of reliability, recommendations were made regarding the specific variables that should be assessed when using these tests on a within- or between-day basis. However, these recommendations were provided in relation to specific tests, and as highlighted in chapter three, many other measures were used by academy RL practitioners. It would be worthwhile for practitioners to assess the reliability of the measures and variables used, prior to making decisions based on monitoring results. Despite initially aiming to do so, this thesis was not able to assess the reliability of the fatigue response that is elicited through-match. Such information would specifically highlight those variables that would be best suited for the measurement of post-match responses (Fitzpatrick et al., 2019) and would be worthwhile to investigate in future research.

6.3 Post-exercise responses

Chapter four also investigated the responses following match-play over five days (i.e., 120 h), using tests and specific variables that were deemed reliable. Whilst only those measures that were found to be reliable, were profiled following match-play, it should be acknowledged that it may also be worthwhile to investigate the other considered variables. Indeed, different variables were excluded based on their larger between-day variance (i.e., a lower ICC and/or a greater CV). However, whilst the noise (i.e., variance) may have been greater, the signal (i.e., response) may also be greater, which may indicate that these variables may still behave in a dose-response manner. Nevertheless, acknowledging the differences in magnitude and time-course between some of the variables assessed, it appears that post-match responses require at least 48 h to recover in academy RL players. However, given the specific (positional) activity profiles that players are exposed to (Gabbett et al., 2012; Waldron et al., 2011), and the individual nature of recovery responses (Markus et al., 2021), not all training activity should necessarily be avoided during this period. Notwithstanding the variability of training schedules between different clubs, match-day +2 is usually preceded by a day off, and some players, dependant on their recovery response, could indeed perform some light training on this day. It would be worthwhile for future research to assess the responses that such a training session elicits and how this may affect any post-match perturbations. To avoid additional muscle damage in the same muscle groups, a high intensity or frequency of eccentric muscle actions and/or collisions would not be recommended here, while light technical skills may be extremely worthwhile to provide academy players with more opportunities to develop (Till et al., 2015a). It is during this critical period of recovery where player monitoring should be used to guide training practices.

In addition to assessing the effect of a multimodal recovery strategy, chapter five investigated changes in performance and wellness variables following RL training; an area of research that is not very well understood. Regardless of the effect of the recovery strategy, training elicited perturbations in jump performance that lasted for at least 24 h. Those post-training reductions may not be surprising due to the distance covered at high intensity (i.e., 350 m), and thus a high frequency of eccentric muscle actions, which are known to cause muscle damage (Peake et al., 2017). Notably, some of the activity profiles of this training session were reflective of the average match profiles in chapter four. Accordingly, practitioners should be particularly mindful when planning consecutive training sessions that rely heavily on the same musculature. If a planned accumulation of fatigue is not the desired outcome, an overload of frequency and intensity of eccentric muscle actions over a short period (i.e., a few days) would not be recommended as reduced performance (Johnston et al., 2013a; Johnston et al., 2013b) and an increased risk of injury may be likely (Pull & Ranson, 2007). Instead, when training on consecutive days, it may be more suitable to train different physical elements and musculatures on the different days.

It has become clear across chapter four and five that different tests and variables vary in sensitivity when responding to a specific stimulus. Given the absence of significant perturbations in the post-exercise period following both match-play and training, it appears that tests of isometric nature (e.g., IMTP) may be less sensitive to rugby-specific exercise than dynamic movements utilising both shortening and lengthening of the muscle (e.g., CMJ). Similar findings have been found elsewhere (Kennedy & Drake, 2018; Raeder et al., 2016), and those claims are supported in the current thesis. Similarly, this thesis repeatedly found increased sensitivity to rugby-specific exercise of a velocity-component than those variables assessing maximal-force capacities. To avoid underestimation of a response, it would be worthwhile to investigate those variables that are most sensitive when responding to stimuli.

6.4 The use of recovery strategies

Chapter three highlights that practitioners highly valued the use of recovery strategies, as they almost all agreed that the effective use of recovery strategies may aid in the enhancement of player readiness. As a result, stretching, foam rolling and gym-based recovery (i.e., resistance exercise, cardiovascular exercise) were often prescribed in the post-match period. However, despite the implementation of these specific and other recovery strategies in the post-match period, only half of the practitioners believed that the recovery process was prioritised and executed well within their organisation. This may be due to a variety of factors. Firstly, the evidence behind the strategies that were implemented most frequently (i.e., stretching, foam rolling and gym-based recovery) is largely equivocal (Tavares et al., 2017). Some evidence suggests the beneficial effects of foam rolling and active recovery, but specifically, stretching, or light resistance training, although unlikely to be detrimental, have not been proven to enhance recovery following exercise (Herbert & Gabriel, 2002; Tavares et al., 2017). Secondly, the time available for the implementation of recovery strategies is limited. Players and half of the members of staff are employed by the club on a part-time basis, which limits the number of hours that they are legally allowed to perform club-related activities. It may therefore be unsurprising that most of the available time is allocated to gym- or field-based training or (p)review sessions, whilst the limited remaining time dictates that recovery strategies are implemented in the quickest and most accessible way.

