Australian Soccer in Asia; the effects of Asian Champions League on Load, Recovery and Injury.

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Certificate of authorship and originality of thesis

I, Kieran Howle declare that this thesis, is submitted in the fulfillment of the requirements for the award of Doctor of Philosophy, in the Faculty of Health at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference of acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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I would like to dedicate this thesis to my late Granddad, Nan and Pa. I hope I have made you proud.

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Publications resulting from this thesis

Howle K, Waterson A, Duffield R. Injury incidence and workloads during congested schedules in football. *International Journal of Sports Medicine.* 2019;40(1)1-7.

Howle K, Waterson A, Duffield R. Recovery profiles following single and multiple matches per week in professional football. *European Journal of Sport Science.* 2019;19(10)1-9.

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Abbreviations, Symbols and Subunits

ACL	Asian Champions League
ACWR	Acute chronic workload ratio
AKE	Active knee extension
AU	Arbitrary units
BPM	Beats per minute
CD	Central defender
CF	Center forward
CK	Creatine kinase
CM	Central midfield
Cm	Centimetre
CMJ	Counter movement jump
CRP	C-reactive protein
CV	Coefficient of variation
DOMS	Delayed onset muscle soreness
EMG	Electromyographic
EPL	English Premier League
ES	Effect size
EWMA	Exponentially weighted moving average
FB	Fullback
FIFA	Football Internationale de Federation Association
FOR	Functional overreaching
GOT	Glutamic oxaloacetic transaminase
GPS	Globalised positioning systems
H	Hours
HAST	Hip adduction squeeze test
HIR	High intensity running
HPBPT	High percentage ball possession team
HR	Heart rate
IMU	Inertial measurement units
IL-6	Interleukin 6
IRR	Injury risk ratio
KTW	Knee to wall
LDH	Lactate dehydrogenase
LIR	Low intensity running
LPBPT	Low percentage ball possession team
MHC	Myosin heavy-chain
MM	Multi-match
MU	Motor unit
MVC	Maximal voluntary contraction
M/min	Meters per minute
NFOR	Non-functional overreaching
OR	Odds ratio
OTS	Overtraining syndrome
PM	Purposeful movement
ROM	Range of movement
SD	Standard deviation
SM	Single match
SR	Sarcoplasmic reticulum

sRPE	Session rating of perceived exertion
SSC	Stretch shortening cycle
S-IgA	Salivary IgA
THIR	Total high intensity running
TMA	Time motion analysis
TNF	Tumour necrosis factor
TQR	Total quality recovery
TRIMP	Training impulse
UEFA	Union of European Football Associations
VHIR	Very high intensity running
VO_2	Oxygen consumption
$VO_{2\ max}$	Maximal oxygen consumption
VS	Versus
WF	Wide forward
YYIRT	Yo-yo intermittent recovery test level 1
s	Seconds
m	Meter
m/s	Meters per second
$\text{mL:kg}_{-1}\text{:min}_{-1}$	Millilitre of oxygen per kilogram of body mass per minute
km.h	Kilometres per hour
>	Greater than
<	Less than
±	Plus or minus
=	Equal
~	Approximately
%	Percentage
%MaxHR	Percentage of maximal heart rate

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Abstract

This thesis examines the effect of congested schedules on injury, training load distribution and recovery in Australian football (soccer) as a consequence of competing in the Asian Champions League (ACL). To achieve this, data were collected across 3 seasons between 2012-2015 from one club playing in concurrent competitions of the A-League and ACL. Acute and prolonged competition periods of congested scheduling were identified, along with seasons with and without congested schedules. For study 1, acute (by week) and prolonged (by season) periods of congestion were investigated independently to establish the effects on injury and training load during multi-match (MM) or single-match (SM) weeks. In study 2, a prolonged 36-day period of 11 matches was identified and compared with a matched non-congested period that maintained 'normal' 1 match/week microcycles. Respective periods were then compared to establish the effect of longer periods of congestion on training loads, recovery profiles and injury risk. For study 3, recovery profiles were compared between SM and MM weeks using subjective wellness and selected outcome measures including; hip adduction squeeze test (HAST), active knee extension (AKE), knee to wall (KTW) and sit and reach.

Key findings from these studies were:

Study 1 - Injury incidence and workloads during congested schedules in football.

- Increased total, match and training injury rates existed in acute congested (MM) periods.
- Total, match and training injuries are increased in seasons with greater volume of fixture congestion.

- No differences existed in session rating of perceived exertion (sRPE) total load between MM and SM, despite significant reduction in sRPE training load in MM weeks.
- Total injury rates are increased in seasons with greater match scheduling despite significantly reduced sRPE total and training load.

Study 2 - Prolonged periods of fixture congestion in Australian soccer; effects on training load distribution, recovery and injury.

- Total load (match + training) during prolonged congested was reduced when compared to the non-congested period.
- sRPE Acute to Chronic Workload Ratio's (ACWR) do not differ between congested and non-congested periods, despite reduced internal and external training loads during the congested period.
- Perceived wellness was reduced at 48h post and 24h pre (72h post) match in a prolonged congested period.
- Increased total, match and training injury rates are evident during prolonged congested periods.

Study 3 - Recovery profiles following single and multiple matches per week in professional football.

- Perceived wellness and total quality recovery were reduced at 48h post MM match 2, when compared to SM and Baseline.
- Measures of wellness returned to Baseline at 72h post-match 1 in SM playing group indicating a 72h recovery period during SM weeks.

- The hip adduction squeeze test measures at 48h post MM match 2 were reduced when compared to SM match and MM match 1.

Collectively, these findings show that both acute and prolonged congested schedules have a negative impact on injury rates for this Australian team competing in A-League and ACL competitions. Of interest, despite similar sRPE total loads (match + training) between SM and MM weeks, increased injury rates existed in acute congested periods. In prolonged periods, the ACWR was also not significantly different between periods, indicating that internal sRPE total load distribution was not sensitive to differences between periods. Further, despite significantly decreased sRPE total and training load, injury rates were increased for total, match and training. Accordingly, increased match exposures within acute and prolonged congested schedules may help to explain the increased match injuries reported; however, the reason for higher training injuries in both acute and prolonged periods is less clear. When considering MM weeks, slower recovery was reported when compared to SM, suggesting that players take longer to recover during acute congested schedules. Therefore, practitioners should consider these findings when planning periodisation of training, recovery and squad rotation during congested schedules.

Chapter 1

Introduction

1.1 Introduction and Overview

In 2006, the move of Football Federation Australia into the Asian Confederation (from Oceania Confederation) resulted in the best two A-League clubs (domestic competition) being involved in the yearly Asian Champions League (ACL) competition. In turn, this additional competition (of arguably a higher standard) often played at the end of the A-League season has had considerable effect on domestic Australian clubs. The prestige of being associated with the ACL, combined with increased potential financial outcomes via exposure to Asian advertising markets and earnings from winnings has resulted in clubs placing a growing importance on the competition. However, qualifying and participating in an additional competition creates greater demand on players and club resources, which unlike European football, is relatively recent in Australia (50, 52). Congested scheduling of matches, resulting from periods where teams compete in concurrent competitions, is perhaps the most significant consequence of the ACL on the domestic competition. Balancing the increased match play and training demands of ACL-induced congested schedules is important for Australian teams; which, is further compounded by greater travel demands specific to the Asian region. Given such circumstances, there is presently no research on the effects of congested schedules resultant from the ACL.

Although several definitions exist, periods of congestion refer to matches typically played in discreet time periods, whereby the time between matches is reduced i.e. <4 days (32). These situations are termed multi-match (MM) weeks, and contrast with traditional scheduling methods of a single match per weekly microcycle (17, 36). During congested schedules, increased match exposure may result in a greater risk of injury, partly due to a higher frequency of matches and also reduced recovery times

(55, 58). To date, the only research on the demands associated with competing in congested schedules is European-centric, focusing on injury risk and match performance (17, 31, 36). Given the specific context of Australian teams competing in the Asian region, there remains a dearth of evidence as to whether findings from Europe are transferable to the ACL and A-League competitions. Regardless of region, there is limited research available on congested schedules and training load distribution or recovery alongside injury and performance outcomes (17, 31, 55), with no evidence specific to Australian teams.

To date, the majority of research investigating the effect of acute congested periods on injury conclude that total injury rates are increased when <4 days separate matches when compared to >6 days (58). Increased total injury rates are predominately a consequence of higher match related injuries sustained when consecutive matches have <4 days of recovery; however, whether injuries result from increased external match load, or simply due to exposure, remains to be established (16, 58). Further, some inconsistencies exist in findings on injury rates in acute congested scheduling, particularly between studies reporting single teams compared to multi-club/seasons (17, 31). For example, investigations examining multiple clubs within individual leagues have reported that total (17) and match (36) injury rates remain unchanged when <3 vs. >4 days of recovery separate matches. Missing from these findings is knowledge of training injuries or training loads, making conclusions and practical applications difficult. Due to the mixed results highlighted, a greater understanding of injury during acute congested schedules is needed, particularly in Australian contexts where no research exists. Further, the training loads that players are exposed to within these periods would create context when considering injury data, which is also yet to be reported. Accordingly, injury and training load distribution during acute congested schedules remain to be reported in Australian football (soccer), and therefore should be considered.

Prolonged congestion refers to periods where successive matches are played with short (~ 4 days) recovery times, which generally extend for multiple days or weeks i.e. 20-30 days (31). Research investigating the effect of prolonged periods is scarce, with only 3 studies emanating from European football (16, 31, 55). When considering injury rates, no clear findings have been reported from the aforementioned research regarding match or training injuries sustained during prolonged congested periods (16, 31, 55). Despite total injuries remaining unchanged, discrepancies exist in regard to reported match injuries with variability between studies (16, 31, 55). The inconsistent effect of congestion on injury rates is most likely a result of rotation policies employed by respective clubs, which consequently reduces the impact of fixture congestion (33, 55). As a result of increased player rotation, match and training injuries are seemingly reduced (via decreased match exposure) in studies with unchanged total injury rates (31, 55). The extent that players are actually exposed to prolonged periods of congestion in Europe appears low-to-moderate, which may also be a reason for limited investigations on this topic (33). However, when considering prolonged periods in Australian football, a lack of squad depth when compared to Europe may theoretically result in greater exposure, as salary caps in Australian football result in teams having less squad depth. Consequently, given the absence of evidence, further research is required to understand the effects of prolonged congested schedule for teams in the ACL.

When considering recovery, research during congested schedules is scarce, with only 3 studies reporting recovery profiles during MM weeks (126, 144, 159). Mixed findings have been reported between previous studies, which are most likely a result of the methodologies used. In European football, wellness profiles were reduced, and blood markers of muscle damage increased following the second match within a week when compared to the first, third and baseline (144). Further, repeat sprint ability and measures of flexibility were also reduced post-match 2 when only 3-days of recovery existed following match 1 (144). In contrast, research reporting physical performance and blood markers of muscle damage showed trivial or unclear findings when comparing the recovery profile following each match in a 3 match week (126). These studies only investigated recovery during a single congested week; therefore, the effect of repeated exposure to MM weeks on recovery is yet to be established. Given that MM weeks occur frequently within a schedule, understanding whether recovery profiles are altered following the second match within a week when compared to the first will help practitioners manage player loads during acute periods of fixture congestion. The mixed findings reported within European football may also be a consequence of acute congested periods occurring in isolation, meaning that players are able to recover between MM weeks (34). However, MM weeks that are extended for prolonged periods present a unique challenge, which remains to be explored (31).

To date, recovery during prolonged congested scheduling has been inferred via match running profiles; however, no research has focused on direct measures of recovery throughout these periods (31). Consequently, a better understanding of recovery profiles surrounding successive matches may help coaches with managing player loads throughout these periods. Given the importance of training loads, and previous suggestions of a load-injury relationship within football, another limitation of existing literature is a lack of reporting training load distribution throughout prolonged periods (31). Due to the extended time periods that prolonged congestion occurs, a more detailed report of recovery profiles following matches and training loads throughout these acute and prolonged periods is needed. An increased understanding of load, recovery and injury may help practitioners with load prescription during times of increased scheduling for teams competing in the ACL, thereby reducing injury risk and aiding performance

1.2 Thesis Aims

Given that congested schedules are common within professional football, and no previous research exists on how acute and prolonged periods affect injury, load and recovery for Australian teams, this thesis aims to:

1. Compare injury rates/risk and training load distribution between acute MM and SM weeks, and between seasons with and without periods of fixture congestion (study 1).
2. Compare training load distribution, recovery and injury rates during a 36-day prolonged period of congestion versus a matched period of time with traditional match scheduling (study 2).
3. Compare recovery profiles following matches played in SM and MM weeks (study 3).

1.3 Justification of Thesis

Congested scheduling of matches is an area that has received increased research attention, specifically focusing on injury and performance throughout these periods (17, 31, 55). However, mixed findings, based on differing methodological approaches (single team vs grouped) and lack of explicit context (training load) makes interpretation of the effect of congested schedules difficult. Further, due to rotation policies used within the teams investigated, previous research has suggested the negative consequences of congested schedules may be mitigated. To date, the small body of research investigating congested schedules is from European teams, which includes research on both acute and prolonged periods (31, 55, 58). Given this body of literature, and the mixed findings reported, further research can provide greater insights. Moreover, currently no research exists which investigates injury, load or recovery during congested periods in Australian football in the context of the ACL. The demands associated with Australian football i.e. squad depth and travel, perhaps create even more challenges for teams competing in congested schedules and should be investigated.

1.4 Limitations

Several limitations are present in this course of studies, including:

- Within each of the studies data was collected from 1 professional club, meaning that the findings may not be relevant to other teams. The coaching style and team strategies would have highly influenced the extent of player rotation in both acute and prolonged congested periods, which would have had significant effect on the results reported. Further, coaching staff for the team designed periodisation and weekly microcycles, which might also be specific to the team investigated (although this team had a novel and iconic ACL experience).

- Within study 1 and 2, restrictions from the Football Internationale de Federation Association (FIFA) meant that GPS technology within matches was banned. As a result, the external load distribution reported within study 1 and 2 for SM, MM weeks, between seasons with and without congested scheduling and for prolonged congested vs. non-congested periods is limited to GPS data collected in training.
- The data collection for the current thesis occurred in a team environment at an elite level, accordingly certain difficulties exist. The collection of travel and sleep data would have provided further evidence for the reduced recovery experienced by players during prolonged periods, however given the nature of the study this was logistically difficult.
- The playing group that participated over the three seasons was not stable and included 8 players completing all three seasons, 7 completed two consecutive seasons (2013-15), while 13 only competed in 1 season (2012-13).
- The low number of injuries that occurred throughout the prolonged congested period in study 2 reduces the statistical significance of some results.
- The staff throughout the period of investigation remained the same except for the club Physiotherapist, which changed between season 1 and 2.

1.5 Delimitations

Several known delimitations are present in the subsequent studies, including;

- Given that an elite population was used within each investigation, there is a possibility that players may have provided inaccurate subjective measures as a means to be included for selection. Despite players having familiarisation with all measures, the nature of testing may have resulted in inflated wellness scores or potentially reduced effort on physical recovery measures.
- All injury classifications were determined by trained physiotherapists and medical staff, and all performance data was collected by well trained staff adhering to strict governing body guidelines to ensure consistency across all measures collected.

Chapter 2

Literature Review

2.1 Overview

The demands of professional football (soccer) are well reported, with significant research focusing on the physical and tactical demands of the sport (11, 24, 61, 165). The intermittent running and tactical demands of football place considerable load on players competing in normal weekly microcycles (24). In turn, these training and competition loads require appropriate provision of recovery. This balance becomes conflicted when players are required to compete in concurrent competitions, be they domestic, continental and/or national team matches (36), requiring multiple matches within a week or extended periods with increased match exposure (31). These periods are termed congested scheduling, and represent increased match exposure, where <4 days of recovery between matches are present (34). As a consequence, increased match exposure and reduced recovery exists, which are thought to be precursors to injury and sub-optimal performance (55, 58).

Given the concerns around congested scheduling demands, a growing body of research exists investigating the effects of acute multi-match (MM) weeks and extended periods of congestion on performance and injury (31, 55). That said, the majority of current research focuses on European leagues where congested scheduling is a longstanding issue (36, 58). In 2006, Football Federation Australia moved into the Asian Confederation (from Oceania Confederation) resulting in the best two A-League clubs being involved in the yearly Asian Champions League (ACL) competition. In turn, this additional competition, often played at the end of the A-League season, has had considerable effect on domestic Australian clubs. For example, congested scheduling of matches, increased travel, extra match loads and the need for recovery balanced against training in an already tight schedule are all consequences of competing in the

ACL. Whilst considerable research on the effect of congested schedules is present within Europe, no such research exists on these demands relating to Australian football. Consequently, this review will first briefly examine literature on the physical and technical demands of football to then understand the increased demands from congested schedules. Once established, the effect of the aforementioned congested scheduling demands on 1) injury, 2) training load and 3) recovery within normal and congested scheduling will be explored. These topics will give rationale for the direction of research undertaken within this thesis.

2.2 Literature Search Methodology

All studies used within the current thesis were chosen following an extensive computer-aided search of the university online databases. Specifically, Health Source, MEDLINE Complete and SPORTSDiscus were utilised from February 2014 until April 2019. The search criteria were restricted to publications focusing on professional football, although if limited research was present, sub-elite studies in football or research from other professional sports was included. Titles were searched using the following operations; (‘football’ OR ‘soccer’) AND (‘injuries’ OR ‘injury’) AND (‘congested’ OR ‘schedule’ OR ‘fixture) AND (‘demands’ OR ‘physical’ OR ‘technical’ OR ‘match’ OR ‘training’ OR ‘wellbeing’ OR ‘subjective’ OR ‘ACWR’ OR ‘load’). Articles were assessed by title, abstract and finally full text to determine their suitability.