Acknowledging the various influencing factors (e.g., type, dosage, duration, preceding stimulus) that may determine the efficacy of a certain recovery strategy (Dupuy et al., 2018), the evidence behind most strategies remains unclear (Tavares et al., 2017). For this reason, it may be questioned whether to spend time, which is already limited, on the implementation of recovery strategies when the effects are uncertain and potentially unnecessary. This may be an especially important consideration for the current population. The annual playing schedule highlights that most academy games are played on a Thursday evening or Saturday afternoon. With the day following match-play, as well as a Sunday being mostly days off, a real-life practical example highlights that when a game is being played on the Thursday, recovery-enhancing activities may take place on the Saturday, and the first real post-match training session may take place on the Monday thereafter (Figure 4.1). In such a schedule, post-match recovery is clearly prioritised, but it appears that this approach limits consequent training opportunities that players are exposed to during this period. Arguably, this may not be the optimal way of achieving long-term physical, technical, and tactical development, which is highlighted as the primary aim in this population (Till et al., 2015a).

As alluded to in chapter two, there should not be a one-size-fits-all approach in relation to the implementation of recovery strategies (Turner & Comfort, 2017). They should be carefully considered in relation to factors such as the population, the preceding stimulus, and the period thereafter (i.e., what is a player recovering from and for). Recovery strategies are generally viewed as a means of enhancing the return of homeostasis in various physiological systems and the restoration of post-exercise perturbations back to baseline values (Dupuy et al., 2018). Whilst this may be true, the cascade of inflammatory events which occurs because of muscle damage, is necessary to cause adaptation in preparation for future exposure (Markus et al., 2021). In a period during which winning performances are not necessarily sought after, and physical adaptation is important to prepare for the professional senior level (Till et al., 2016b), practitioners in academy RL may consider limiting chronic exposure to recovery strategies. Especially when some evidence suggests that certain interventions may attenuate physiological adaptation when exposed to over an elongated period (Roberts et al., 2015; Yamane et al., 2015).

This is not to say that there is no place for recovery strategies in academy RL. For example, players may sporadically be exposed to CWI when there is a short between-match period, whilst high-quality CG may be encouraged following match-play and those training sessions of high-intensity. The academy period is particularly suitable for experimenting with different interventions, subsequently priming good practice in preparation for professional senior RL. Altogether, the focus should be on building long-term habits, especially in relation to recovery-modulating factors such as nutrition, hydration, and sleep. These factors have consistently been highlighted as crucial in relation to post-exercise recovery (Halson, 2008; Peake, 2019), and this was once again proven in chapter five, where a balanced post-exercise meal appeared equally effective relative to a multimodal recovery strategy. It is therefore especially important for practitioners to implement appropriate nutrition and provide players with education around this subject to stimulate correct decision making when players are responsible for their own post-exercise nutrition. Given the part-time nature of the bespoke population, players are often left to make their own decisions regarding such recovery-modulating factors, which emphasises that the appropriate guidance and education is required.

6.5 Recommended practice

Altogether, this thesis has provided an insight into the academy RL environment and some of the potential challenges faced in relation to fatigue and recovery processes. Whilst acknowledging the varied weekly schedules that exist at different clubs, Figure 6.2 highlights a practical example of a weekly schedule based on some of the findings of the current thesis. Substitutes or partial-match players likely require a different training regime as this weekly schedule is based upon players who completed at least a large part of the match. Between-match periods naturally differ throughout the season, but as highlighted in Figure 2.1, a between-match period of six days (i.e., match-day on Saturday, next match on the following Saturday) occurs regularly and is therefore used in Figure 6.2. The model replicates Figure 2.2, which prescribed the structure for a training week in senior professional RU but includes changes which may be more fitting in an academy RL environment. Specifically, the model highlights periods of recovery (i.e., players do not undertake any training and focus on recovery from previous training or match-play), acquisition (i.e., players participate in group training to improve tactical, technical, physical, and mental skills, whilst a specific physical element is emphasised) or individual training (i.e., additional training opportunities may be given to certain players based on their individual recovery responses). The following findings and considerations from the previous chapters have been included:

- Following match-play, nutritional interventions such as those described in chapter five (i.e., a balanced meal as well additional snacks and shakes) should be included. Although any additional benefits of also performing a multimodal recovery strategy were limited following high-intensity training compared to the consumption of just a balanced meal, some evidence suggests that such strategies are more effective following match-play.
- As highlighted by findings in chapter three, the day following match-play is a day off. Players are not exposed to any supervised activities and will rely on given education and advice by practitioners to make the correct decisions regarding any recovery-modulating activities.
- Perturbations in performance and subjective well-being following academy RL match-play typically require at least 48 h to recover. However, depending on individual recovery profiles and match demands, some players may be able to perform light training on match-day +2. Monitoring of post-match responses will be useful here to assess player readiness

to train, and practitioners are recommended to use both subjective (i.e., a wellness score) and objective measures (e.g., PP in CMJ) where possible.