The exclusion criteria included:

- Full text not available
- If research existed on professional athletes prior to inclusion of studies on sub-elite teams
- Not available in English
- Articles before 1980
- Non peer reviewed articles
- Articles not related to sport

The PRISMA flow diagram (Figure 2.1) outlines the procedure for selection of appropriate material for inclusion within the review process.

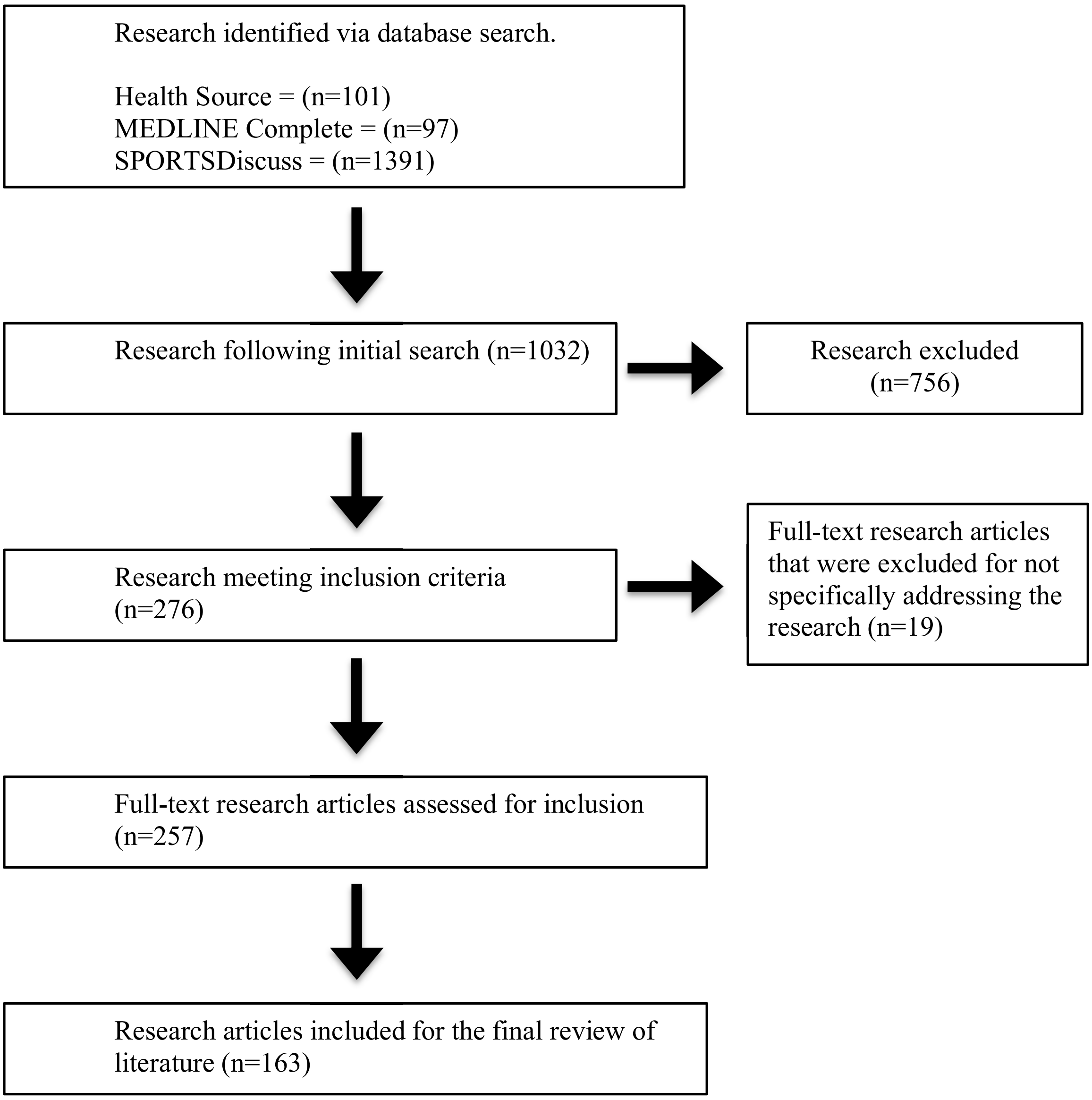


Figure 2.1: PRISMA flow diagram

2.3. Demands of Professional Football and Effects of Congested Schedule

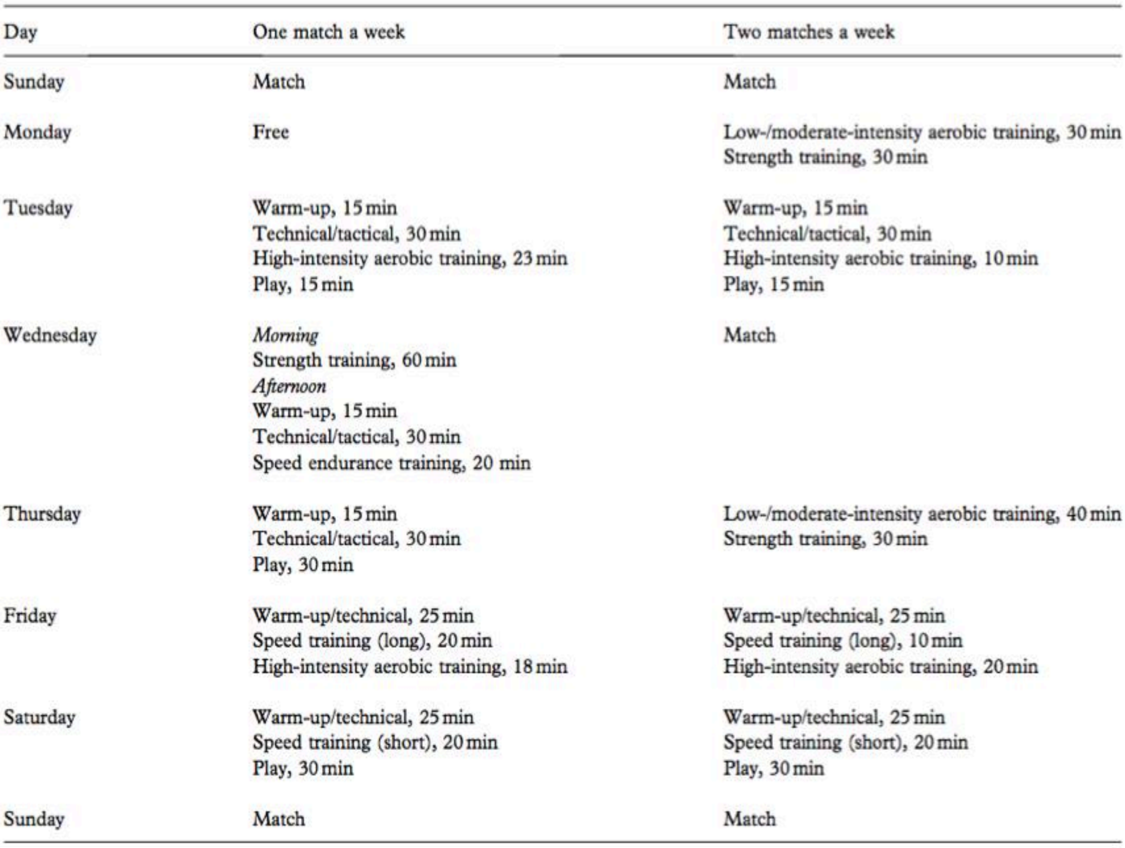
In modern football, the collective demands of playing in professional competitions vary significantly for individual teams. Within this section of the review, the primary focus will be to establish the demands of football competitions as based on the predominance of evidence from European contexts, while making comparison to the domestic Australian league where possible. Specifically, playing schedules, internal and external physical match demands and technical/tactical requirements will be discussed during ‘normal’ scheduling of competitions. Once established, during each section the aforementioned demands will also be discussed in the context of congested schedules.

2.3.1. Playing Schedule and Effects of Congested Schedules

Modern professional players are exposed to significant match exposures with a continually growing number of competitions and matches (36, 126). For various competitions within Europe, a typical season usually begins in mid-August and runs until mid or late-May, with teams competing in 38 ± 8 matches during their respective domestic competitions (24). In contrast, the Australian domestic professional competition starts in mid-October, running until late-April, consisting of 27 matches. Like Europe, typical in-season mirocycles consist of one match per week, with a week usually defined as Monday-Sunday (130). In Europe, teams are often required to compete in multiple competitions resulting in a significantly increased number of matches. For example, teams competing in the English Premier League (EPL) can play between 50-70 matches across a season, resulting from domestic, FA Cup, Europa and Champions League competitions (126). Recently, research has reported that the mean number of matches for teams competing in all formats of Union of European Football Associations (UEFA) competitions is 61.5 ± 3.4 (33). For the A-League, moving into the ACL competition has also increased the number of matches teams are required to complete. Similar to European football, the increased number of matches will depend on how successful the team is within Champions League competitions. As a minimum, teams competing in the ACL will have a total of 42 matches across the season instead of 27. Although the potential number of matches for Australian teams is lower than European clubs, the season is two months shorter, meaning that frequent periods of fixture congestions are still possible.

These increased match demands result in both ‘acute’ and ‘prolonged’ periods of fixture congestion, whereby players are required to play successive games separated by ≈3 days. Over 4 seasons of professional French football, the longest time interval between consecutive matches was 127.4 ± 9.1 and 111.0 ± 7.7h (33). Conversely, the shortest time intervals observed between matches were 119.0 ± 63.2 and 103.1 ± 36.8h (33). ‘Acute’ congested periods often refer to discreet congested matches i.e. microcycles with two consecutive matches within 72h, whereas ‘prolonged’ periods generally last 4-5 weeks with multiple matches played with 3-4 days of separation. Collectively, the demands of increased scheduling places considerable pressure on teams and players needing time to recover between matches. Within ‘normal’ one match weeks, teams generally have 5 on field training sessions (Table 2.1), which primarily focus on recovery at the start of each week (11). In contrast, during MM weeks teams average 3-4 training sessions per week, needing to incorporate recovery and preparation for the ensuring match (5, 55). As a result of these differing microcycles, player rotation strategies are often employed by teams to allow certain players with high loads to be rested between matches while the remaining squad prepares for the next match (58).

Table 2.1: An example of an in-season weekly schedule for a European team when playing one or two matches per week.



Day	One match a week	Two matches a week
Sunday	Match	Match
Monday	Free	Low-/moderate-intensity aerobic training, 30 min Strength training, 30 min
Tuesday	Warm-up, 15 min Technical/tactical, 30 min High-intensity aerobic training, 23 min Play, 15 min	Warm-up, 15 min Technical/tactical, 30 min High-intensity aerobic training, 10 min Play, 15 min
Wednesday	*Morning* Strength training, 60 min *Afternoon* Warm-up, 15 min Technical/tactical, 30 min Speed endurance training, 20 min	Match
Thursday	Warm-up, 15 min Technical/tactical, 30 min Play, 30 min	Low-/moderate-intensity aerobic training, 40 min Strength training, 30 min
Friday	Warm-up/technical, 25 min Speed training (long), 20 min High-intensity aerobic training, 18 min	Warm-up/technical, 25 min Speed training (long), 10 min High-intensity aerobic training, 20 min
Saturday	Warm-up/technical, 25 min Speed training (short), 20 min Play, 30 min	Warm-up/technical, 25 min Speed training (short), 20 min Play, 30 min
Sunday	Match	Match

(11)

Squad sizes for European teams can range from 35-42 players, for instance, in the EPL teams are allowed 25 ‘home grown’ and up to 17 international players. Increased squad sizes allow for greater player rotation, with previous research showing that despite >85% squad availability to play in successive matches only 50% of players complete >75 minutes of match time in MM weeks (33). In contrast, the maximum squad size for an A-League team is 26 with a salary cap of ~$3 million that restricts the practical likelihood of rotation strategies. Salary caps are another unique demand of the A-League competition, which potentially impinges on playing depth in squads when compared to European leagues. Currently, there is no information on the extent of player rotation in the A-League competition, and hence the exposure of players to these demands remains unknown. Regardless, the salary-induced restrictions in Australian football create further complexities when rotating players, and therefore allowing appropriate recovery from the physical demands of the sport, particularly during times of increased match scheduling.

2.3.2. Physical Demands of Football and Effects of Congested Schedules

The physical activity profile of players during match play is often referred to as ‘external load’, which describes various match-based movements i.e. running, accelerating and decelerating (11). Camera based technology is commonly used within European competitions to quantify external load, though due to expensive installations these systems are not widespread in other parts of the world (38, 203). Although camera technology does allow analysis of different aspects within matches, for example different tactical team styles, quantification of external load is limited to running demands (38). As a result, the most common method of measuring external load in both matches and training is globalised positioning systems (GPS), which allow practitioners to analyse both running demands and micro-movements within football (25, 101).

2.3.2.1 External Match loads from Single Matches

The external loads within football match are well established, with current literature noting the intermittent aerobic-based running demands in elite-level football (23, 130, 165). A summary of research investigating running demands in shown in Table 2.2, though the majority conclude that distance covered by players is largely dependent on position, ranging from ~10-12km depending on match circumstances (25). Distance within matches is often reported within 5 discrete speed zones including; low intensity movement (<7km/h), jogging (14.4km/h – 19.8km/h), high-running (14.4 – 19.8km/h), very high-intensity running (19.8 - 25.5km/h) and sprinting (>25.2km/h). The variation of distance within these zones, particularly high-speed running (14.4 – 19.8km/h) is often the focus of investigations on match demands within football (25). An investigation of high-intensity running (HIR) demands for positional groups within the EPL reported wide midfielders as covering the most distance (3138 ± 565m) when compared to central midfielders (2825 ± 473m, p=0.04), full-backs (2605 ± 387m, p<0.01), attackers (234 ± 575m, p<0.01), and central defenders (1834 ± 256m, p<0.01) (25). In agreement, match demands reported for Italian professional football players recorded midfielders with the highest HIR (3051 ± 445m), when compared to centre backs (1885 ± 467m), fullbacks (2892 ± 488m), and forwards (2259 ± 363m) (165). More recently, HIR profiles were expanded upon by quantifying the number of high-speed acceleration and decelerations (>3 m/s) performed by positional groups in the EPL (188).

Table 2.2: Summary of research investigating the physical demands of professional football matches.

First Author	Title	Year	Physical Performance Variables Investigated	Method of Data Collection	Subjects	League	Results	Conclusions
Mohr et al. (145)	Match performance of high-standard soccer players with special reference to development of fatigue	2003	Standing (0km/h) Walking (0-6km/h) Jogging (6-8km/h) Low Speed (8-12km/h) Moderate speed (12-15km/h) High Speed (15-18km/h). Sprinting (>18km/h)	Computerised coding of the activity pattern	n=18, 2 consecutive seasons.	Italian Serie A	Mean duration (s) Standing = 7.0+0.4 Walking = 6.4+0.3 Jogging = 3.0+0.1 Low-speed= 2.6+0.0 Moderate-speed = 2.2+0.0 High-speed = 2.1+0.0 Sprinting = 2.0+0.0	Midfield players and full-backs covered a greater (P<0.05) distance than attackers and defenders.
Bloomfield et al. (19)	Physical demands of different positions in FA premier league soccer.	2007	Percentage of time spent traveling purposefully in different directions: Directly Forward Directly Backwards Lateral Left Lateral Right Fwd Diagonal Left Fwd Diagonal Right None.	Multi-Camera System (PlayerCam).	n=55	English Premier League	Directly Forward = 48.7±9.2% Directly Backwards = 7.0±3.7% Lateral Left = 4.5±2.5% Lateral Right = 3.9±2.3% Fwd Diagonal Left = 4.6±1.9% Fwd Diagonal Right = 5.0±2.6% None = 20.6±6.8%	Position had a significant influence on the percentage of time completing different 'purposeful' movements. However, position did not influence the intensity of purposeful movements.
Rampinini et al. (164)	Variation in Top Level Soccer Match Performance.	2007	Total Distance High Intensity Running (HIR) (14.4-19.8km/h) Very High Intensity Running (VHIR) (>19.8km/h).	Multi-Camera System (ProZone).	n=20 n=34 (matches).	European National League	**Fullbacks** Total Distance = 11233±664 HIR = 2892±488 VHIR = 997±221 **Midfielders** Total Distance = 11748±612 HIR = 3051±445 VHIR = 904±223 **Forwards** Total Distance = 10233±677 HIR = 2259±363 VHIR = 778±167	Total distance (r = 0.62, p < 0.05), High intensity running (r=0.51, p<0.05), and Very high intensity running (r=0.65, p<0.05) for the team investigated was influenced by the activity profile of the opposition teams. Total distance and High intensity running was also higher against better opponents when compared worse teams (p < 0.05)
Bradley et al. (25)	High-intensity running in English FA Premier League soccer matches	2009	Standing (0–0.6 km/h) Walking (0.7-7.1km/h) Jogging (7.2–14.3 km/h) Running (14.4-19.7km/h) High-speed (19.8-25.1 km/h) Sprinting (>25.1 km/h).	Multi-Camera System (ProZone).	n=370, n=28 (matches).	English Premier League	**Wide Midfielders** Total Distance = 11535±933m Running = 3138±565m High-speed = 1214±251m Sprinting = 346±115m **Central Midfielders**	Wide midfielders (3138 m ± 565) covered a greater distance in high-intensity running than central midfielders (2825±473m, P=0.04), full-backs (2605±387m, P<0.01), attackers (2341±575m,

							Total Distance = 11450±608m Running = 2825±473m High-speed = 927±245m Sprinting = 204±89m **Central Defenders** Total Distance = 9885±555m Running = 1834±256m High-speed = 603±132m Sprinting = 152±50m	P<0.01), and central defenders (1834±256m, P<0.01).
Vigne et al. (198)	Activity Profile in Elite Italian Soccer Team	2010	Total Distance, Distance Per Minute, Walking Distance (<5 km/h), Jogging Distance (5-13 km/h), Distance below Anaerobic Threshold (13-16 km/h), Distance above Anaerobic Threshold (16-19 km/h) and Sprint Distance (>19 km/h).	SICS Multi-Camera Match Analysis System.	n=25, n=293 (matches).	Italian Serie A	**Defenders** Total Distance = 9698±2901m <5km/h = 3791±1171m 5-13km/h = 2914±945m 13-16km/h = 1299±422m 16-19km/h = 791±286m 19km/h = 902±406m **Midfielders** Total Distance = 8943±3992m <5km/h = 3226±1481m 5-13km/h = 2712±1276m 13-16km/h = 1301±594m 16-19km/h = 827±376m 19km/h = 875±438m **Forwards** Total Distance = 7733±3650m <5km/h = 3409±1674m 5-13km/h = 2066±1071m 13-16km/h = 848±417m 16-19km/h = 562±278m 19km/h = 846±454m	The main results show that midfielders cover significantly more distance than players in other positions (p < 0.001).
Di Masico et al. (56)	Evaluation of the Most Intense High Intensity Running Period in English FA Premier League Soccer Matches	2013	Percentage of time spent in movement categories: Standing (0–0.6km/h). Walking (0.7– 7.1km/h). Jogging (7.2–14.3km/h). Running (14.4– 19.7km/h). High-speed (19.8–25.1km/h). Sprinting (>25.2km/h).	Multi-Camera System (ProZone).	n=100, n=20 (matches).	English Premier League	Standing = 5.7±2.3% Walking = 58.8±4.7% Jogging = 26.2±3.6% Running = 6.6±1.6% High Speed = 2.1±0.6% Sprinting = 0.6±0.3%	High-intensity running, work: rest ratios, and average high-intensity distances change markedly during the most intense period of matches and are highly dependent on positional role.

Bradley et al. (24)	Match performance and physical capacity of players in the top three competitive standards of English professional soccer.	2013	Walking (<7.1km/h) Jogging (7.2-14.3km/h) Running (14.4-19.7km/h) High-speed running (19.8-25.1km/h) Sprinting (>25.2km/h).	Multi-Camera System (ProZone).	n=190, n=947 (matches).	English Premier League	**Fullback** Walking = 3783±217 Jogging = 4181±417 Running = 1750±265 High-speed running = 727±176 Sprinting = 288±109 **Central Defender** Walking = 3910±216 Jogging = 3983±410 Running = 1311±225 High-speed running = 459±110 Sprinting = 153±64 **Wide Midfielder** Walking = 3680±301 Jogging = 4651±604 Running = 2067±393 High-speed running = 883±170 Sprinting = 331±114 **Central Midfielder** Walking = 3678±301 Jogging = 4783±492 Running = 2031±323 High-speed running = 736±187 Sprinting = 217±93 **Attackers** Walking = 3824±280 Jogging = 4259±648 Running = 1711±428 High-speed running = 681±215 Sprinting = 248±119	Players also covered more (p < .05) high-intensity running when moving down (n = 20) from the Premier League to the Championship (ES: 0.4) but not when players moved up (n = 18) standards (ES: 0.2).
Scott et al. (175)	The Physical Demands of Professional Soccer Players During In-Season Field Based Training and Match-Play.	2014	Standing (<0.07 km/h) Walking (0.7-7.2 km/h) Jogging (7.2-14.4 km/h) Running (14.4-19.8 km/h) High-speed (19.8-25.2 km/h) Sprinting (>25.2 km/h).	Global Positioning System (GPS).	n=27	A-League	**Percentage of Total Distance** Standing = 0.1±0.1 Walking = 41.7±9.1 Jogging = 36.5±5.6 Running = 13.9±4.6 High-speed = 5.5±2.4 Sprinting = 1.6±1.1 **Percentage of Total Duration** Standing = 2.7±2.7	Results indicated that when compared with matches, players spent significantly more time performing low-speed activities, and less time performing high- speed running, during training (p < 0.001).

							Walking = 59.7±7.1 Jogging = 26.1±6.7 Running = 6.4±3.1 High-speed = 1.9±0.9 Sprinting = 0.5±0.3	
Mallo et al. (129)	Physical Demands of Top-Class Soccer Friendly Matches in Relation to a Playing Position Using Global Positioning System Technology	2015	Standing (0-0.6 km/h) Walking (0.7-7.1 km/h) Jogging (7.2-14.3 km/h) Running (14.4-19.7 km/h) High-speed (19.8-25.1 km/h) Sprinting (>25.1 km/h). Number of Accelerations (<1.0m/s, 1.0-1.5m/s, 1.5-2.0m/s, 2-2.5m/s, >2.5m/s.	Global Positioning System (GPS).	n=111, n=17 (matches).	Spanish League 1	**Mean Accelerations:** <1.0m/s = 348±51 1.0-1.5m/s = 114±24 1.5-2.0m/s = 168±73 2-2.5m/s = 33±8 >2.5m/s = 19±7	Distance covered during a match averaged 10.8 km, with wide and central midfielders covering the greatest total distance.
Tieney et al. (163)	Match play demands of 11 versus 11 professional football using Global Positioning System tracking: Variations across common playing formations	2016	Total Distance High-speed (>19.8km/h) High Metabolic Distance (high-speed + Acc/Dec) High-speed Accelerations (>2m/s) High-speed Decelerations (>2m/s)	Global Positioning System (GPS).	n=46	N/A	**Wide Defender** Total Distance = 10152±714 High-speed = 660±117 High Metabolic Distance = 1850±200 Accelerations = 34±6 Decelerations = 56±14 **Central Defender** Total Distance = 9669±454 High-speed = 396±76 High Metabolic Distance = 1527±192 Accelerations = 27±7 Decelerations = 45±8 **Wide Midfielder** Total Distance = 10523±456 High-speed = 636±172 High Metabolic Distance = 1912±366 Accelerations = 35±5 Decelerations = 62±9 **Central Midfielder** Total Distance = 10395±619 High-speed = 429±133 High Metabolic Distance = 1781±345 Accelerations = 33±10 Decelerations = 53±12	TD was significantly lower in 4-4-2 formation compared to 3-5-2. HSR was also lower in 4-4-2 v 3-5-2 and 4-2-3-1.

							Forward Total Distance = 10502±778 High-speed = 690±186 High Metabolic Distance = 1781±345 Accelerations = 38±8 Decelerations = 55±12	
Torreno et al. (193)	Relationship Between External and Internal Loads of Professional Soccer Players During Full Matches in Official Games Using Global Positioning Systems and Heart-Rate Technology	2016	Total Distance. Distance Per Minute (m/min) Moderate Distance (>13km/h). High-speed Distance (>18km/h).	Global Positioning System (GPS).	n=26	National, Europa League, National Cup.	Full Match = 112.9±10.6m/min First half = 117.0±10.4m/min Second half = 108.8±10.7 m/min	Decreased physical performance (in all measures) for all positional groups towards the end (last 15 minutes) of a match.
Gomez-Piqueras et al. (87)	Relation between the physical demands and success in professional soccer players	2019	Total Distance. High Intensity (21-24km/h). Very High Intensity (>24km/h).	Multi-Camera System (Tracab).	n=378 (matches).	Spanish League 1st & 2nd Division.	1st Division Players Total = 108 823 ± 2653m 21-24km/h = 2987 ± 199m >24km/h = 2853 ± 192m 2nd Division Players Total = 107 744 ± 1970m 21-24km/h = 2839 ± 175m >24km/h = 2656 ± 273m	Significant relationship between physical performance and success reported via season ranking and higher external load.

It was concluded that wide midfielders performed the highest number of overall efforts (35 ± 5, 62 ± 9 for acceleration and deceleration, respectively) when compared to wide defenders (34 ± 6, 56 ± 14), central defenders (27 ± 7, 45 ± 8), central midfielders (33 ± 10, 53 ± 12) and forwards (38 ± 8, 55 ± 12). Although these previous studies have examined the physical profiles associated with different positions, many contextual factors can affect running demands in football, such as quality of opposition (position on ladder), point of the season, time in the match and also the score (24, 121, 165).

Further this point regarding context dictating demands, opposition (teams placed higher or lower in the competition) and match outcome (winning or losing) are suggested to exert some influence on running patterns (24). For example, in elite Italian football mean total distance ($r = 0.62$, $p < 0.001$), HIR ($r = 0.51$, $p < 0.05$), and very high-intensity running (VHIR) ($r = 0.65$, $p < 0.001$) were all significantly increased when competing against lower ranked teams in UEFA competition (165). Further, in Spanish football the time spent in possession of the ball was also significantly increased when playing against lower ranked teams in the top tier of the competition (120). Interestingly, in English football it was also suggested that as players were demoted through competition tiers, their HIR profiles increased, indicating that higher ranked teams complete less HIR (24). In agreement, high-intensity activity was also related to team success in EPL football, with teams finishing in the bottom 5 (919 ± 128m) and middle 10 (917 ± 143m) positions completing significantly ($p=0.003$) more total high-intensity running distance (THIR) than teams in the top 5 (885 ± 113m) (57). It is important to note however, that running patterns were not reported to be a determinant for success, which highlights the tactical and technical effectiveness of teams (57).

To date, limited research exists on the demands associated with the A-League competition. Therefore, knowledge of running demands specific to the A-League are limited. That said, an investigation of running demands in 12 home and away (6 home v 6 away) A-League matches has reported external load (75). Mean team distances in home matches were 10,620 meters at 111 m/min, HIR (>14.5km/h) was 2280 m and 519 m of VHIR (>20km/h). Interestingly, players increased total distance in away matches, though at a lower intensity. Furthermore, Scott et al., (176) reported the percentage (%) of total distance accumulated within different thresholds, standing (<0.07 km/h) 0.1%, walking (0.7-7.2 km/h) 41.7%, jogging (7.2- 14.4km/h) 36.5%, running (14.4-19.8 km/h) 13.9%, fast running (19.8-25.2 km/h) 5.5% and sprinting (>25.2 km/h) 1.6%. Although there may be difference in technical ability from the A-League to the EPL, the aforementioned research suggests that running demands (as a volume) are somewhat similar (75, 176). As previously mentioned, many variables can affect running demands in football not only the quality of the competition which may be evident here, but also the time point of the season and the scheduling of matches. As a result, not only is quantifying a player's external match load important, an understanding of a player's response (internal load) is also beneficial to inform how individuals are responding to match loads (164).

2.3.2.2 Internal Match Loads from Single Matches

Internal loads represent the psycho-physiological response of a player to an external physical stimulus, which in turn is dependent on individual characteristics (107). The internal loads of professional football are predominately aerobic (11), with cardiovascular loads of between 70-80% $VO_{2\ max}$ and 80-90% Heart Rate max (HR_{max}) (29, 55). When investigating differences in positional groups, it was reported that average $\%HR_{max}$ was highest for central midfielders (86.0 ± 4.5) and lowest for fullbacks (83.0 ± 5.2), without significant differences between positional groups ($p>0.05$) in professional Spanish footballers. Further, the majority of match time was spent at 81-90% and 91-95% HR_{max} for all positional groups with central midfielders and central defenders spending significantly more time >91% HR_{max} ($p<0.05$) than other positions (129).

Specifically, when considering the time accumulated within specific zones; 70%, 70–85%, 85–90%, 90–95% and >95% of the HR_{max}, it was demonstrated that heart rate (HR) was predominately maintained in zone 85–90% and 70–85% of the HR_{max} for approximately 37% of match time (98). In agreement, an investigation of elite Brazilian players also reported that the greatest duration of time was attributed to the 70–85% HR_{max} zone (41). However, when reporting on players at lower levels of competition, it has been observed that match intensity may be reduced (170). For example, Rohde & Espersen, (170) reported that second division professional Danish players spent 63% of the match in the HR zone between 73 and 92% HR_{max}. Further, an investigation of fourth division Brazilian footballers reported that HR was above 77% HR_{max} during 66% of total match time (63).

In addition to the objective assessment of internal load from matches, subjective measures are also commonly reported within football due to their non-invasive methods of collection (106). The use of session rating perceived exertion (sRPE) to monitor training loads during simulated football activity correlates ($r = 0.50$ to $r = 0.85$) with HR. As described previously, like other measures of external and internal load, sRPE derived internal loads are dependent on multiple factors, such as opposition quality (24). For example, sRPE of 7.8 ± 0.8AU and associated total match loads (650-780AU) reported for EPL players are higher than those in lower tiers (6.9 ± 0.05AU, 600-720AU) (24). Similar findings have been reported in Australian professional football, with a mean sRPE of 8.1 ± 3 and sRPE derived match load of 722AU (672-747) and 748AU (721-775) at home and away, respectively (75). Overall, the internal loads of football matches show prolonged and pronounced demands of single matches; however, no such reporting of sRPE during congested schedules exists, whereby short recovery times between matches may negatively influence internal load.

2.3.2.3 External Match Loads from Congested Schedules

A growing volume of literature recently reports congested schedules and the influence that these periods may have on the physical movement profiles of players in matches to infer the effect of fatigue and recovery between matches (16, 58, 168). When considering acute congested periods, the use of video analysis and computer tracking has reported that running profiles remain unchanged compared to matches outside of congested periods in UEFA competitions (16, 58, 109, 196). Specifically, during multi-match (MM) weeks it was reported that total, high-intensity and sprinting distances remained unchanged during 2 seasons of Scottish Premier League football (58). Further, the number of sprinting efforts also remained unchanged between match contexts, suggesting that external load profiles in matches are unaffected by multiple consecutive matches (168).

In agreement with the literature outlined above, running demands in Spanish football reported no significant differences for 42 players when two consecutive matches were played with <4 days of recovery (168). As evidence, no differences were reported for total, high speed and sprinting distances in the 1st vs. 2nd half of the match in either match 1 or 2 in the same week (168). However, mean speeds recorded during the 2nd half of match 1 and 2 were significantly lower ($p<0.01$) when compared to the 1st half. Lastly, peak speed remained unchanged between each half and when comparing between consecutive matches, indicating that maximal effort during acute congested schedules is unaffected by reduced recovery between matches (168). When considering these findings, it appears that reductions in match performance are not present during acute congested schedules. However, whether these results explicitly indicate that match related fatigue is not present during congested scheduling remains to be determined, as findings only relate to physical performance from a complete match (168).

More recently, running profiles of Brazilian players during acute congested periods reported that activity profiles in matches were unchanged in MM weeks over 3 seasons (196). However, when reporting high-intensity activity, there was only slight to moderately reduced efforts performed at >15 km/h in 2 match weeks (196). Somewhat in contrast to the aforementioned research, running profiles were reported to change when investigating 15min blocks in the 1st, 2nd and 3rd match within a week for players in the EPL (114). It was reported that the distribution of distance accumulated within low, moderate and high-intensity activity changed in 15min blocks when comparing between the 3 matches within a week (114). Significantly, the high-speed distance covered in the last 15min of match 3 was reduced in comparison to match 1 and 2 ($p<0.05$) (114). However, the overall distances within zones remained unchanged in matches and between positional groups, suggesting self-pacing strategies being utilised by players and therefore high-speed actions could be performed when required (114). These findings provide further evidence that acute congested schedules may not effect physical match performance; however, the specific variables investigated may not quantify explosive movement patterns which could be impacted as a result of reduced recovery from the congested nature of matches (8, 114).

When considering prolonged congested schedules, physical performance reported during matches remains similar to matches played outside of these periods i.e. with more than 5 days between matches (36, 55). Specifically, more distance was covered during game 4 and 7 when compared to 2 and 3 (126.6 ± 12.3m/min and 125.0 ± 13.2m/min vs. 116.0 ± 8.0m/min and 115.5 ± 11.0m/min, respectively) in an 8 match congested period of 26 days in professional French football (31). Further, no differences were reported between halves throughout the matches, including high-intensity activity in the 2nd half (31). However, the transferability of the aforementioned research may be questioned with small numbers (n= 7) reported for players completing all matches within the study (31). Despite these suggestions, similar findings were reported for 3 separate periods of fixture congestion where 6 matches were played with 3 days of recovery separating all matches (55). It was concluded that total, moderate and high-intensity running demands remained unchanged between matches for 16 outfield players analysed in French League 1 football (55). The total distance reported for players was the only significant difference when comparing between periods ($p<0.001$); however, moderate and high-intensity running remained unchanged (55).

In elite youth football, similar findings have also been reported for running demands during congested schedules in an under 15's world cup competition (8). No differences were observed when 5 matches were played in 3 days for measures of total distance, high-intensity runs, total distance per minute, high-intensity meters and peak running speeds (8). However, differences did exist for accelerometer measures examining 'intense' efforts of accelerations per minute and body load impacts (8). As a result, accelerometer derived data, focusing on high-intensity actions may be more suitable for quantifying the extent that congested schedules effect physical match performance (8). Although these conclusions provide an alternate measure of performance during congested schedules, the fact that participants were elite youth players and matches were played in non-typical congested schedules means results are less applicable in professional football. That said, a better understanding of physical loading within matches would allow practitioners to make more informed decisions when managing players at times of increased fixture congestion (31).

Collectively, the aforementioned research for both acute and prolonged periods of congestion appear consistent when reporting that physical match performance remains unchanged when compared with matches played within typical weekly mircocycles (36, 55, 58, 168). These findings are potentially a result of increased player rotation during congested schedules, which is highlighted as a primary reason for the somewhat unexpected results (36, 58). Player rotation is key in managing fatigue during congested schedules, which may mask the effect that reduced recovery time between matches has on performance (31, 36, 55).