- Match-day +3 will focus largely on the defensive side of the game and will include a large number and intensity of collisions as well as accelerations and decelerations. Match-day -3 will predominantly focus on the attacking side of the game and will involve greater covered distances and increased high-speed running. Other in-game elements, specifically transitions (i.e., defence to attack and attack to defence), may be trained on either day depending on preference and philosophy of the coaching staff. Both sessions could take 60-75 min to complete. A similar strategy in training activities was mentioned by both technical and physical practitioners (chapter three).
- As highlighted in chapter five, high-intensity training may result in reductions in performance and subjective well-being at +24 h. For this reason, match-day -2 will be a day off for players to recover.
- The day prior to match-play will be classified as ‘captains run’, but whilst being shorter in duration (i.e., 30-60 min), this session should be viewed as a regular training session during which individual and team development should be prioritised.

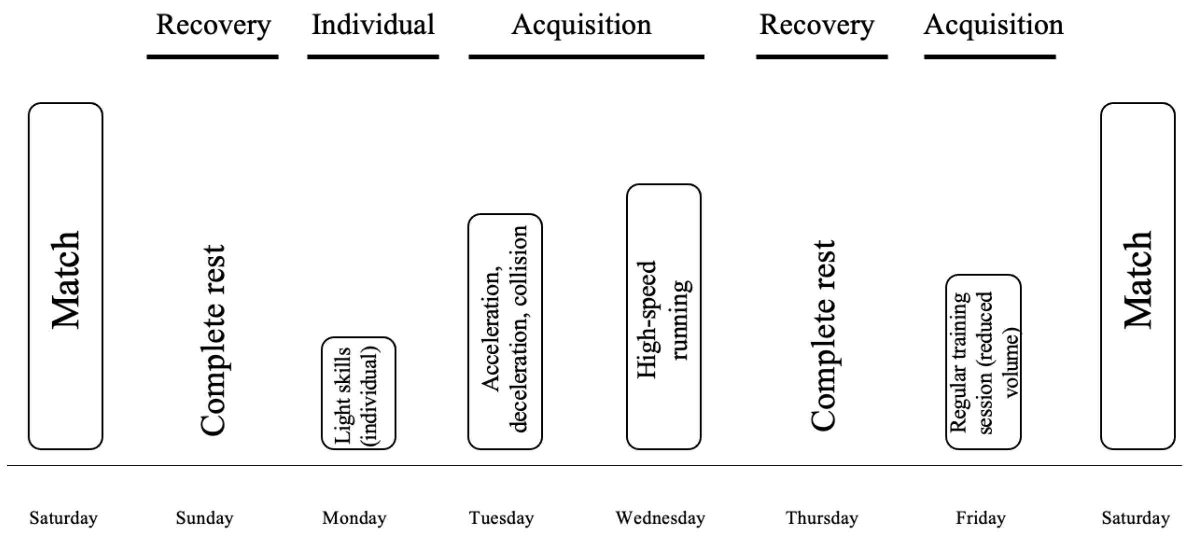

Figure 6.2 Proposed model for a weekly training structure in academy rugby league.

Chapter 7.0 Conclusion

Like their senior counterparts, academy RL players suffer from post-match perturbations that require at least 48 h to recover. Notwithstanding the variety in training schedules that exists between clubs, the day following match-day is usually a day off, which highlights that any recovery-enhancing protocols or activities on this day need to be performed by the players themselves, without the supervision of a member of staff. Players often return to the club facilities on match-day +2, and it is during this critical period of recovery where player monitoring may be used to guide practice. Differing match demands and individualised post-match responses dictate that some players may be able to perform some light training on this day. Using monitoring tools to assess player readiness will aid in the decision making of this process. However, although practitioners currently use monitoring tools, mainly wellness questionnaire, knee to wall test, adductor squeeze test, and measures of soreness, results currently do not often inform practice. It is important for practitioners to establish the extent of change that may prompt adaptations in practice (e.g., modification of training load). Using those tools and variables that are reliable and sensitive to fatigue will aid in this process and some examples are provided in this thesis (e.g., PP in CMJ). Like match-play, high-intensity training, incorporating a high frequency and intensity of eccentric muscle actions and/or collisions, is likely to cause perturbations that may last at least 24 h. To avoid accumulated fatigue throughout the training week, consecutive training sessions focusing on the same musculature (e.g., eccentric muscle actions through high-speed running and RHIE) should be carefully considered, especially close to match-play.