Actual player exposure to congested schedules has been investigated over 4 seasons in professional French football whereby the club competed in Domestic League, National Cup and League Cup competitions (33). The mean time interval between consecutive matches throughout the 4-season period was 127.4 ± 9.1 and 111.0 ± 7.7h across all formats of competition, which is greater than what would normally be considered as 'congested schedules' (33). The mean number of acute congested matches (2 consecutive matches with <3 days of recovery) throughout the 4 seasons was 12.5 ± 5.1, of which club and national team players completed 90mins of match exposure on 38.2 ± 9.9 and 40.5 ± 20.4% of occasions, respectively. Further, club and national team players completed >75mins of match time 47.6 ± 5.6 and 50.0 ± 15.8%, respectively of all available acute congested matches (33). When congested periods were extended for 4, 5 and 6 consecutive matches, the percentage of players completing >75mins of match time was even further reduced (22.4, 13.2 and 0%, respectively), indicating even higher player rotation (33). These results show, that despite a high percentage of match availability (90.0 ± 4.8%) across the squad, that significant player rotation was implemented when recovery time between 2 consecutive matches was reduced or when prolonged congested periods exist (33). In Australian football, playing squads are limited to 26 players, which when combined with a heavily reduced salary cap (~$3 million) creates difficulty for player rotation. Therefore, implementing the recommendations from previous studies is difficult and the effect of reduced player rotation in Australian football is yet to be established.

2.3.3. Technical Demands of Football and Effects of Congested Schedules

Although the technical demands of football matches are not a focus of the current thesis, it is important to recognise its contribution to match demands and ensuing load accumulation (19). Throughout a match, players will change activities every 5sec, resulting in approximately 1300 respective actions (200 high-intensity) per match (164). Collectively, these actions can result in fatigue both intermittently throughout and following a match (105). Therefore, research suggests that running volume or intensity alone is not the sole cause of post-match related soccer fatigue as other physical activities (ball strikes, headers, collisions, tackles) may contribute more significantly to match fatigue than locomotive demands (166).

An investigation of movement demands, determined via video analysis, reported that players in the EPL spent 40.6 ± 10% of a match performing purposeful movement (PM). PM took into account directional changes, intensity, jumps, dive, turn/type, movement to control the ball, pass/shoot, technique of pass, start and end of dribble and number of touches (19). Position was reported to have the greatest influence on time spent performing PM ($p<0.05$) with players performing >700 turns on average throughout the game (19). Collectively, these demands show a significant amount of time in football is spent performing high-intensity activities that do not include running demands (24). Collectively, these results show that a combination of both running demands and high-intensity activities results in the high work rates demonstrated in football (19).

Technical demands vary based on positional groups with central midfielders reporting the highest number of passes (39.8 ± 14.0) when compared to central defenders (23.7 ± 11.7), fullbacks (33.8 ± 10.6), wide midfielders (30.4 ± 11.4) and attackers (22.2 ± 9.6)

(24). However, differences between positional groups are not so exaggerated when also considering headers, tackles, balls received and entries in the final third (166). Recognising other factors influence match technical demands, the influence of competitive standards has been investigated, with Premier League players reported to perform a greater number ($p < 0.01$) of total passes, successful passes, forward passes, balls received and touches per possession compared with Championship and League 1 teams (ES: 0.30–0.60) (24). However, players in League 1 and the Championship performed more headers and interceptions ($p < 0.05$) than those in the Premier League (ES: 0.20–0.60) (24). These findings are consistent with technical demands reported in relation to match performance, with differences also observed for technical/physical performance between the 5 lowest vs. highest ranked teams in professional Italian football (166). It was suggested that 'more successful teams' have an increase in involvements with the ball, short passes and long passes when compared to lower ranked teams ($p<0.01$), while physical measures are reduced (166). Further, technical performance had a significant decline in both groups when comparing the second half to the first ($p<0.01$) (166). In agreement, it was also reported that decreased (10 ± 7%) possessions per player were evident in the 2nd compared to 1st half ($p=0.010$) in 23 home matches for English Championship players (174). Further, total distributions per player were also reduced (11 ± 8%) in the 2nd half of matches ($p=0.009$) potentially indicating fatigue towards the end of a match in lower quality teams (174).

Previous research has reported the extent that technical performance is influenced by position, level of competition and match time (first vs. second half) (166). However, more recently the influence of time in possession and technical performance during matches has also been investigated (24, 151). Specifically, when reporting differences in physical and technical performance indicators for EPL players (n=810) in either ‘high’ (HPBPT) and ‘low’ (LPBPT) percentage ball possession teams, it was reported that physical performance did not differ between the groups; however, technical performance was significantly altered (24). For example, HPBPT performed 44% more ($p<0.01$) passes than LPBPT players (35.3 ± 14.2 vs. 24.6 ± 11.2; ES = 0.83), with more successful passes, received passes, touches per possession, shots, dribbles and final-third entries (ES range of 0.20–0.94) (24). Further, total passes and passes received were higher ($p<0.01$) across all positions in HPBPT than LPBPT (ES range of 0.82–1.52) (24). Collectively, the aforementioned research demonstrates that technical as well as physical demands can influence post-match fatigue in football. Although not explicitly related to congested schedules within football, technical demands should also be considered as high match exposures will also increase involvement of technical factors (71).

2.3.3.1 Technical Demands and Congested Schedules

Despite significant research reporting the effect of congested schedules on physical demands within matches, the influence on technical demands is not well established (62, 71). Early research, which reported match performance during congested schedules via a panel of experts (individually analysing matches independently) found that increased scheduling of matches prior to the 2002 World Cup resulted in 32% ($n=65$) of players underperforming (62). In comparison, players with reduced scheduling of matches were reported to perform above expectation ($p<0.05$) (62). During acute periods of fixture congestion, it was reported from pooled data analysis that the percentage of successful passes did not differ between microcycles where matches were played with <4 days vs. 4–5 days or >5 days of recovery from 18 teams participating in 306 matches in German Premier football ($p > 0.05$) (109). Furthermore, match performance, determined via win/loss records, was not affected in matches with < 3 vs >3 days of recovery including multiple teams in UEFA competitions (16).

When considering prolonged congested schedules, no differences have been reported for physical actions such as; duels won, the number of ball contacts per possession, the percentage of successful passes and the number of balls lost during six successive matches from 3 separate congested periods (55). Further, ball possession from 8 matches during a period of 26 days also reported no difference in possession (70.0% (CI: 57.6–90.3%) when compared to matches played in normal match scheduling before and after the prolonged congested period ($p=0.617$) (31). Collectively, the aforementioned research suggests that both physical and technical performance during matches is largely unaffected during times of increased match scheduling. However, it has been suggested that players may instinctively employ 'self-pacing' strategies during weeks where multiple matches exist in order to maintain their ability to perform high intense activity when required (58). Despite physical/technical performance being unaffected, questions remain whether increased match exposure resulting from fixture congestion leads to higher injury rates in professional football (55). Consequently, the following section of this review will focus on injury, firstly examining the rates and risk factors that exist within normal scheduling and then congested schedules.

2.4. Injury in Football and Congested Schedules

When considering injury in professional football, significant literature exists which examines the incidence rates, severity and location of injury (17, 61, 93). Consideration for each of these factors is important, not only within the context of normal match scheduling, but particularly during times of congested scheduling (55).

Injury is a key issue within football as the time lost from injury has an associated monetary cost when players are unavailable for selection (48). In two seasons of English football, on average (SD) players missed 24.2 (40.2) days of training due to injury, with 78% of all injuries resulting in a missed match (97). Interestingly, teams that have reduced injury rates and severity also 'outperform' those when considering final ladder position within league competitions (91). For example, a study investigating 27 UEFA teams over an 11 period concluded that lower injury burden (p=0.011) and higher match availability (p=0.031), compared with the preceding season, were associated with a higher final league ranking and average points scored within a match (91). Further, in Qatari professional football lower injury incidence was correlated with higher team ranking (r=0.929, p=0.003), more games won (r=0.883, p=0.008), more goals scored (r=0.893, p=0.007), greater goal difference (r=0.821, p=0.003) and total points (r=0.929, p=0.003) (60). When considering this evidence, the impact of injuries on performance outcomes are important and consideration of the risk factors existing within professional football are required to minimise the associated cost of injury on players and teams (59).

2.4.1 Risk Factors and Mechanism of Injury in Football

Professional football players are exposed to multiple risk factors during both training and competition, which will ultimately influence the likelihood of sustaining an injury (59, 103). As shown in Figure 2.2, both intrinsic and extrinsic factors exist which contribute to the overall risk of a player sustaining an injury (103, 136, 175).

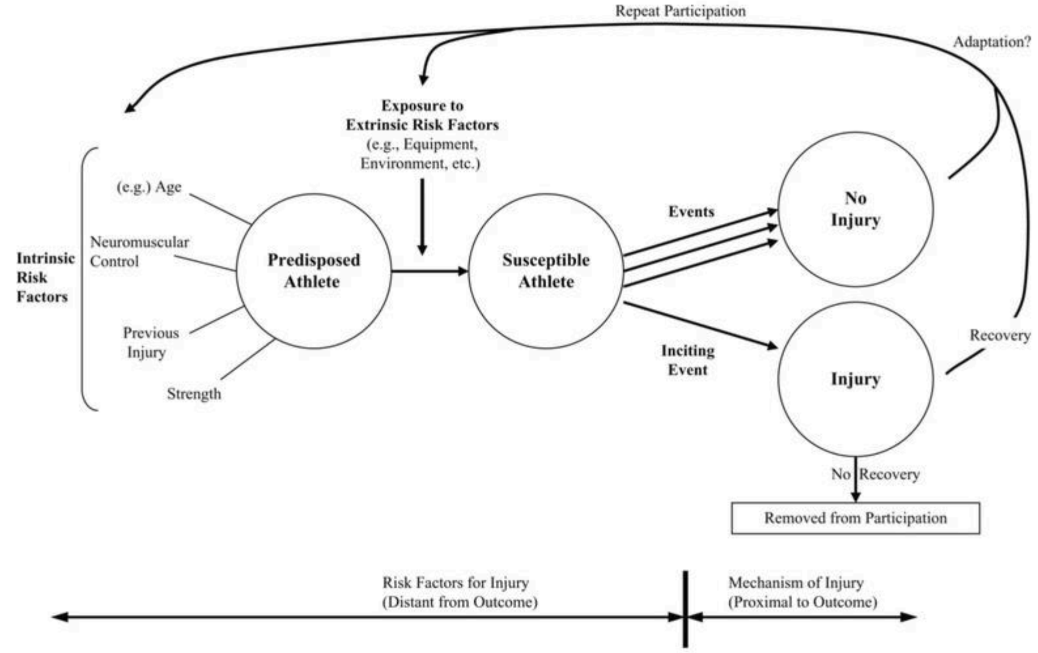


Figure 2.2: A dynamic model of injury etiology within sport showing both Extrinsic and Intrinsic risk factors (103).

Intrinsic factors are considered as ‘predisposed’ and categorised as either non-modifiable (previous injury and older age) or modifiable (lower flexibility, decreased muscle strength and muscle imbalances) risks (103). These factors have all been suggested to influence injury risk, though despite extensive research inconsistent findings exist in current literature for their effect (91, 136). In contrast, extrinsic risk factors, which include; training load volume and distribution, environmental factors, match location and opponent are considered as ‘modifiable’ and are less frequently investigated regarding the effect on injury risk (185). It is beyond the scope of this review to consider all intrinsic/extrinsic risk factors, though specific factors relevant to the current thesis should be discussed – particularly contextualising match and training loads to then discuss their relevance within congested schedules.

When considering extrinsic risk, the physical match demands (as outlined earlier) of players are an important part of match exposure and injury risk (119, 145, 174). These findings are of interest when 63% of all injuries have been reported to occur during a match, and significantly ($p<0.01$) more of these are sustained towards the end of each half; which may suggest fatigue as an influencing factor (97). Although non-contact injuries are multifactorial, elite football practitioners consider fatigue as the second most important risk factor for non-contact injuries sustained in match play and training (137). Therefore, a greater understanding of the influence that successive matches have on the fatigue and recovery profiles of athletes is needed, as reduced recovery may lead to accumulative fatigue and increased injury risk in both training and match-play during these busy periods (32, 181).

Training loads are also highlighted as a major extrinsic risk factor for injury, which has more recently received increasing attention (110, 184). Evidence of a load-injury relationship has previously been reported in football (80), which highlights the importance for practitioners to administer appropriate training loads. For example, in professional European football 64 injuries were analysed in total across a season for one professional team (110). The research reported that high 2 (>59 185m) and 1 (>31 161) weekly total distances have a likely harmful effect on injury risk (OR: 2.25, 90% CI: 1.17–4.34; OR: 1.42, 90% CI: 0.92–2.21, respectively). Further, medium 2 (48 050 - 59 185m, OR: 1.93, 90% CI: 0.93–4.02) and high 3 (>86 422m, OR: 1.88, 90% CI: 1.08–3.26) weekly total distances were also found to have a likely harmful effect on injury (110). Harmful effects were also reported for medium 1 (634 - 1028m, OR: 1.56, 90% CI: 0.99–2.46) weekly total high-speed running (>20km/h) distance (110). It should be noted that the total injuries reported within the aforementioned research are low, therefore the statistical power of the results are raised as a limitation (124). However, the research was a case study of one team which is relevant to comparisons within the current thesis. Given that substantially more high-speed running occurs throughout matches when compared to training, as discussed previously, congested schedules may be of concern due to higher accumulative physical demands in multi-match when compared to single weeks.

2.4.1.1 Mechanism of Injury

Injuries are typically classified according to their mechanism, specifically, as either traumatic injuries (acute onset) or overuse injuries (gradual onset) (97). An acute injury can be defined as those occurring from a specific, identifiable event, whereas overuse injuries are typically caused by repeated micro trauma without a specific, identifiable event resulting in injury (77). The majority of injuries in both match (81%) and training (59%) are primarily the result of sudden onset injuries, which are reported to occur from traumatic events (61). During matches, the highest number of injuries were reported to occur while performing ‘running’ movements (19%), while being tackled (15%) and tackling (9%) were also reported from a total of 6030 injuries (97). In agreement, an investigation of 224 injuries reported that 71% were a result of a traumatic event caused by player contact, while 24% were related to overuse mechanisms (92). Further, acute match (sudden onset following an identifiable event) injuries have also been reported as 15.9 per 1000h (95% CI: 14.9 to 16.8), whereas the incidence of acute injuries during football training was 1.9 (95% CI: 1.7 to 2.0) in professional Norwegian footballers (18).

In contrast to the above, only 28% of injuries have been reported to result from ‘overuse’, which the authors suggest may have been preventable (61). Similarly, an investigation of 6140 injuries over 9 seasons and 1401 players concluded that 34% of all injuries were defined as overuse (91). From these overuse injuries, hamstring injuries (n=284) had the highest occurrence, followed by adductors (n=214), quadriceps (n=138) and calves (n=92) (91). Collectively, the aforementioned research suggests that injury risk is higher during matches when compared to training (61). Further, acute and overuse injuries are also both increased during matches when compared to training (185). Therefore, it could be assumed that injury rates would increase during congested schedules as a result of increased match exposure. The following section will therefore explore injury rates in football prior to examining rates in the context of congested schedules.

2.4.2. Injury Rates in Football and Effects of Congested Schedules

A significant body of literature exists from different leagues around the world reporting on injury incidence rates in professional football (18, 61). To date, findings on injury occurrence (Table 2.3) throughout professional football are relatively consistent when reporting rates for total, match and training injuries, as well as the distribution of match and training injuries (61). Injuries are reported to predominately occur during match play (57%) when compared to training (43%) from 4483 injuries over 7 seasons of EPL football (61). In agreement, during a 6-year period for elite Norwegian football, match (58.2%) and training (39.4%) injury occurrences were reported that are also comparable to previous studies (18). Although the distribution of injuries occurring in matches and training over the course of a season are important, the specific total, match and training injury rates (based on exposure time) throughout the season are needed in order to make comparison with rates at times of increased scheduling.

Table 2.3: Studies investigating the incidence of injury in professional football.

First Author	Title	Year	Study material	Study focus	Subjects	League	Results
Morgan et al. (130)	An Examination of Injuries in Major League Soccer: The Inaugural Season	2001	10 teams over 1 season. 256 injuries in total recorded.	Injury incidence, severity, location and influence of position.	n=237	Major League Soccer	Total injury rate = 6.2/1000h Match injury rate = 35.3/1000h Training injury rate = 2.9/1000h
Hawkins et al. (97)	The association football medical research programme: an audit of injuries in professional football	2001	92 teams from the EPL and 3 football leagues below over 2 seasons. 6030 injuries from training and match play.	Injury occurrence, location and severity.	n=2376	English professional football.	Total injury rate = 1.3/1000h. 63% of all injuries were sustained in a match, while 34% were in training.
Walden et al. (198)	Injuries in Swedish elite football: a prospective study on injury definitions, risk for injury and injury pattern during 2001	2005	14 teams over 1 season. 715 injuries from a total of 93 353h of exposure (81 801 training hours and 11 552 match hours	Injury incidence, location, and severity of soft tissue injuries.	n=310	Swedish League 1	Total injury rate = 8.3 ± 5.0/1000h Match injury rate = 27.2 ± 17.0/1000h Training injury rate = 5.7 ± 3.7/1000h
Walden et al. (200)	UEFA Champions League study: a prospective study of injuries in professional football during the 2001-2002 season	2005	11 teams competing in UEFA competitions from 1 season. 658 injuries from a total of 69 707 hours (58 149 training hours and 11 558 match hours).	Injury incidence, severity and location from different phases in the season.	n=266	UEFA Competitions	Total injury rate = 9.4/1000h (7.3-11.5). Match injury rate = 30.5/1000h (23.1-37.9). Training injury rate = 5.8/1000h (3.6-6.4).
Hagglund et al. (92)	UEFA injury study—an injury audit of European Championships 2006 to 2008	2009	16 UEFA European professional teams	Injury incidence at different levels of competition and age groups.	n=367	UEFA Competitions	Total injury rate = 10.4/1000h (8.0-13.6). Match injury rate = 41.6/1000h (30.9-55.9). Training injury rate = 2.8/1000h (1.6-4.9).
Ekstrand et al. (62)	Injury incidence and injury patterns in professional football: the UEFA injury study	2011	23 UEFA teams over a 7 year period. 4483 injuries in total, 2546 (57%) in matches and 1937 (43%) for training. A total, 566 000 h of exposure (475 000 of training and 91 000 of match play).	Injury rates, severity and type documented.	n=N/A	UEFA Competitions	Total injury rate = 8.0 ± 3.4/1000h Match injury rate = 27.5 ± 10.8/1000h Training injury rate = 4.1 ± 2.0/1000h

Dauty et al. (49)	Incidence of Injuries in French Professional Soccer Players	2011	1 team over 15 seasons resulting in 903 injuries. Injuries classified as major (more than 28 days), moderate (7–28 days) and minor (less than 7 days).	Injury incidence over a 15 year for different positional groups and injury types/severity.	n=173	French League 1	Total injury rate = 4.7 ± 5/1000h. Minor injury rate = 1.36 ± 2.03/1000h. Moderate injury rate = 3.5 ± 3.34/1000h. Major injury rate = 0.25 ± 0.66/1000h .
Hagglund et al. (91)	Injuries affect team performance negatively in professional football: an 11-year follow-up of the UEFA Champions League injury study	2013	24 UEFA teams over a 11 season period. 7792 injuries reported from 1 026 104 hours of exposure.	Injury incidence rates and time loss associated with performance (win/loss).	n=N/A	UEFA Competitions.	Total injury rate = 7.7/1000h (1.7-20.5). Match injury rate = 26.6/1000h (6.7-57.0). Training injury rate = 4.0/1000h (0.5-12.1).
Eirale et al. (60)	Epidemiology of football injuries in Asia: A prospective study in Qatar	2013	10 professional level teams over 1 season. 217 injuries from a total exposure per player of 170.0±56.0h (27.2±14.9 and 142.8 ±51.6h of match and training, respectively).	Injury incidence, severity and type in Asian football.	n=230	Qatar Stars League	Total injury rate = 6.0/1000h (95% CI: 4.9 to 6.5). Match injury rate = 14.5/1000h (95% CI: 11.6 to 18.0). Training injury rate = 4.4/1000h (95% CI: 3.7 to 5.2).
Bjorneboe et al. (18)	Gradual increase in the risk of match injury in Norwegian male professional football: A 6-year prospective study	2014	14 professional Norwegian teams over a 6 year period. Collectively, 34 8521h (70.5%) of football training and 84 503h (17.1%) of other training and 61 133h (12.4%) for matches. 2365 injuries, 1664 (70.4%) acute injuries and 701 (29.6%) overuse injuries.	Assessment of injury rates over a 6-season period.	n=N/A	Norwegian Premier League	Total injury rate = 4.8/1000h (95% CI: 4.6 to 5.0), 3.4/1000h (95% CI: 3.2 to 3.5) for acute injuries, and 1.4/1000h (95% CI: 1.3 to 1.5) for overuse injuries. Match injury rate = 15.9/1000h (95% CI: 14.9 to 16.8). Training injury rate = 1.9/1000h (95% CI: 1.7 to 2.0).
Malone et al. (132)	The acute:chonic workload ratio in relation to injury risk in professional soccer	2017	2 teams over 1 season. 75 injuries recorded in total.	Injury risk associated with certain ACWRs.	n=48	Irish league 1	Total injury rate = 1.6/1000h Match injury rate = 4.9/1000h Training injury rate = 6.9/1000h
Jaspers et al. (110)	Examination of the external and internal load indicators' association with overuse injuries in professional soccer players	2018	1 team over 2 seasons (pre and in-season). 64 overuse injuries in total.	Relationship between internal/external load demands and overuse injuries.	n=35.	Dutch Premier League	Overuse injury rate = 5.8/1000h for both seasons. 4.9/1000h and 6.8/1000h in season 1 and 2, respectively.

Total injury rates (match + training) were reported for professional French football over a 15-season period, a total of 903 injuries were investigated for 173 players competing from a single team (49). A total injury incidence of 4.7 ± 5/1000h was reported, which importantly did not change significantly across the 15-seasons reported (49). Injury incidence also remained unchanged during 7 seasons, in a study which included 50 of the best European teams (61). A total of 4483 injuries were recorded during 566 000 hours of exposure during matches and training, resulting in 8 injuries per 1000h and 2 per player each season (61). Similar total injury rates (7.7/1000h) have also been reported over an 11 season period for 24 teams competing in UEFA competitions, which included 7792 injuries (91). Injury rates in Swedish football are also consistent with previous findings, with 8.3 injuries per 1000h reported from 14 professional teams during 1 season, which resulted in a total of 715 injuries (198).

In contrast to the aforementioned multi-club investigations, a comparatively low total injury rates (1.6/1000h) was recently reported for 2 professional Irish football teams over a 2-season period (132). Match injuries were extremely low within the study, which explains the reduced total rates, though not the reasoning for these findings (132). These results show the importance of investigating both match and training injuries rates, as both provide further context which may provide an explanation of changes in total injury rates in some studies (92, 97).

Match injury rates are considerably higher when compared to total rates, though significantly more variation between studies has been reported (60, 61, 110, 132). Over a 6-year period for Norwegian professional football players the incidence of match injuries was 15.9 injuries per 1000h, with a total of 2365 injuries increasing by 49% over the duration of the study (18). In contrast, match injury rates (27.5 ± 10.8/1000h) over a 7-year period appear much higher for 23 professional teams in UEFA competitions (61). These results highlight potential differences for injury rates between competitions, which should also be considered as demands unique to respective competitions may significantly influence injury rates (136). As further evidence, reduced match injuries (14.5/1000h) were also reported for professional teams in Qatar (60). Further, match injuries in Irish football (4.9/1000h) were extremely low when compared to all previous research (132). The reason for low injury rates reported in these leagues in not clear, though significantly smaller samples sizes did exist when compared to the aforementioned multi-club investigations (132).

Collectively, when considering research on match injuries, studies focusing on UEFA competitions report relatively consistent findings, which are typically higher rates than those previously mentioned (61, 91, 92, 199). Although speculative, the reason for the increased injury rates within these competitions may be a result of increased match exposure. As evidence, during a 7-year period in UEFA competitions, on average participants played an average of 34 matches (61). While the previous investigation, which examined the Qatar premier league reported a mean of 19 matches per player (60). These differences highlight the effect of competition type and match exposure for match injury rates, though not reporting congested periods specifically, the increased rates reported in UEFA competitions provides further rationale for examining rates during isolated congested periods (92).

When considering training injuries, reduce rates reported throughout the literature are predominately a result of the reduced training intensities and a reduction in 'sudden onset' or contact-based injuries when compared to match injuries (49, 61, 92). Training injury rates of 4.1/1000h have been reported in UEFA competitions over a 7 year period from a total of 475 000h of exposure (61). Similarly, over an 11 year period in UEFA competitions, training injury rates (4.0/1000h) were also considerably low (91). Unlike match injuries, the training injuries reported from different competitions remain similar when compared to UEFA for the Qatar (4.4/1000h), American (2.9/1000h) and Norwegian (1.9/1000h) professional leagues (18, 60, 149). Due to these relatively low rates, the majority of existing literature regarding injuries and associated risk factors has focused on match injuries (49, 97, 110). However, during times of congested scheduling reduced recovery times between matches may cause altered weekly periodisation, potentially resulting in negative consequences for training injury rates (58).

2.4.2.1 Injury Rates and Congested Schedules

When considering injury in congested schedules, a growing body of literature has investigated the influence that reduced recovery time between matches may have on incidence and rates in professional football (36, 55, 58). To date, the results reported are somewhat mixed between acute and prolonged periods of congestion, with some contrasting findings on whether these periods have a negative influence on injury (17, 31, 55). Given the differing demands associated with acute vs. prolonged periods of congestion, the methodology between studies is one reason that may explain these mixed findings (17). Further, the actual time periods investigated vary substantially;

therefore, it is important to discuss acute and prolonged periods of congestion independently.

Acute Congestion

Current literature investigating the effect of acute periods of congestion on injury are limited to Europe, with a small body of research examining discreet weeks where short recovery times exist (Table 2.4) (16, 17, 58). An investigation of 27 European professional football teams from 10 different countries reported injury occurrence over an 11 season period, which included 8150 total matches (16). Injury rates were reported as not significantly different with <3 or >3 days of recovery (27.8 vs 28.3/1000h) in League matches (p=0.713).

Table 2.4: Studies investigating the effect on injury rates and performance in acute congested schedules within football.

First Author	**Title**	**Year**	**Study material**	**Match congestion variable**	**Subjects**	**League**	**Results**
Dupont et al. (58)	Effect of 2 Soccer Matches in a Week on Physical Performance and Injury Rate	2010	1 team over 2 seasons. 67 matches 3 or 4 days recovery, 56 matches >5 days recovery.	Matches played with <4 days of recovery following the previous match, compared with matches played with >5 days from the previous match.	n=23.	Scottish Premier League	Overall (25.6 vs. 4.1/1000h), match (97.7 vs. 19.3/1000h), and training (8.3 vs. 2.5/1000h) injury rate was higher in congested vs. non-congested matches. Running performance remained unchanged.
Carling et al. (36)	Match Injuries in Professional Soccer: Inter-Seasonal Variation and Effects of Competition Type, Match Congestion and Positional Role	2010	1 team over 4 seasons playing in multiple competitions. 192 matches played, with median of 23 matches per player per season.	Matches played with <3 days (n=76) of recovery compared to >4 days (n=116).	n=31±2.5 across the 4 seasons.	French League 1	No difference (p = 0.406) was observed in in matches with <3 days (45.0±54.6 per 1000h, 0.8±0.9 injuries per match) compared to >4 days 37.7±48.4 per 1000h, injuries 0.6±0.8 per match). Mean layoff time per injury was identical (15±25 days vs. 15±28 days, p=0.730) between consecutive games separated <3 days vs. >4 days.
Bengtsson et al. (16)	Muscle injury rates in professional football increase with fixture congestion: an 11-year follow-up of the UEFA Champions League injury study	2013	27 teams over 11 seasons. Data collected from 8150 matches.	Matches played with <3 days vs. > 4 days of recovery. Also, <4 days vs. > 6 days.	n=5622	Multiple teams competing in UEFA competitions.	Total and muscle injury rates increased in Europa league matches with <3 (23.9/1000h) days compared with >3 (30.2/1000h) days recovery, specifically hamstring and quadriceps injuries. Injury and performance remained unchanged in other competitions for congested vs. non-congested. Team performance remained unchanged between periods.
Carling et al. (34)	The impact of short periods of match congestion on injury risk and patterns in an elite football club.	2016	1 team over 6 seasons.	1) 2 successive matches separated by <3 days 2) 3 successive matches separated by <4 day intervals starting the day immediately after each match.	n=25	French League 1	1) No significant difference for injury rates between the 1st and 2nd match. 2) Injury rates were twice as high in the last match of a 3 match cycle when separated by <4 days of recovery.
Bengtsson et al. (17)	Muscle injury rate in professional football is higher in matches played within 5 days since the previous match: a 14-year prospective study with more than 130 000 match observations	2018	57 teams over 14 consecutive seasons.	Short-term match congestion defined as the number of days between consecutive matches (<3, 4, 5, 6 and 1-10 days).	n=2672	UEFA competitions	No differences in total match injury rates were found between the reference category (<3 days) and the other categories of short-term congestion. Muscle injury rates were significantly lower in matches preceded by 6 or 7–10 days compared with <3 days since the last match exposure.

However, when <4 (29.0/1000h) were compared with >6 days (26.6/1000h) of recovery, injury rates were reported to increase (p=0.045). The reason for these mixed findings is unclear; however, teams may have utilised different player rotation strategies given the reduced recovery (<3 days) between matches. Similar total injury rates have also been reported when <3 days (25.2/1000h) or 4 days (25.0/1000h) of recovery exists between matches from over 65,000 observations (17). These findings were reported from data collected across 14 seasons with 57 teams competing in UEFA competitions, which also consisted of data from 16 different countries and concluded that injury rates are not influenced by short-term match congestion (17). In contrast to the previous multi-club/season investigations, across 2 seasons of Scottish premier league football total injury rates of 25.6/1000h and 4.1/1000h were reported in 2 versus 1 match weeks from one club, respectively (58). Despite being speculative, these findings are perhaps more suggestive of the difficulties that individual clubs face as a result of congested schedules when compared to other epidemiological studies (58). Collectively, the aforementioned research demonstrates mixed findings for total injury rates during acute congested schedules. Whether differences result from methodology i.e. multi-club vs. single club remains to be determined; however, consideration of individual match and training rather than total injuries alone does provide further context.

When considering match injury rates, research investigating elite level Scottish footballers has reported match injury rates for 2 (97.7/1000h) and 1 (19.3/1000h) match weeks, demonstrating a significantly higher injury rate during acute 2 match weeks (58). Furthermore, muscle injury rates, as a result of match play have been reported to increase by 21% when players have <3 vs. >6 days of recovery between matches in professional European teams (17). Although these findings suggest significantly higher injury rates in MM weeks, research in Europe investigating French League 1 footballers found no difference (p = 0.406) for the incidence of match injury when <3 days (45.0 ± 54.6 per 1000h, 0.8 ± 0.9 injuries per match) versus >4 days (37.7 ± 48.4 per 1000h, injuries 0.6 ± 0.8 per match) of recovery separated matches (34). Across the 4 seasons investigated in the previous research, the mean squad size was 31 ± 2.5, with a total of 76 and 116 matches played with <3 days versus >4 days of recovery, respectively. Collectively, the total matches played resulted in players participating in a mean of 23 matches per season (range 1-48) (34). The reduced number of participants and increased player rotation may provide rationale for differences in findings when compared to the aforementioned research, particularly considering the significantly different injury rates reported (34).

The majority of existing literature regarding injury in acute congested schedules has a focused on total and match injury rates that occur throughout these periods (36, 58). However, the training injuries that occur within acute congested periods are less frequently reported (55). That said, training injury rates reported in 2 (8.3/1000h) versus 1 (2.5/1000h) match weeks does suggest increased injury incidence during acute congested periods for professional French footballers (58). However, the injury rates reported are still relatively low, which research suggests is due to reductions in training load during periods of fixture congestion as a means to focus on player recovery (58). The increased training injury rates reported, along with increased match and total injuries in the aforementioned research do suggest an overall negative trend between injury and existence of acute congested schedules (58). However, injury rates for Australian teams competing in congested schedules have not been reported. Given increased travel demands, reduced squad sizes and salary caps are all consequences of Australian competitions the ability to manage load, recovery and injury risk during acute congested schedules is potentially more pronounced.

Prolonged Congested

Current literature reporting total incidence of injuries during prolonged congested schedules show consistent conclusions that injury rates remain unchanged when compared to non-congested periods (Table 2.5) (16, 17, 55). An investigation of matches with <3 days of recovery, reported total injury rates for periods where 6 matches were played on average during 30 days (16). Specifically, each match sequence comprised of 27 ± 9 days (range 7-104), or a mean of 6.0 ± 1.6 matches played over a standardised 30-day period (range 1.4-12.9). When compared to non-congested periods, no differences were reported for total injury rates during these periods of high match loads (16).

More recently, an investigation of ‘long-term’ match congestion over a 14 year prospective period, which comprised of 130,000 match observations also reported similar findings to the aforementioned research (17). Long-term match congestion was defined as the total hours of match exposure that a player had been exposed to in the 30 days prior to the observation (injury).

Table 2.5: Studies investigating the effect on injury rates and performance in prolonged congested schedules within football.

First Author	Title	Year	Study material	Match congestion variable	Subjects	League	Results
Ekstrand et al. (60)	A congested football calendar and the wellbeing of players: correlation between match exposure of European footballers before the World Cup 2002 and their injuries and performances during that World Cup	2004	11 teams over 1 season.	World Cup players completing 46 matches within a season vs. non World Cup players who played 33 matches. .	n=266.	UEFA competitons	23 (60%) of the 38 players who had played more than one match a week before the World Cup incurred injuries or underperformed during the World Cup. No differences in injuries between groups reported during regular season.
Carling et al. (31)	Are Physical Performance and Injury Risk in a Professional Soccer Team in Match-Play Affected Over a Prolonged Period of Fixture Congestion?	2012	1 teams over 1 season.	A 28 day period where 8 matches were played.	n=19 - 1 match. n=2 - completed all matches (1 goalkeeper) n=6 - <75% of total match time) n=8 - >75% total match time.	French League 1	Match injury incidence during the prolonged congested period was similar to rates reported during normal scheduling though the mean lay-off duration of injuries was substantially shorter during the non congested ($p < 0.05$). The overall distance covered varied across successive matches ($p < 0.001$) as more distance was run in games 4 and 7 compared to 2 and 3, respectively.
Bengtsson et a. (16)	Muscle injury rates in professional football increase with fixture congestion: an 11-year follow-up of the UEFA Champions League injury study	2013	27 teams over 11 seasons. Data collected from 8150 matches.	Prolonged periods containing 6 matches in 30 days (on average) were identified. For example, five matches played over a period of 27 days equals a standardised match load of 5/27×30=5.56 matches/month	n=5622	Multiple teams competing in UEFA competitions	Muscle injury rates increased in periods with increased match load. No further associations were found between match load and training or match and or total injury rates in the same match sequence.
Dellal et al. (54)	The effects of a congested fixture period on physical performance, technical activity and injury rate during matches in a professional soccer team	2015	1 team over 1 season.	3 periods of fixture congestion identified where 6 consecutive matches with 3 days recovery between.	Period 1 n=5 Period 2 n=6 Period 3 n=5	French League 1	Total incidence of injury (matches + training) during congested periods did not differ significantly to non-congested periods. Match injuries were significantly higher during the congested period compared with the non-congested period ($p<0.001$). Training injury rate was significantly lower during the congested period. No differences were found across the six successive games in the congested periods, and between non-congested for all physical and technical activities.