Academy players frequently undergo a variety of easily accessible recovery strategies (i.e., stretching, foam rolling, gym-based recovery) following match-play. The efficacy of such strategies may be questioned, especially if limited time is available. Indeed, when considering the primary aim of academy RL (i.e., long-term development of technical, tactical, and physical attributes), chronic implementation of recovery strategies may not be necessary. This is especially true given that muscle damage and the consequent cascade of inflammatory events is necessary for physical adaptation to occur. Acknowledging that certain times may still be suitable for players to use recovery strategies (e.g., short between-game period, experimenting), it may be more worthwhile for practitioners to educate their players and prime good practice in relation to recognised recovery-modulating factors such as nutrition, hydration, and sleep. This is emphasised by findings in chapter five, highlighting that there was no additional benefit to a multimodal recovery strategy compared to a balanced post-training meal.

8.0 References

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8.0 Appendices

8.1 Appendix 1: Confirmation of ethical approval (chapter three data collection)

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Hendrickus Aben

Professor Mark Russell
Chair of SSHS Ethics Committee
Tel: 0113 283 7100 ext 649
E-mail: m.russell@leedstrinity.ac.uk

Date: 16th May 2019

Dear Hendrickus

Re: SSHS/2019/006
Perceptions relating to recovery in academy rugby league: a survey

Thank you for your recent application for ethical approval for the above named project.

After reviewing the application it has been resolved that the research project is granted ethical approval.

I wish you well in your study

Yours sincerely

Prof. Mark Russell
Chair of School of Social and Health Sciences Ethics Committee

8.2 Appendix 2: Survey questions

Introduction

Thank you for taking the time to participate in this survey; your participation is greatly appreciated. Throughout this survey, you will be asked to answer questions that are mainly concerned with your practice in relation to monitoring player readiness to train/play and the use of recovery strategies within your organisation. Further questions will be related to your training practices throughout the week. The survey has received ethical approval and results may be published in a scientific journal and/or presented at conferences. Responses will always remain anonymous.

Please answer the questions below based upon what you consider to be *typical* for you/your team.

Please refrain from using the back button on your browser as this may lead to loss of data. Instead, please use the next and previous buttons only to navigate through the survey.

Which of the following would apply to you most? ✱ *Required*

- ◯ I am a full-time paid member of staff
- ◯ I am a part-time paid member of staff
- ◯ I am an intern/volunteer

What is the sport you play/have played the highest level at? ✱ *Required*

Which level do/did you play this sport at? ✱ *Required*

- ◯ Amateur
- ◯ Semi-professional
- ◯ Professional
- ◯ International
- ◯ I play/have not played any sport

How long have you worked in academy rugby league? (either as an intern or a paid member of staff) ✱ *Required*

- ◯ < 1 year
- ◯ 1-3 years
- ◯ 3-5 years
- ◯ 5-10 years
- ◯ > 10 years

What is the highest level of education you have completed? * *Required*

- ◯ Secondary eduction (GSCE)
- ◯ Secondary eduction (BTEC)
- ◯ Secondary education (A-levels)
- ◯ Graduate of any higher education (College or University)
- ◯ Masters
- ◯ Doctorate
- ◯ Post-doctoral
- ◯ None
- ◯ Other

If other, please specify below.

Monitoring player readiness to train/play

Do you use any tools to monitor player readiness to train/play? * *Required*

- ◯ Don't know
- ◯ Never
- ◯ Rarely
- ◯ Sometimes
- ◯ Often
- ◯ All of the time

Which tool(s) do you use to monitor player readiness to train/play? (please select all that apply) * *Required*

- ☐ Countermovement jump
- ☐ Drop jump
- ☐ Squat jump
- ☐ Isometric mid-thigh pull
- ☐ Adductor squeeze test
- ☐ Measures of testosterone/cortisol through samples of blood/saliva
- ☐ Measures of creatine kinase through samples of blood/saliva
- ☐ Wellness questionnaire
- ☐ Measures of (lower- and/or upper-body) soreness
- ☐ Sit & reach test
- ☐ Knee to wall test
- ☐ Other

At which time-points do you monitor player readiness to train/play? Please assume a 7-day turn around (i.e., match-day on Saturday, next match on the following Saturday) (please select all that apply) ✱ *Required*

- ☐ Directly post-match (within 60 minutes)
- ☐ Match-day +1
- ☐ Match-day +2
- ☐ Match-day +3
- ☐ Match-day -3
- ☐ Match-day -2
- ☐ Match-day -1
- ☐ Match-day (pre-match)

How important do you consider each of the following factors when deciding which tool(s) to use to monitor player readiness to train/play? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 5 answer(s).

	Not at all important	Not very important	Neither important nor unimportant	Important	Very important
Time that is required to complete the monitoring process	☐	☐	☐	☐	☐
Time that is required to analyse the results	☐	☐	☐	☐	☐
The availability of equipment that is required to complete the monitoring process	☐	☐	☐	☐	☐
The information that is derived from a specific tool	☐	☐	☐	☐	☐
The research that is available in support of the specific tool that is chosen	☐	☐	☐	☐	☐

How do the results of monitoring player readiness to train/play affect training in the week following match-play? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 6 answer(s).