Bengtsson et al. (17)	Muscle injury rate in professional football is higher in matches played within 5 days since the previous match: a 14-year prospective study with more than 130 000 match observations	2018	57 teams over 14 consecutive seasons.	Long-term match congestion was defined as individual match exposure hours in the 30 days preceding a match, observations were categorised into three groups (low, ≤4.5; medium, >4.5 to ≤7.5; and high, >7.5 hours).	Observation number for: Low n=16652 Medium n=41092 High n=27416	UEFA Competitions	No differences between general or muscle injury rates were reported when <4.5h or >4.5h to <7.5h were compared with with >7.5hours. The research concluded that long-term match congestion does not influence injury rates.

A total of 2672 players were investigated from 57 professional European clubs competing in UEFA competitions, with previous match exposure grouped into ‘low’ (<4.5 hours), ‘medium’ (4.5 to <7.5h) and ‘high’ (>7.5h) based on matches played in the last 30 days (17). Despite slightly higher rates being reported to the previous research, the total injury rates reported for low (24.1/1000h), medium (24.2/1000h) and high (23.1/1000h) remained unchanged (17). The evidence reported on total injuries during prolonged periods of congestion does seem consistent; however, the methodology between studies does vary significantly between more ‘defined’ congested periods and longitudinal studies (16, 17, 55).

Despite consistent findings in regard to total injury incidence, the aforementioned research has reported somewhat mixed findings for match injury occurrence during prolonged congested schedules (16, 17, 55). Early research investigating the effect of prolonged fixture congestion suggests an increased match injury risk for players competing in MM weeks for extended periods (62). Injury incidence was reported for non-World Cup and World Cup players during a season of European professional football, which included 14 of the top teams competing in UEFA competitions (62). Thirty-eight players (out of the 65 investigated) participated in MM weeks during the last 10 weeks of their regular seasons, which resulted in 61% (23/38) either sustaining an injury or underperforming during the 2002 World Cup (62). More recently, injury in more defined prolonged periods of congestion was reported i.e. a specific number of matches within an observable time period (16, 55). A prospective study, which investigated 27 teams competing in elite level UEFA competitions for 11 seasons reported increased muscle injury rates during periods of increased matches with <3 days of recovery, though match injury rates remained unchanged (16).

From a single-club perspective, an investigation of 6 matches in 30 days for French League 1 footballers reported significantly increased match injury rates in 3 prolonged periods of congestion (43.3/1000h) versus non-congested (18.6/1000h) periods (55). Discrepancies between these studies may relate to the cohort investigated, i.e. multi-club vs. single. Longitudinal studies may dilute the negative consequences that individual teams face as a result of congested schedules, particularly when considering the aforementioned individual rates reported (55). Furthermore, the demands associated with competing in congested periods may vary significantly depending on the region investigated. For example, travel demands, squad sizes, and the extent of player rotation will also influence the results reported (33). Collectively, these mixed findings show a need for further research, which investigated the influence of prolonged congestion on match injuries.

In contrast to the above, match injury rates reported for 8 successive matches during a 26-day period remained unchanged when compared to matches played outside of fixture congestion (50.3 vs. 49.8/1000h, respectively; p=0.940). However, the number of participants completing all 8 matches was low (n=1) and only 8 players completed >75% of the total match time throughout the 26-day period (31). Teams competing within European competitions general have large squad sizes, which results in significant player rotation during times of increased scheduling (31). This is perhaps one reason for the variation in time frames and periods investigated, and given the differences in methodology, a more consistent approach may be needed to draw conclusions between studies investigating prolonged periods of congestion (36).

Training injuries during prolonged congested schedules are scarcely reported, with only 1 previous study reporting injury incidence. In 3 separate periods of congestion, training injuries were decreased ($p<0.001$) in congested (4.6/1000h) when compared to non-congested periods (14.6/1000h) (55). The reason for reduced training injuries was suggested to be a result of decreased training intensities, whereby training was focused on player recovery and preparation for subsequent matches (55). Despite these suggestions, the actual training loads during the congested period were not reported. Whether a reduction in training load over a prolonged period effects injury rates outside of match congestion is of interest and is yet to be reported.

Despite mixed findings reported to date regarding total injury incidence during prolonged periods, evidence of increased match related injuries appears more consistent (17, 55). The unchanged total injuries rates reported are likely a result of reduced training injuries during these periods, however training injuries are under-reported within the previous research (36). In contrast, acute periods of congestion have reported increased training injuries, which may provide a rationale for the more consistent findings reported between studies (36, 58). Further, the mixed findings reported during prolonged congested schedules may be due to the periods that are defined as congested, which vary significantly and make comparison between investigations difficult (36).

2.4.3. Injury Severity and Effects of Congested Schedules

Injury severity in professional football is reported in terms of time-loss that is associated with individual injuries, assuming more severe injuries result in longer absences (61). These considerations within professional football are crucial, as higher player availability is attributed to success as determined by final ladder position and points awarded in UEFA competitions (91). Therefore, an understanding of injury severity throughout the duration of the season is important for teams to determine the effectiveness of their training and rehabilitation programs (92).

An investigation of 91 clubs in English football (4 tiers), consisting of 2376 players across 2 seasons reported injury severity and time-loss associated with 6030 injuries (97). On average, 1.3 injuries occurred per player, with 34 and 63% occurring in training and matches, respectively (97). Further, 68% were classified as either minor or moderate, while 23% of injuries resulted in at least 4 weeks of time loss (97). Throughout the duration of the study 145, 973 days were lost in total from injuries, which resulted in a mean of 24.2 ± 40.2 days per injury. In addition to days lost, the mean number of matches missed due to individual injuries was 4 ± 6.5 (97). When considering the mechanism of injury, the highest percentage (19%) occurred when players were performing ‘running’ movements which was slightly higher than when being tackled (15%) (97).

More recently, a prospective 6 year study investigating injury in Norwegian football players reported that about half of acute training (51%), acute match (49%) and overuse (55%) injuries were defined as mild (1-7 days), whereas 21% of all injuries were severe (18). The average time-loss associated with injuries appears lower when compared to previous findings in English football (18). Similarly, 16% of all injuries were determined as ‘severe’ (>28 days of absence) from a total of 4483 injuries over a

7 years period when investigating injury severity from 14 different elite European teams (61). Each player within the study missed 37 days on average as a result of injury occurrence; meaning that approximately 12% of a standard season is missed (61).

In contrast to the multi-club studies mentioned previously, injury severity was investigated from a single professional French club over a 15-season period, which resulted in a total of 903 injuries (49). From a total of 143 players, injury severity was reported via injury incidence (/1000h), with 1.36 ± 2.03 minor injuries, 3.5 ± 3.34 moderate injuries and 0.25 ± 0.66 major injuries occurring during matches (49). Interestingly, the incidence of muscle injury also doubled throughout the 15-year period examined from 1995–1996 (1.09/1000h) to 2009–2010 (2.3/1000h) with the highest recorded in 2007– 2008 (2.84/1000h). The research suggests that increased injury occurrence may result from more regular intensive and short periods of reduced recovery times (congested schedules) whereby an appropriate level of fitness is not able to be maintained to withstand the stresses associated with competitive football (49).

2.4.3.1 Injury Severity and Congested Schedules

The severity of injuries during acute congested schedules is not extensively reported, with only two studies investigating the potential effect of reduced recovery times (34, 58). Injury occurrence was investigated across 2 seasons in professional Scottish football, whereby regular acute congested periods resulted in increased time-loss injuries during MM weeks with reduced recovery (<3 days) between matches (58). Specifically, slight (n=26), minor (n=33), moderate (n=33) and major (n=15) injuries were all higher for MM weeks when compared to matches played with >5 days of recovery for slight (n=22), minor (n=16), moderate (n=17) and major (n=3) (58). Predominantly, injuries were a result of overuse injuries during MM weeks (n=84), when compared to non-congested weeks (n=42), which suggests increased soft tissue as opposed to traumatic injuries as a result of match exposure (58). In contrast, over a 4 year period in professional French football, injury severity was reported as unchanged when comparing matches played with short (<3 days) versus long (>4 days) periods of recovery (34). Severity was determined via time-loss per injury and was reported as identical (15 ± 25 days vs. 15 ± 28 days, p=0.730) when consecutive matches were separated by short versus a long interval (34). Given that mixed findings are evident from a small body of literature, further research may help with understanding the extent of injury severity during acute fixture congestion (34, 58).

Injury severity in prolonged congested schedules also has limited reporting in previous literature, with two studies reporting consistent findings (31, 55). Firstly, injury severity during 3 periods of fixture congestion reported that major injuries (>28 days) accounted for 4.2% of total injuries in comparison to 14.8% in non-congested matches (55). While moderate (39.8% vs. 22.2%) and minor (27.9% vs. 14.8%) injuries were higher in congested versus non-congested match periods (55). Similarly, severity during a period of 26 days, which included 8 successive matches determined that the majority of injuries were classed as minor (6 out of 7, 85.7 %) with only 1 injury requiring a longer layoff period (5 days in total) in professional French football (31). Collectively, these results suggest that the actual severity of injury during prolonged periods of congestion is reduced when compared to non-congested periods (31, 55).

Although unexpected, research suggests that results may be influenced by the reduced training intensities that occur during prolonged periods of congestion (58). However, studies reporting actual training load distribution throughout these periods are scare, making it difficult to conclude the effect that load has on severity of injury (5). Further, severity of injury during prolonged congested schedules in Australian football is unknown. Given the small squad sizes and reduced playing depth, an understanding of injury severity is perhaps even more important.

2.4.4. Injury Location and Effects of Congested Schedules

The location of football injuries has been extensively reported in previous research, as the understanding of where injuries are sustained enables practitioners to better prepare players for the demands of football competition (61). Injuries over a two-year period were prospectively reported for 91 of the 92 football clubs competing in the 4 tiers of professional English football, with all injuries reported for location in both competition and training (97). The study reported thigh injuries as the highest (23%) location for injury, followed by knee (17%), ankle (17%), lower leg (12%) and groin (10%) when competition and training injuries were pooled together (97). Similar findings were also reported during competition vs. training injuries for thigh (24 vs. 22%), knee (17 vs. 16%), ankle (19 vs. 14%), lower leg (12 vs. 13%) and groin (6 vs. 16%) (97). Strains, sprains and contusions were reported to represent 69% of all the injuries sustained over the 2-year period, with 'other' hard tissue injuries the cause of the remaining percentage (97). Interestingly, a greater number of injuries occurred to a player's 'dominant' side compared to non-dominant (50% vs. 37%, $p<0.01$), with 87% of all injuries sustained in the lower extremity (97). Predominantly, 81% of muscular strains occurred in the thigh muscles compared with 18% in the groin (97). The location of the aforementioned injuries was significantly influenced by preceding injury location, which is highlighted via injury reoccurrence rates (97). Further, re-injury severity was reported as more detrimental than the original injury with the number of missed training days averaging 25.1 (31.8) compared with 19.1 (27.3) days for the initial injury ($p<0.01$). Although the mechanism of injury reoccurrence is hard to establish, it can be concluded that previous injury locations may have an increased risk of re-injury (97).

More recently, similar findings were also reported during 6 seasons of elite Norwegian football, which resulted in 2365 injuries occurring in training and match play (18). The most common injury type was muscle injuries (46%), joint injuries (27%) and contusions (14%), which maintained a similar occurrence of injury incidence over the study duration (18). Injuries sustained to the thigh were most common (22%), with ankle (18%), knee (16%), groin (11%) and lower leg (10%) the other regions reported (18). Reoccurrence of injury was also reported, with approximately 20% of all injuries and 58% of muscle injuries a result of re-injury, primarily localised to the thigh and hip/groin region (18). These findings are also consistent with research spanning 7 years from European teams' in UEFA competitions, whereby 4483 injuries were prospectively investigated (61). It was also reported that the single most common injury subtype was thigh strain, which represented 17% (n=743) of all injuries (61). Posterior thigh strains (hamstrings, n=525, 12%) were more common than anterior (quadriceps, n=218, 5%), with the research suggesting that teams with a mean of 25 players can expect 10 thigh muscle injuries per season (61).

The findings of the aforementioned research are consistent in the location of injuries previously reported; however, recently suggestions have been made that groin injuries are underreported in current literature (95). Investigating the prevalence of groin injuries across different levels of men's football (97% elite men), it was reported that from a squad of 20 players, approximately 6 have experienced groin problems, with only a third of these being captured via traditional time-loss associated injuries (95). As such, it is suggested that groin injury prevalence may be higher than those reported in current literature as the majority of injuries are long-standing issues which result in altered training programs rather than missed matches (95). Despite these suggestions in relation to groin injuries, collectively the literature shows that injuries are predominantly isolated to the lower body, with thigh injuries occurring most frequently, followed by knee, hip/groin, ankle and other lower leg injuries (61, 91). These findings can help guide practitioners in determining which recovery tests are most suitable, when attempting to better monitor injury risk at the aforementioned locations (91).

2.4.4.1 Injury Location and Congested Schedules

When considering the impact of acute periods of congestion on injury location, the majority of injuries reported are sustained in the thigh region and are significantly higher in MM weeks (58). Specifically, MM versus non-congested weeks reported differences for a count (n) in thigh (32 vs. 15), knee (22 vs. 6), hip/groin (13 vs. 10), ankle (15 vs. 6), lower leg (8 vs. 10) and foot/toe (5 vs. 5) injuries suggesting that increased match exposure or reduced recovery results in a higher overall injury occurrence though localised to similar regions (58). Further, injuries in both groups were mostly related to muscle/tendon tissues in the form of ruptures, tears, strains and cramps (93 out of 165), while sprains (n=34) were also high (58). In agreement, an investigation of injuries sustained in short (<4 days) versus long (>6 days) recovery post-match reported hamstring injuries as the most commonly injured location (16). However, no differences were reported for the incidence of injury between recovery times, with hamstring (5.74 vs. 4.47/1000h), quadriceps (1.53 vs. 0.85/1000h), adductor (2.64 vs. 2.38/1000h) and calf (1.21 vs. 1.07/1000h) injuries all marginally higher in <4 days versus >6 days of recovery, respectively (16). These results are consistent with recent research, which also reported the location of injury in matches with <3 days or recovery versus 6 or 7-10 days (17). Similar patterns were reported in regard to injury location as those previously; however, hip/groin and thigh injuries were reduced by 18-22% when matches were separated by 6 or 7-10 days when compared to <3 days indicating that some injury locations may benefit from longer recovery times (17).

Based on the previous research, it is evident that the location of injuries during acute congested schedules remain unchanged; however, the actual number of injuries sustained at each location does increase as a result of reduced recovery between matches (16, 17, 58). Further, injuries are predominately a result of non-contact muscular injuries occurring within soft tissue (17). In contrast to MM acute periods, injury location within prolonged congested fixtures has only been reported once (31). The reason for the limited research is most likely a result of insufficient injuries recorded during prolonged periods, which therefore makes it difficult to infer findings. During a 26-day period where 8 matches were played in succession, a total of 7 injuries were reported, which included 4 contusions (quadriceps, knee and foot), 2 muscle strains (groin and hamstrings) and 1 sprain (ankle) (31). All contusions were a result of direct contact with an opponent, while strains/sprains occurred from non-contact in match play (31). Although limited to 1 study, these results show a more random distribution in injury location than those in discreet MM weeks, which highlights the nature of contact injuries in prolonged congested periods primarily as a result of increased match exposure (31). Within prolonged and acute congested periods, reduced training loads are suggested to result in reduced training injuries, as such the majority of research has focused on match related injuries. However, training load distribution has not been reported in any of the aforementioned research, therefore the effect that load may have on injury in these periods is relatively unknown.

2.5. Training Loads in Football and Effects of Congested Schedules

2.5.1. Theory and Methods of Training Load Monitoring

A mediating factor of injury occurrence is the training and match loads encountered (184, 185), and of interest for the current thesis is how these change during congested schedules (5). Before discussing training and match loads encountered in normal and congested schedules, some initial discussion of training load concepts and measures are appropriate. The early beginnings of training load monitoring are a result of the fitness-fatigue model proposed by Banister et al., (12) (Figure 2.3). The model describes the dose-response relationship to training, where following a training stimulus an athlete sustains both acute fatigue and chronic fitness responses (12). The difference between these two variables results in a performance outcome, with a positive result achieved when fitness outweighs fatigue, conversely a negative response occurs with greater fatigue (12).

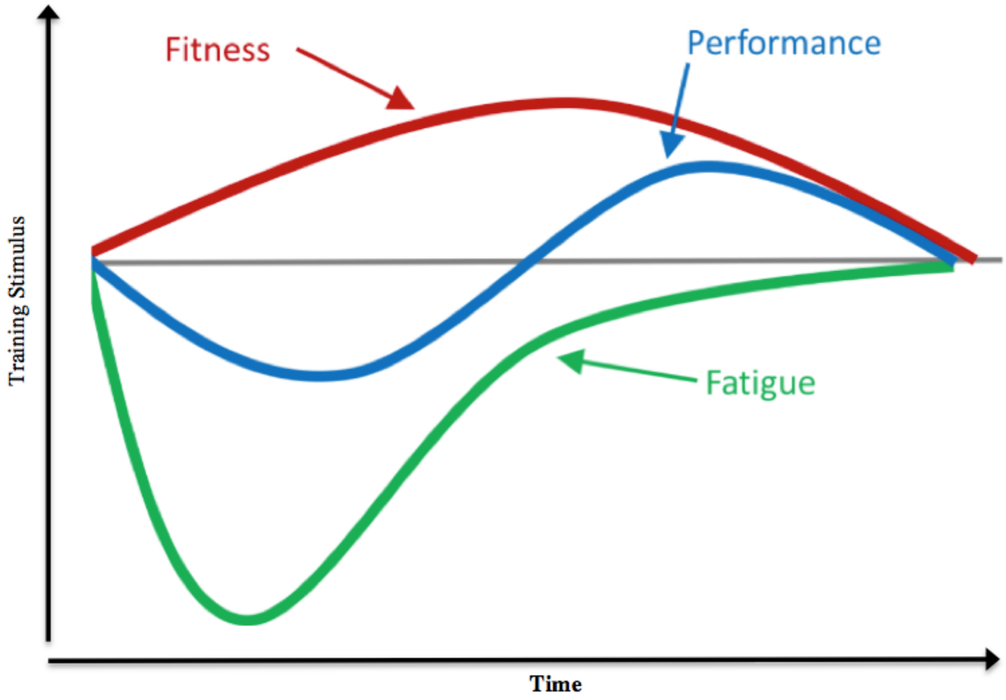


Figure 2.3: The fitness-fatigue model as proposed by Banister et al. (12)

Given this theoretical rationale, correct monitoring of training loads can maximise a player's performance gains by ensuring appropriate stimulus is administered to reduce the effect of fatigue (141). Training loads can be classified as either external or internal, with various methods used to calculate each within professional sport (186). External load describes the amount of work completed irrespective of an athlete's physical characteristics, which is typically quantified from either training or match play (136). Alternatively, internal load describes the physiological and psychological stress response to the dose of training (107). Quantifying, monitoring and understanding the external and internal load distribution within elite football is considered important to ensure players are optimally prepared for the demands of competition (107). An individual's response to training load is dependent on many different factors including; age, sex, training history, genetics, stress tolerance and non-training environmental stressors (107). Therefore, multiple objective and subjective measures of internal/external load are used to ensure a comprehensive understanding of each player's responses to a training program (107). Accordingly, a discussion of external and internal load factors is important before describing the values (and the effects of congested schedules) in football.

2.5.1.1 External load measures

External load can be considered as the amount of work completed by an athlete, which is measured independent of the individuals' internal psycho-physiological characteristics (107). External load provides an understanding of the capabilities and capacity of athletes when completing a designated bout of work, though it does not consider the relative physiological and psychological stress caused as a by-product of load (94). Time-motion analysis (TMA), including global positioning systems (GPS) are the most common method used to track player movement (100). In part, the popularity of GPS monitoring in team-sports relates to the ability to quantify various physical stressors that are otherwise difficult to measures i.e. distances and speed (44).

GPS units, and accompanying accelerometers provide empirical data on locomotive demands within sport such as; total distance, distances in discreet speed zones, accelerations and declarations (94). More recently, changes in wearable GPS unit microsensor technology has seen the integration of inertial measurement units (IMU), with devices now considered reliable for detecting small or intense changes of direction (127) and collision events (101). A large volume of research has been conducted on GPS validity and reliability (44, 164, 195, 200), with most studies concluding that total distance and distance in different speed zones to be of acceptable reliability. For example, GPS derived measures for all variables of distance and speed were reported as reliable (CV = 1.62% to 2.3%), particularly peak speed (95% limits of agreement LOA) = 0.00 ± 0.8 km/h; CV = 0.78%) (200). However, research has shown that reliability during high-intensity efforts, including change of direction to be less consistent (CV = 4.69% to 5.16%) (111).

Despite the aforementioned limitations, GPS monitoring of external loads in both training and matches is widely used in professional football (130, 161, 186). Specifically, GPS is useful in quantifying the quantity and quality of load specific to the team and individual players (107). Traditionally, measures of GPS were only used to quantify the load in training sessions, though more recently, a change in regulations from FIFA meant that teams were able to wear devices in matches. As a result, quantification of external match load provides practitioners with a more detailed analysis of individual player loadings, allowing for better management of ensuing recovery periods (94). The most common measures collected via GPS include; total distance, mean speed (m/min), acceleration/decelerations and distances within individual speed zones, which are widely reported within literature (110, 176). While GPS monitoring does provide important quantification of the speeds, distances and acceleration of player movements, such measures provide no indication as to how the athlete responds to such external demands.

2.5.1.2 Internal load measures

In contrast to the above, internal load represents the physiological and perceptual responses to the training stimulus/external load, with heart rate (HR) and perception of effort responses the most common measurement tools used (94). Perception of effort is acquired via methods proposed by Borg (20) and use the category ratio scale. The session Rating of Perceived Exertion (sRPE) scale ranges from 0-10, with a score of 0 representing 'nothing at all' and 10 'very very hard' (maximal exertion) (20). Further developments by Foster, (73) proposed using the RPE scale and multiplying a participants' response with session duration, to calculate the training load. The validity of sRPE in quantifying training load has previously been assessed during competition, which reported strong correlations to session intensity ($VO_{2\ max}$) and heart rate (r=0.80 and r=0.92, respectively) (201). Due to the simplistic non-invasive nature of obtaining sRPE, it is considered as the most commonly used method for quantifying training load at multiple levels of competition (94). Further, aside from its simplicity, being a subjective measure sRPE also accounts for inter-individual variations in response to the same training stimulus (94). Although sRPE has reported strong correlation with measures of heart rate at different levels of exercise intensity (201), the use of heart rate as an objective method to quantify internal load during training and matches is still widespread (94).

The stressors associated with training potentially involve the autonomic nervous system, which may result in variation to heart rate as a representative marker of cardiovascular load (2). Although common in a clinical environment, the use of HR measures to quantify internal load are also popular and heavily utilised due to the intermittent nature of football, which leads to high cardiovascular load (3, 157, 186). Further, HR measures are reported to have acceptable levels of reliability as a measure of exercise intensity in sport (3.9% CV, 0.863% ICC), demonstrating linear relationships with VO_2 (107, 201). Several methods of HR monitoring have been proposed in football, which aim to quantify the load response of training and matches (107).

In professional football, measures of mean and max HR (HR_{max}) are frequently used and well documented within literature (54). However, the use of these measures to calculate overall percentage of max HR ($\%HR_{max}$) and time spent within intensity zones does provide greater insight into a player's response to training and matches (67, 98). As a consequence, various methods of quantifying banded $\%HR_{max}$ have been proposed (13) such as training impulse (TRIMP) to monitor fatigue. TRIMP scores are calculated by multiplying session duration with subjective ratings of exercise session HR intensity (50-60%=1, through to 90-100%=5) (13). Several limitations of TRIMP scores do exist, including; limited HR entries into higher zones and HR not responding to abrupt changes in work rate (201). Furthermore, these measures of HR monitoring make comparison between individuals difficult, as high variability exists due to the age range of players resulting in varying HR_{max} (54). As a consequence, sRPE is typically collecting in conjunction with internal measures of HR to provide a more holistic method of monitoring the training response in athletes (94).

2.5.1.3 Acute Chronic Workload Ratio

Acute chronic workload ratios (ACWR) have become an increasingly popular method to quantify training loads within professional sport (94). ACWR is an adapted representation of the negative fatigue (acute load) and positive fitness (chronic load) response to training, which has been suggested as a good method for monitoring stochastic changes in training load (80). As previously discussed, the external and internal load-injury relationship is somewhat based on the fitness-fatigue model of Banister et al. (12). ACWR's are gaining popularity as a method to factor in both acute and chronic workloads (80). Specifically, acute and chronic workloads are calculated using rolling averages of load (either internal or external) within selected timeframes, typically 7 and 28-days, respectively (80). Although individual sports differ in the timeframes used to report acute and chronic load, field-based teams sports justify the use of 7 and 28 days due to alignment with typical micro and mesocycles (79, 102). The ratio between acute and chronic workloads is used to create the ACWR, which is commonly reported and used in research to assess the relationship between load and injury (79, 102). However, recent research has questioned whether monitoring loads using rolling averages via ACWR fails in quantifying the extent that fatigue and reductions in fitness have over time (124, 142, 202). Furthermore, although ACWR's have reported an association with injury risk, the actual ability to 'predict' injury is limited, with evidence questioning whether ACWR's do relate to injury occurrence (68).

One aspect of concern with the ACWR is the method in which it is calculated (142). For example, an alternative load model to ACWR has more recently been suggested, the exponentially weighted moving average (EWMA), which incorporates a decay factor to loads over time (152). The EWMA places greater emphasis on more recent loads experienced by the athlete with a decreased weighting applied for each older session (104, 152). Recent research, which investigated differences between EWMA and ACWR in elite Australian footballers, reported EWMA as a more sensitive indicator of subsequent injury (152). Further, it has also been suggested that another limitation of ACWR is the calculation used, when using 7 and 28-day acute and chronic timeframes; the 7-day acute period is also included within the 28-day chronic calculation (124). As a result, research has suggested the removal of the acute load timeframe from the chronic load calculation, meaning that chronic load would be calculated using day 8-28, while acute load would be day 1-7 (124). Despite these limitations, ACWR's are frequently used within research, with the majority of investigations focused on the relationship between ACWR and injury (102, 152).

When considering ACWR's and injury, investigations in football are relatively consistent with negative findings reported for high and low ACWR's. For example, 75 time-loss injuries were investigated over two seasons in the EPL to determine whether a relationship existed between injury and ACWR (132). It was reported that players who recorded in-season sRPE ACWR's ranging from >1.00 to <1.25 were at a significantly lower risk of injury than a reference group of <0.85 (OR=0.68, 95% CI: 0.08–1.66, p=0.006) (132). Similarly, an investigation of the load-injury relationship in professional Dutch football reported that a ‘medium’ (0.85 - 1.12, OR: 0.39, 90% CI: 0.23–0.65) and ‘high’ (>1.12, OR: 0.69, 90% CI: 0.42–1.13) sRPE ACWR had a likely beneficial effect on injury risk (110). Further, a very likely beneficial effect was found for a medium ACWR for deceleration (0.86–1.12, OR: 0.38, 90% CI: 0.20–0.72) and acceleration efforts (0.87–1.12, OR: 0.49, 90% CI: 0.24–1.02) above or below 1 m/s (110). Also in agreement, a recent UEFA study of 130 players from 5 different clubs in France, Italy, Spain and England reported on 237 non-contact lower body injuries (53). Injury incidence was higher when the ACWR was <0.85 vs. >0.85 (RR=1.31, CI 95%: 1.02–1.70), however, high ACWR (>1.50) did not have a higher injury risk compared to low (<0.85) (53). Similar findings have been reported in Australian Rules football, also showing that medium (0.85 - 1.02) and moderate (1.02 - 1.18) ACWR’s have a positive influence on injury risk (184). In contrast, low (<0.6) and high (>1.5) ACWR’s were found to increase the likelihood of injury (184). Despite the literature presented, questions still do remain over the use of ACWR’s, particularly in regard to the ranges deemed as ‘low’, ‘medium’ and ‘high’ reported here, which are not based on individual player responses (27, 68).

During congested schedules, high fluctuation or ‘spikes’ in load may result between weeks in acute and prolonged congested periods. Therefore, based on the evidence presented, ACWR’s seem appropriate to monitor load during these periods (152, 184). As evidence, recently reported data from the EPL suggests that a stronger association to non-contact injury risk was determined with ACWR’s when compared with accumulated loads (21). Specifically, very high acute spikes in ACWR’s (>2.0) for different metrics (distance <14.4km/h, accelerations and decelerations >0.5m/s/s) corresponded with a higher non-contact injury risk when comparable chronic loads were low (21). However, the aforementioned investigation spanned a 3-season period, which despite containing congested periods, did not determine what influence these specific periods have on ACWR (21). Accordingly, understanding the internal and external loads, as well as the distribution of those loads (via ACWR) will provide insight into loads during congested periods in professional football.

2.5.2 Training Load in Football and Effects of Congested Schedules

The following section of the literature review will focus on mean daily and total weekly loads reported within professional football. Specifically, internal and external load within 'normal' match scheduling will be established in order to compare load profiles during congested schedules.

2.5.2.1 Internal Training Load

When considering in-season training sessions, mean daily loads of 462 ± 237AU have been reported in semi-professional football players and 272 ± 168AU in the EPL (37, 130). However, daily training loads of 379 ± 198 (95% CI: 334–430AU) have also been reported for other professional European teams (133). These differences regarding daily total load are largely dependent on periodisation and the focus of the specific training day, which is heavily influenced by coaching staff and varies significantly within individual teams (130). For example, previous research on second division Spanish footballers reported the highest session training loads following skill drills/circuit training and small sided games (642 ± 108AU), while lowest loads were reported in pre-match activation sessions (328 ± 82AU) (178). Further, the loads reported show a clear 'tapering' strategy throughout the week whereby load is progressively reduced leading into a match (160). These 'tapering' strategies are also an important consideration during congested schedules, as repeated match exposures within a week disrupt the typical training schedule (55).

In contrast to session load, total weekly sRPE training loads of 1549-1983 AU have been reported at different time points during the season for Australian footballers (75). In agreement, mean weekly total loads also reported for an Australian professional team ranged from 1500-2000AU over the course of a season (125). In Europe, research has reported slightly higher mean sRPE total in-season weekly (2441 ± 215AU) loads for an EPL team (132). However, collectively weekly training loads during the competitive period range between 1700 – 2500AU, which is largely dependent upon individual player match duration (143). When sRPE match loads are not included, mean weekly total loads of 644 ± 224AU have been reported for professional Italian football players (133). Collectively, this research shows that total weekly loads between competitions do not vary significantly. However, given that total loads are significantly influenced by match load, congested periods of successive matches should be considered for their influence on total load (5). Further, how an athlete responds (HR) to sRPE load throughout training sessions and weeks is also of interest.

Mean and max heart rate responses during training sessions are reported as 134 ± 11 and 183 ± 19 beats per minute (BPM), respectively for Swedish professional football player's (157). Further, mean $HR_{\%max,}$ which is a commonly reported objective measure within professional football (116), was reported as 71 ± 5% throughout all training sessions (157). $HR_{\%max}$ during in-season training sessions has been reported as 58 ± 6% in Korean football players, while 65-71% and 69 ± 2% has also been reported for UEFA and EPL teams, respectively (30, 112, 130). The duration of time spent within discreet zones of $HR_{\%max}$ are significantly different during training when compared to match-play, where the majority of time is predominately spent >85% max

HR (133). In training, the percentage of time spent at 0-60%, 60-75%, 75-85%, 85-95% and >95% has been reported as 22%, 35%, 21%, 11%, 9% and 2%, respectively throughout the duration of a season in Swedish football (157). However, the percentage of duration attributed to individual HR zones is significantly impacted by the type of training/drill within a session, for example $HR_{\%max}$ of >90% have previously been reported for high intensity aspects of training (54). Although HR varies significantly between individual players, collectively the evidence reported here shows typical normative values throughout seasons, which are able to be compared to periods of congested scheduling (outlined below).

2.5.2.2 External Training Load

External loading patterns differ significantly throughout a week in professional football, though when considering the total loads reported similar periodisation is evident for individual weekly microcycles (160, 193). Total distances also vary depending on the competition investigated, with mean daily distances of 6000-7000m reported for EPL players, which appears lower when compared to 6800-11 800m in the Scottish premier league (130, 160). Similar training load distribution was also reported for EPL footballers throughout individual training weeks (130). Mean session external load during the 'early phase' of season (week 7) was reported for distance (6182 ± 1841m) and mean speed (81 ± 9m/min). While during the later phase of the season (week 39) loads were significantly reduced ($p<0.05$) (130). Specifically, distance (4714 ± 1581m), mean speed (79 ± 7m/min) were lower compared to earlier phases in the same season (131).

Typically, the last day of a training week before a match has the lowest load, with 2800-3800m reported for different positional groups in UEFA competitions (160). In contrast, the highest loads during the week were reported 3 days pre match, with distance (6000-7400m), mean speed (79.9-62.0m/min) ranging significantly ($p<0.05$) between positional groups (160). Mean speed ranges significantly on all training days during a week, with 1 (50.1-79.8m/min), 2 (80.5-99.0m/min), 3 (62.0-79.9m/min, and 4 days pre (75.7-82.9m/min) match all reporting differences in load (160). When considering the distance throughout a training week, total distances of 23.5-31.1km have been reported in professional Finnish football (110). While in Australian football, training distances (without match) of 15-20km have been reported with a mean speed of 65-70m/min (125).

When considering distances within different speed zone, the majority of research has focused on the distance covered at higher intensities (130). High-intensity running (21.6-25.5km/h) and sprinting distance (>25.2km/h) reported for elite European football ranged significantly during training sessions with means of 95.0-123.1m and 1-63.6m, respectively reported (160). These results are consistent with those reported in the EPL, with mean daily high-speed distances (>5.5m/s) of 243 ± 229m demonstrated (130). The loads reported during the latter part (week 24) of the season were significantly different however ($p<0.05$), with reductions in high-speed distance (146 ± 104m) reported when compared to the early phase of the season (ES = 0.84 [0.28-1.39], moderate) (130).

During a week, high-speed distances (>20km/h) range from 634-1028m for professional Finnish football (110). In contrast, distances of 2000-2500m high speed (14.4-19.8km/h) have been reported in Australian football (125). Overall, it appears that external load is significantly influenced by individual team characteristics and the competition in which they compete (160). Further, loads fluctuate significantly throughout the season, particularly in the later stages of a season, which interestingly also corresponds with times of increased match scheduling (130).

2.5.2.3 Training Loads and Congested Schedules

When considering internal and external load distribution in congestion schedules, research to date is limited to European football with 1 study investigating load in acute periods (5). Training loads in 1, 2 and 3 match weeks were investigated for 12 outfield players in the EPL (5). In SM weeks, it was reported that highest mean distance and speed was on day 4 (5223 ± 406 m; 80.7 ± 6.3m/min), while loads were progressively reduced on day 5 (3097 ± 149 m; 51.7 ± 2.5m/min) and 6 (2912 ± 192m; 41.7 ± 2.8m/min) (5). The load profile reported for MM weeks reports very similar results for day 4 (5493 ± 421m; 70.8 ± 5.4m/min), 5 (4395 ± 261m; 70.0 ± 3.8m/min) and 6 (2470 ± 184m; 41.0 ± 2.9m/min) when compared to SM weeks (5). The biggest difference between weeks was day 3, which in a MM week (1453 ± 65m; 63.0 ± 2.0m/min) was at 48h post-match and therefore had an emphasis on recovery compared to SM week (5).