	Never	Rarely	Sometimes	Often	All the time
Training volume/intensity of a training session is adapted for the full team	☐	☐	☐	☐	☐
Training volume/intensity of a training session is adapted for individual members of the team	☐	☐	☐	☐	☐
Recovery strategies are modified for the full team	☐	☐	☐	☐	☐
Recovery strategies are modified for individual members of the team	☐	☐	☐	☐	☐
Team selection is modified in the following match	☐	☐	☐	☐	☐
Keep a close eye on individual members on the following day(s) in the case of a 'red flag'	☐	☐	☐	☐	☐

If no restrictions were in place (i.e., no time restrictions, financial restrictions or shortage of staff), which monitoring tool(s) would you use? (please select all that apply)

- ☐ Countermovement jump
- ☐ Drop jump
- ☐ Squat jump
- ☐ Isometric mid-thigh pull
- ☐ Adductor squeeze test
- ☐ Measures of testosterone/cortisol through samples of blood or saliva
- ☐ Measures of creatine kinase through samples of blood or saliva
- ☐ Wellness questionnaire
- ☐ Measures of (lower- and/or upper-body) soreness
- ☐ Sit & reach test
- ☐ Knee to wall test
- ☐ I would not monitor player readiness to train/play
- ☐ Other

Please provide a rationale for your answer: ✱ *Required*

If no restictions were in place (i.e., no time restrictions, financial restrictions or shortage of staff), at which time-points would you monitor player readiness to train/play? (please select all that apply) * *Required*

- ☐ Directly post-match (within 60 minutes)
- ☐ Match-day +1
- ☐ Match-day +2
- ☐ Match-day +3
- ☐ Match-day -3
- ☐ Match-day -2
- ☐ Match-day -1
- ☐ Match-day (pre-match)
- ☐ I would not monitor player readiness to train/play

Please provide a rationale for your answer: * *Required*

Question asked to those who indicated not to be routinely using monitoring tools.

What are the reasons you do not monitor player readiness to train/play? * *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 4 answer(s).

	Not at all important	Not very important	Neither important nor unimportant	Important	Very important
Shortage of personnel to undertake and analyse the results of monitoring	☐	☐	☐	☐	☐
Shortage of time to undertake and analyse the results of monitoring	☐	☐	☐	☐	☐
Priority lies elsewhere (e.g., review of previous match, field-based training, gym-based training, preview of following match)	☐	☐	☐	☐	☐
Results that monitoring provides, would not alter practice (e.g., training load, player selection)	☐	☐	☐	☐	☐

Question asked to those who indicated not to be routinely using monitoring tools.

If no restrictions were in place (i.e., no time restrictions, financial restrictions or shortage of staff), which monitoring tool(s) would you use? (please select all that apply) * *Required*

- [ ] Countermovement jump
- [ ] Drop jump
- [ ] Squat jump
- [ ] Isometric mid-thigh pull
- [ ] Adductor squeeze test
- [ ] Measures of testosterone/cortisol through samples of blood or saliva
- [ ] Measures of creatine kinase through samples of blood or saliva
- [ ] Wellness questionnaire
- [ ] Measures of (lower- and/or upper-body) soreness
- [ ] Sit & reach test
- [ ] Knee to wall test
- [ ] I would not monitor player readiness to train/play
- [ ] Other

Please provide a rationale for your answer: * *Required*

Question asked to those who indicated not to be routinely using monitoring tools.

If no restictions were in place (i.e., no time restrictions, financial restrictions or shortage of staff), at which time-points would you monitor player readiness to train/play? (please select all that apply) * *Required*

- [ ] Directly post-match (within 60 minutes)
- [ ] Match-day +1
- [ ] Match-day +2
- [ ] Match-day +3
- [ ] Match-day -3
- [ ] Match-day -2
- [ ] Match-day -1
- [ ] Match-day (pre-match)
- [ ] I would not monitor player readiness to train/play

Please provide a rationale for your answer: * *Required*

What does your schedule generally look like in the week following a game? Please assume a 7-day turn around (i.e., match-day on Saturday, next match on the following Saturday) ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 6 answer(s).

	Players attend the club (i.e., this may include any venue and is not limited to the club's main training facility)	Players do not attend the club
Match-day +1	☐	☐
Match-day +2	☐	☐
Match-day +3	☐	☐
Match-day -3	☐	☐
Match-day -2	☐	☐
Match-day -1	☐	☐

Are there any specific days throughout the week (e.g., Sunday) on which the players will almost always have a day off, regardless of what day the game is played that week? (unless a game is being played that day) ✱ *Required*

○ Yes
○ No

Please provide details regarding which day and a rationale for your answer: ✱ *Required*

At what time do you usually train on the following days? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 6 answer(s).

	Early morning (6-9 am)	Late morning (9 am-12 pm)	Early afternoon (12-3 pm)	Late afternoon (3-6 pm)	Evening (6-9 pm)	Players don't usually attend the club on this day
Match-Day +1	☐	☐	☐	☐	☐	☐
Match-Day +2	☐	☐	☐	☐	☐	☐
Match-Day +3	☐	☐	☐	☐	☐	☐
Match-day -3	☐	☐	☐	☐	☐	☐
Match-day -2	☐	☐	☐	☐	☐	☐
Match-day -1	☐	☐	☐	☐	☐	☐

Please provide a rationale for your answers: ✱ *Required*

What is your occupation within the organisation? ✱ *Required*

- ○ Technical Coach/Head of Youth
- ○ Strength & Conditioning Coach/Sport Scientist
- ○ Medical Team (i.e., physiotherapist/doctor)
- ○ Other

Question asked to physical practitioner (i.e., strength and conditioning coach/sport scientist) only.

Which type of field-based training would you generally perform during the week following a game? Please assume a 7-day turn-around (i.e., match-day on Saturday, next match on the following Saturday) (please select all that apply). ✱ *Required*

Please don't select more than 4 answer(s) per row.

Please select at least 6 answer(s).

	On-feet conditioning	Conditioning games	Speed training	Change of direction/agility training	There is no S&C/sport scientist-led field-based training on this day	Players don't usually train on this day
Match-Day +1	☐	☐	☐	☐	☐	☐
Match-Day +2	☐	☐	☐	☐	☐	☐
Match-Day +3	☐	☐	☐	☐	☐	☐
Match-day -3	☐	☐	☐	☐	☐	☐
Match-day -2	☐	☐	☐	☐	☐	☐
Match-day -1	☐	☐	☐	☐	☐	☐

Please provide a rationale for your answer: ✱ *Required*

Question asked to physical practitioner (i.e., strength and conditioning coach/sport scientist) only.

Which type of gym-based training would you generally perform in the week following a game? Please assume a 7-day turn-around (i.e., match-day on Saturday, next match on the following Saturday). ✱ *Required*

Please don't select more than 5 answer(s) per row.

Please select at least 6 answer(s).

	Lower-body resistance training	Upper-body resistance training	Full-body resistance training	Plyometric training	Off-feet conditioning (i.e., bike or rower)	Players don't usually participate in gym-based training on this day
Match-Day +1	☐	☐	☐	☐	☐	☐
Match-Day +2	☐	☐	☐	☐	☐	☐
Match-Day +3	☐	☐	☐	☐	☐	☐
Match-day -3	☐	☐	☐	☐	☐	☐
Match-day -2	☐	☐	☐	☐	☐	☐
Match-day -1	☐	☐	☐	☐	☐	☐

Please provide a rationale for your answers: ✱ *Required*

Question asked to physical practitioner (i.e., strength and conditioning coach/sport scientist) only.

How important are the following factors when prescribing gym-based training? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 7 answer(s).

	Not at all important	Not very important	Neither important nor unimportant	Important	Very important
Perceived difficulty of upcoming match (i.e., expected quality of opposition)	☐	☐	☐	☐	☐
Perceived importance of upcoming match	☐	☐	☐	☐	☐
Physical cost of previous match	☐	☐	☐	☐	☐
Anticipated physical cost of next match	☐	☐	☐	☐	☐
Athletic needs of individual players	☐	☐	☐	☐	☐
Total weekly micro-cycle training load (acute)	☐	☐	☐	☐	☐
Total meso-cycle training load (chronic)	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

If you selected Other, please specify:

Question asked to physical practitioner (i.e., strength and conditioning coach/sport scientist) only.

How long would training in the gym generally last for on the following days? Please assume a 7-day turn-around (i.e., match-day on the Saturday, next match on the Saturday). ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 6 answer(s).

	<30 min	30-45 min	45-60 min	60-75 min	>75 min	Players don't usually participate in gym-based training on this day
Match-Day +1	☐	☐	☐	☐	☐	☐
Match-Day +2	☐	☐	☐	☐	☐	☐
Match-Day +3	☐	☐	☐	☐	☐	☐
Match-day -3	☐	☐	☐	☐	☐	☐
Match-day -2	☐	☐	☐	☐	☐	☐
Match-day -1	☐	☐	☐	☐	☐	☐

Please provide a rationale for your answers: ✱ *Required*

Question asked to technical practitioner (i.e., technical coach/head of youth) only.

Which type of field-based training would you generally perform during the week following a game? Please assume a 7-day turn-around (i.e., match-day on Saturday, next match on the following Saturday) (please select all that apply). ✱ *Required*

Please don't select more than 6 answer(s) per row.

Please select at least 6 answer(s).

	Defensive skills & tactics	Attacking skills & tactics	Position-specific skills	General skills	Conditioning games / small-sides games	Wrestling/combat	Captains run	Players don't usually train on the field this day
Match-Day +1	☐	☐	☐	☐	☐	☐	☐	☐
Match-Day +2	☐	☐	☐	☐	☐	☐	☐	☐
Match-Day +3	☐	☐	☐	☐	☐	☐	☐	☐
Match-day -3	☐	☐	☐	☐	☐	☐	☐	☐
Match-day -2	☐	☐	☐	☐	☐	☐	☐	☐
Match-day -1	☐	☐	☐	☐	☐	☐	☐	☐

Please provide a rationale for your answer: ✱ *Required*

Question asked to technical practitioner (i.e., technical coach/head of youth) only.

How important are the following factors when prescribing training? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 8 answer(s).

	Not at all important	Not very important	Neither important nor unimportant	Important	Very important
Perceived difficulty of upcoming match (i.e., expected quality of opposition)					
Perceived importance of upcoming match					
Physical cost of previous match					
Anticipated physical cost of next match					
Areas of improvement required by the team					
Areas of improvement required by individual players					
Total weekly micro-cycle training load (acute)					
Total meso-cycle training load (chronic)					
Other					

If you selected Other, please specify:

Question asked to technical practitioner (i.e., technical coach/head of youth) only.

How long would field-based training generally last on the following days? Please assume a 7-day turn-around (i.e., match-day on the Saturday, next match on the following Saturday). * Required

Please don't select more than 1 answer(s) per row.

Please select at least 6 answer(s).

	<30 min	30-45 min	45-60 min	60-75 min	>75 min	Players don't usually train on the field this day
Match-Day +1	☐	☐	☐	☐	☐	☐
Match-Day +2	☐	☐	☐	☐	☐	☐
Match-Day +3	☐	☐	☐	☐	☐	☐
Match-day -3	☐	☐	☐	☐	☐	☐
Match-day -2	☐	☐	☐	☐	☐	☐
Match-day -1	☐	☐	☐	☐	☐	☐

Please provide a rationale for your answers: * Required

Recovery Strategies

How much do you agree with the following statement? "Recovery strategies in academy rugby league are important in order to improve readiness to train and play" * Required

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

How much do you agree with the following statement? "The recovery process of academy rugby league players is prioritised and executed well within my organisation" * Required

- Strongly disagree
- Disagree
- Neither agree nor disagree
- Agree
- Strongly agree

Do you use recovery strategies within your organisation? ✱ *Required*

- ◯ Don't know
- ◯ Never
- ◯ Rarely
- ◯ Sometimes
- ◯ Often
- ◯ All the time

Which specific recovery strategies are being used by you/your team? (select all that apply) ✱ *Required*

- ☐ Cold-water immersion
- ☐ Hot-water immersion
- ☐ Contrast-water therapy
- ☐ Swimming (or recovery taking place in a pool)
- ☐ Compression garments
- ☐ Massage
- ☐ Stretching
- ☐ Foam rolling
- ☐ Gym-based recovery (e.g. cardiovascular exercise)
- ☐ Gym-based recovery (e.g. resistance exercise)
- ☐ Other

How often are the following recovery strategies used throughout the season? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 10 answer(s).

	Never	Rarely	Sometimes	Often	All the time
Cold-water immersion	☐	☐	☐	☐	☐
Hot-water immersion	☐	☐	☐	☐	☐
Contrast-water therapy	☐	☐	☐	☐	☐
Swimming (or recovery taking place in the swimming pool)	☐	☐	☐	☐	☐
Compression garments	☐	☐	☐	☐	☐
Massage	☐	☐	☐	☐	☐
Stretching	☐	☐	☐	☐	☐
Foam rolling	☐	☐	☐	☐	☐
Gym-based recovery (e.g., resistance exercise)	☐	☐	☐	☐	☐
Gym-based recovery (e.g., cardiovascular exercise)	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

If you selected Other, please specify:

On which days are these recovery strategies used? Please assume a 7-day turn-around (i.e., match-day on Saturday, next match on the following Saturday). * *Required*

Please don't select more than 8 answer(s) per row.

Please select at least 10 answer(s).

	Directly post-match (within 60 minutes)	Match-day +1	Match-day +2	Match-day +3	Match-day -3	Match-day -2	Match-day -1	Match-day (pre-match)	Strategy not used
Cold-water immersion	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hot-water immersion	☐	☐	☐	☐	☐	☐	☐	☐	☐
Contrast-water therapy	☐	☐	☐	☐	☐	☐	☐	☐	☐
Swimming (or recovery taking place in the swimming pool)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Compression garments	☐	☐	☐	☐	☐	☐	☐	☐	☐
Massage	☐	☐	☐	☐	☐	☐	☐	☐	☐
Stretching	☐	☐	☐	☐	☐	☐	☐	☐	☐
Foam rolling	☐	☐	☐	☐	☐	☐	☐	☐	☐
Gym-based recovery (e.g., resistance	☐	☐	☐	☐	☐	☐	☐	☐	☐
Gym-based recovery (e.g., cardiovascular exercise)	☐	☐	☐	☐	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐	☐	☐	☐	☐

If you selected Other, please specify:

How important do you consider each of the following factors when you choose a specific recovery strategy? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 4 answer(s).

	Not at all important	Not very important	Neither important nor unimportant	Important	Very important
Availability of facilities/equipment	☐	☐	☐	☐	☐
Time that is required to undertake the recovery strategy	☐	☐	☐	☐	☐
Player preference	☐	☐	☐	☐	☐
The research that is available in support of the specific strategy that is chosen	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

If you selected Other, please specify:

Recovery Strategies

If no restrictions were in place (i.e., no time restrictions, financial restrictions or shortage of staff), would you choose to do anything differently compared to your current practice in relation to recovery strategies? Please provide an answer below. ✱ *Required*

How often do players make use of the following in the early stages of post-match recovery (i.e., within two hours of the match finishing)? * Required

Please don't select more than 1 answer(s) per row.

Please select at least 5 answer(s).

	Never	Rarely	Sometimes	Often	All the time
Shower post-match	☐	☐	☐	☐	☐
Supplementation (e.g., protein shakes or equivalent)	☐	☐	☐	☐	☐
Protein- and carbohydrate-rich meal post-match	☐	☐	☐	☐	☐
Rehydration (e.g., water)	☐	☐	☐	☐	☐
Carbohydrate restoration (e.g., sweets or a carbohydrate drink such as a Lucozade)	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

If you selected Other, please specify:

Question asked to those who indicated not to be routinely implementing recovery strategies.

How important do you consider each of the following factors when you choose not to use any specific recovery strategies? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 5 answer(s).

	Not at all important	Not very important	Neither important nor unimportant	Important	Very important
Lack of personnel to undertake or lead the recovery strategies	☐	☐	☐	☐	☐
Lack of time to undertake the recovery strategies	☐	☐	☐	☐	☐
Lack of understanding of the results that the recovery strategies could provide	☐	☐	☐	☐	☐
Priority lies elsewhere (e.g., review of previous match, field-based training, gym-based training, preview of upcoming match)	☐	☐	☐	☐	☐
Effects of recovery strategies are minimal	☐	☐	☐	☐	☐
Other	☐	☐	☐	☐	☐

If you selected Other, please specify:

Question asked to those who indicated not to be routinely implementing recovery strategies.

If no restrictions were in place (i.e., no time restrictions, financial restrictions or shortage of staff), would you choose to do anything differently compared to your current practice in relation to recovery strategies? Please provide an answer below. ✱ *Required*

Further Research

Do you believe more research should be conducted in relation to fatigue/recovery in academy rugby league? ✱ *Required*

- Yes
- No

If no, why do you believe that fatigue/recovery in academy rugby league should not be researched further? Please insert N/A if answered 'yes' in the question above. ✱ *Required*

How important do you consider future research into each of the following areas? ✱ *Required*

Please don't select more than 1 answer(s) per row.

Please select at least 5 answer(s).

	Not at all important	Not very important	Neither important nor unimportant	Important	Very important
Monitoring tools					
Recovery strategies					
The effect of field-based training on player 'fatigue'					
The effect of gym-based training on player 'fatigue'					
The effect of match-play on player 'fatigue'					
Other					

If you selected Other, please specify:

8.3 Appendix 3: Confirmation of ethical approval (chapter four data collection)

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Dr Mark Russell
Chair of SSHS Ethics Committee
Tel: 0113 283 7100 ext 649
E-mail: m.russell@leedstrinity.ac.uk

Date: 15th March 2018

Dear Hendrickus,

Re: SSHS/2017/080 - The test-retest reliability of various measures of fatigue in elite adolescent rugby league players

Thank you for your recent application for ethical approval for the above named project.

After reviewing the application it has been resolved that the research project is granted ethical approval.

I wish you well in your study,

Yours sincerely

M. Russell

Dr Mark Russell
Chair of School of Social and Health Sciences Ethics Committee

8.4 Appendix 4: Confirmation of ethical approval (chapter five data collection)

Leeds Trinity University

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Dr Martin Barwood
Vice Chair of SSHS Ethics Committee
Tel: 0113 283 7100 ext 249
E-mail: m.barwood@leedstrinity.ac.uk

Date: 9th September 2019

Dear Hendrickus

Re: SSHS/2019/017 - The effect of a variety of recovery strategies following training in elite adolescent rugby league players

Thank you for your recent application for ethical approval for the above named project.

After reviewing the application it has been resolved that the research project is granted ethical approval.

I wish you well in your study,

Yours sincerely

Dr Martin Barwood
Vice Chair of School of Social and Health Sciences Ethics Committee