Of note, only when playing 3 matches within a week was external load significantly reduced during training, which also resulted in 2 days of training when compared to 4 in SM and 2 match weeks (5). The training days within 3 match weeks were not significantly different when compared to day 6 (1-day pre match) within SM and 2 match weeks, suggesting a tactical and recovery focus of these sessions (5). However, overall total distance and high-speed running were significantly higher in 3 match weeks due to increased match exposure when compared to SM ($p<0.01$) and 2 match weeks ($p<0.01$) (5). When compared the aforementioned research, the external loads reported within normal microcycles appear higher than those in congested schedules (5, 130). Clearly loads are reduced during acute congested schedules as a means to positively influence recovery, however, whether loads are reduced over prolonged periods of fixture congestion remains to be investigated. Further, what effect prolonged reductions in load may have on performance and injury is also yet to be established as a consequence of congested schedules.

Reporting of external loads during prolonged congested periods are also lacking in existing literature, with the majority of studies focusing on physical workloads within matches (31, 55, 150). External loads were reported during training for a 32-day period of fixture congestions in the EPL, which included 7 matches and 18 training sessions (150). In contrast to acute congested periods, the recovery time between matches during prolonged periods varies more significantly, which results in higher training loads being reported between matches that have increased recovery time (150). Total distance (508 ± 443 - 5780 ± 1885m), high-speed running (0 ± 1 - 133 ± 89m) and sprint distance (0 ± 0 - 24-30m) in training all varied significantly during the 32 day period, with the lowest loads reported the day before matches (150). Interestingly, 4 out of the 7 matches played were completed in 11 days during the 32 day period, accordingly, the mean external load reported around these matches was significantly reduced for distance (1447m), high-speed (8.5m) and sprint distance (0.5m) (150). In contrast, match 2, 6 and 7 within the congested period were played with >5 days of recovery between exposures, as a result the mean external load preceding these matches was much higher for distance (3623m), high-speed (80m) and sprint distance (11m) (150). Therefore, it appears that external loads are only reduced between matches with reduced recovery, while greater recovery times between other matches allow for increased external loads (150).

Summary

As discussed in the above sections, the internal and external training demands currently imposed on professional athletes are extensive with considerable research investigating the influence that loads have on injury occurrence (110, 160). Although extensive, training load distribution for individual teams appear to fluctuate significantly with different coaching styles influencing the load exposure for players (6, 130, 160). Despite such contextual factors, practitioners use a variety of measures to quantify the extent of internal and external load during training to monitor players (110). However, high workloads from both training and matches are becoming increasingly difficult to manage, with busy schedules commonly experienced at high levels of competition (55). As a result, recovery time is often limited and perhaps insufficient for players to fully recover before experiencing further match demands. Furthermore, typical in-season training schedules are potentially disrupted as a consequence of congested schedules, though these effects are relatively unknown and underreported. In order to better manage player loads, external load measures from GPS, aligned with internal load measures of heart rate and psychometric rating tools are commonly used. These measures outline the load and response to that load during training and matches, though they do not in turn explicitly relate to the recovery status of the athlete (94, 186). The recovery of athletes and their individual response to training stressors is also frequently monitored, with the aim of balancing performance outcomes and fatigue.

2.6. Recovery in Football and Effects of Congested Schedules

2.6.1. What is Recovery?

Athletes are exposed to significant physical and perceptual demands as a result of both match play and training (as discussed previously); therefore, management of load, recovery and fatigue is imperative to ensure success in professional football (85, 87, 106, 134). High training volumes, paired with fluctuating intensities are required for players to develop the physiological, psychological and technical abilities needed for football (35). In fact, evidence suggests that higher accumulative workloads (i.e. medium 4-weekly accumulative loads of >7087 AU loads) are actually protective in nature when compared to lower loads (110). Therefore, given that high workloads result from matches, and are also necessary during training, it is important to understand appropriate recovery requirements in order to minimise the influence of residual fatigue (179).

Training programs are designed to induce adaptation through the super-compensatory theory, which suggests that disruption of homoeostasis (from periods of intensified training) will result in performance decrements; however, following sufficient recovery, the same training stimulus will result in less disruption of homoeostasis (141). Occasionally, coaches allow less recovery time following periods of hard training in order to overload the athlete, commonly referred to as functional overreaching (FOR). FOR is also accompanied with temporary reductions in physical performance; however, following adequate recovery a super-compensatory effect occurs with an associated increase in performance (141). Given the above theoretical rationale, correct monitoring of not only the training dose is required, but also the following recovery period (141).

Despite the super-compensation theory, periods of increased load are not always beneficial for athletic outcomes, as excessive increases of training duration, intensity or frequency have the potential to increase the likelihood of injury, prolonged performance decrements and progress an athlete through the fatigue continuum (141) (Figure 2.4). The fatigue continuum starts with an acute fatigue response to a training stimulus that is followed by an insufficient period of recovery. If further training stimuli is applied (either planned or otherwise, i.e. congested scheduling of matches) before sufficient recovery, then fatigue will accumulate, leading through the fatigue continuum and ultimately to non-functional overreaching (NFOR) and symptoms of overtraining syndrome (OTS) (141). The negative consequences of OTS (hormone dysregulation, psychological disturbances, decreased immune function, sleep disorders) can take anywhere from weeks to months before athlete’s return to their previous physical capacities (141).

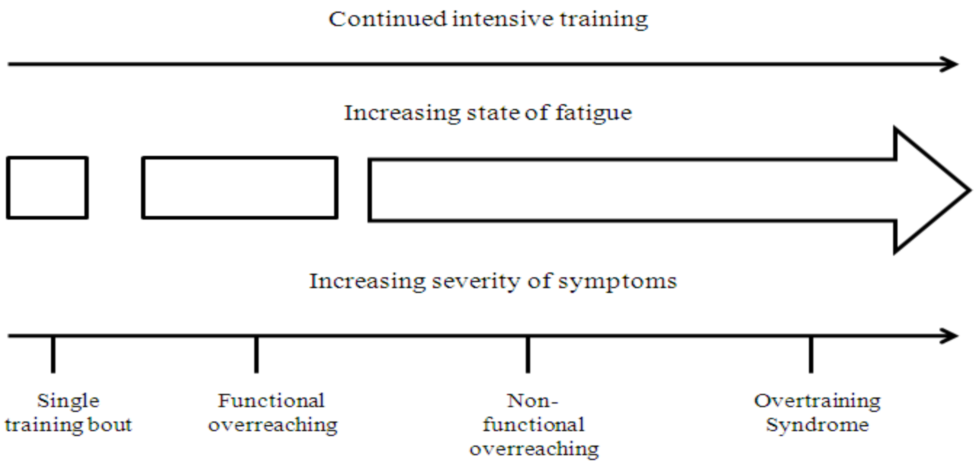


Figure 2.4: Theoretical representation of the fatigue continuum (140, 141).

Due to the aforementioned issues surrounding training intensity and recovery, several methods have been developed to monitor the recovery and fatigue state of an athlete. Monitoring an athletes’ recovery to training and matches provides critical information on the ability of the athlete to ‘cope’ with the demands of a training program (179). Correct monitoring can maximise the athletes’ performance gains, whilst also allowing coaches to program ensuing training sessions in response to the psycho-physiological stressors of the training program (107, 141).

Fatigue often results from the physical demands imposed on football players during both training and matches (134). The mechanisms that cause fatigue are not fully understood; however, fatigue can be described as the inability to maintain performance, which ultimately leads to a decline in output variables (64, 66). Depending on the context, the cause of fatigue is multi-factorial (1); including

- Mechanical: A reduction in force output of a muscle
- Psychology: The sensation or perception of tiredness, or a decrease in cognitive function
- Physiology: A limitation of a specific physiological system, such as the inability of the heart to supply ample blood flow to working tissues or a failure in the muscle excitation-contraction coupling process
- Neurology: Reduced motor drive or neural activation.

Fatigue has been suggested to result from both central and peripheral mechanisms (22). Peripheral mechanisms often refer to fatigue causing properties in the muscle itself affecting the action potential, extracellular and intracellular ions, and many intracellular metabolites (4). Traditional mechanisms causing a decline in performance are attributed to an accumulation of intracellular lactate and hydrogen ions, which impair the function of contractile proteins (4). Further, ionic changes on the action potential and a failure of the sarcoplasmic reticulum (SR) to release calcium have also been suggested to be mechanisms of fatigue to exercising muscle (4).

In contrast, central mechanisms of fatigue are less understood, though increases in brain serotonin (5-HT) have been suggested as leading to mental fatigue (50). More recently, it has also been determined that dopamine release may contribute to central fatigue by causing tiredness and lethargy, which accelerate the onset of fatigue (140). Regardless of the definition, post-match fatigue following a football match can result from multiple sources, which have potential to cause both central and peripheral fatigue; including dehydration, glycogen depletion, muscle damage and mental fatigue (50). Regardless of the origin or cause of fatigue, understanding athlete responses to acute and residual fatigue are important to assist optimal performance (179). Thus, monitoring of athlete preparedness based on the potential issues outlined above is crucial to determine whether players have recovered sufficiently from previous workloads and what state they are in for ensuing session prescription (128). Furthermore, enhancing the recovery process will allow coaches to better manage residual fatigue that could lead to decreased performance, overtraining and/or injury (138).

2.6.2. *Measures of Recovery and Timelines Following Matches*

A football match results in decreases to physical performance as a direct result of the demands associated with competition (26). The ensuing recovery period could be considered the duration of time it takes for athletes to return to pre-match levels of physical performance (153). If players engage in further physical activity with insufficient recovery, symptoms of acute or chronic fatigue may result - potentially leading to overtraining and/or injury (179). With busy schedules associated with professional football, including congested matches, training, travel and public appearances it is difficult for coaches to allow for sufficient recovery between matches (33). Therefore, monitoring of individual players recovery is imperative to ensure that players are not exposed to increased risk of injury (134).

A range of different recovery measures are commonly used in professional sport, including strength/power assessments, sprint test performance, biochemical markers, heart rate responses and perceptual ratings of perceived stress and recovery (186). Due to the invasive nature of many monitoring practices, their use is somewhat limited in a professional environment. Further, some muscular performance tests themselves have fatigue causing potential (94). Despite these limitations, a survey of 100 professional sporting teams (strength and conditioning coaches, sport scientists) concluded that 61% of teams surveyed used maximal neuromuscular performance tests to monitor player fatigue and recovery (186). Specifically, tests such as; maximal jumps, sprints, sub-maximal cycling, sub-maximal running and sports specific running tests were performed within teams to monitor recovery (186). However, the largest percentage (84%) of respondents used a form of self-reporting questionnaires to monitor their athletes, potentially as these methods are non-invasive and are an easy to administer measure of player recovery (94). Further 55% of these respondents noted the use of self-reporting questionnaires on a daily basis (186).

2.6.2.1 Subjective Wellness

Recovery and stress are commonly inferred in professional sport with the use of psychometric questionnaires, which align key questions to identify psychological stresses influenced by fatigue (117). Given the multifactorial influences of training on psychological stressors, self-reported questionnaires are popular and commonly used in sport, which may provide early warning signs of negative training and maladaptation (186). Significant research exists using various subjective questionaries in sport, including; profiles of mood states (POMS), daily analyses of life demands of athletes (DALDA), total quality recovery (TQR) and recovery stress questionnaire for athletes (REST-Q), which all aim to assess the subjective wellbeing of player's (94, 117). However, these methods are not always practical given the time needed for players to complete the questionnaires, which can take extended periods (monthly) (45, 47). As a result, customised psychometric scales which are reported as sensitive to daily, within-weekly and seasonal changes in training load have been proposed (82, 138).

One form of popular psychometric testing involves wellness questionnaires, which represent an individual's perceived state of stress and commonly incorporate questions such as fatigue, sleep, muscle soreness, stress and mood (82, 138). Several studies have demonstrated the usefulness of wellness measures in training monitoring (45, 46, 190). When using a questionnaire comprising of 9 items (fatigue, general soreness, hamstring, quadriceps, pain/stiffness, power, sleep quality, stress and wellbeing) and using a 1-5 Likert scale is was reported that wellness was sensitive to weekly training sRPE manipulations ($n=2583$). Results showed that player's wellness steadily improved throughout the week leading up to match day ($p<0.001$), and wellness responded to periods of unloading throughout the season ($p<0.05$) (82). Further, perceived ratings of fatigue have been reported as sensitive to daily fluctuations in high-speed running for elite EPL players (190).

When considering the timeline for recovery post-match, perceived wellness (using a 5 response questionnaire) was reported to be reduced for up to 48h following a match before improving to baseline levels in professional Australian footballers (138). Similarly, recovery profiles post-match were demonstrated for EPL players during standard '1 match-weeks' also reporting reduced wellness for 48h post-match during the competitive season (190). In Australian football, total perceived wellness has also been reported to recover by 48h post-match following both home and away competition (75). However, a description of the sub-components for wellness demonstrated that perceived sleep quality and duration are further suppressed in away matches compared with those played at home ($p<0.05$) (75). Thus, further highlighting the usefulness of wellness in elite sport, whereby certain psychological stressors are able to be examined subjectively, which may not otherwise present with objective measures of recovery (35).

2.6.2.2 Neuromuscular Function

Neuromuscular fatigue can develop at any location, or potentially in multiple locations during the muscle stretch shortening cycle (SSC) (155). Typically, the mechanisms associated with neuromuscular fatigue are classified based on the site where a decrement in force is apparent and categorised as central fatigue (α-motoneuron pool or above) or peripheral (motoneuron end plate or below) in origin (155). A progressive reduction in force and decreased tension development is evident in fatigued muscle, which has been suggested to occur intermittently and towards the end of a football match (88, 155, 164). The ability to produce force during a maximal voluntary contraction (MVC) is dependent on motor unit (MU) firing frequency and the pattern of MU recruitment (65). As fatigue can impede performance of MVC, measures of recovery often assess the physical performance of players post-match (65).

Jumps

The most popular measure of neuromuscular recovery is vertical jump height, which is most commonly assessed with the use of force plates (186). Vertical jump height, measured via a countermovement jump (CMJ) or squat jump, allows variables such as, peak power, velocity, acceleration and height to be measured, which may identify decreases in muscular function, suggestive of neuromuscular fatigue (139, 193). CMJ and squat jumps have both been proven as indicators for the stretch-shortening cycle (SSC) and neuromuscular performance, while displaying very good levels of reliability (CV: 2.6-5%) in both physically active men and elite team sport athletes (146). CMJ height provides information on the ability of the neuromuscular system to produce lower body power, which is affected by mechanisms such as muscle soreness and damage (193). Given that lower body injuries are highly prevalent in professional football (as outlined earlier), the use of CMJ and performance tests have frequently been used within research, though few investigations exist in elite populations (108, 189)

When assessing CMJ height, EPL footballers reported prolonged reductions in recovery for up to 5 days, with the biggest reductions reported at 24 and 48h post-match (131). Specifically, when compared to match day there was a moderate to large reduction in CMJ at 24h (36.3 6 4.2cm; $p = 0.032$) and 48h (33.4 6 4.8cm; $p = 0.001$) post-match. Further, positional profiling revealed that CMJ values for midfielders had a 'very likely' ($p=0.001$) higher reduction post-match when compared to other positional groups (131). CMJ height was also reported as reduced at 24h post for 14 elite football players when compared to baseline, though measures were not taken at 48 or 72h post (108). Mixed findings are evident when examining measures of CMJ height, as no reduction in post-match values have been reported for EPL players when compared to baseline at 24 or 40h post-match (194). Similarly, in elite junior football CMJ height remained unchanged immediately post-match when compared to baseline (189). The previous findings may highlight the difficulties of measuring post-match neuromuscular recovery in an elite environment, especially when considering movements that require maximal force production (35).

Sprinting and Repeat Sprint Ability

The ability to perform high-intensity running and sprinting efforts during professional football are critical for performance (24); therefore, testing sprint and repeat sprint ability post-match are a popular method to assess a player's recovery (108). Investigations of sprint performance post-match in elite football are limited, though timelines suggest that performance can be suppressed by ~8% at 24h post-match, with only small improvements for up to 3-days post (9, 108, 164). In semi-professional trained men, it was reported that 20m sprint performance was reduced (~5%) at 72h post-match when compared to baseline (9). While 40m sprint performance was reported to return to pre-match levels at 48h post-match for professional Italian footballers (164). In agreement, an investigation of 20m sprint performance also demonstrated a return to baseline values at 48h post-match in 24 elite footballers, though participants only completed 68 minutes of match time (108). These timelines of recovery only represent those post single match weeks; therefore, further research is needed to understand the influence of congested schedules on running performance.

Maximum Voluntary Contraction

Post-match reductions in measures of maximal voluntary contraction (MVC) are suggested to be a result of both peripheral and central fatigue, due to match demands (164). Given that lower body injuries to the knees are common within professional football, assessment of maximal voluntary knee flexion/extension strength is prevalent in previous research as a marker of fatigue (7, 9, 189). Test-retest validation of peak concentric forces of knee flexion/extension are also reported to have good-to-excellent (ICC>0.75 and 0.90 respectively) reliability, with low-velocity assessments shown to be the most reliable (90). MVC measures for knee flexion have been reported as significantly reduced (~7-10%) in elite footballers immediately post-match, though returned to baseline between 24-48h post (7, 189). Similarly, MVC knee extension and flexibility was also reduced (~10%) immediately post-match in the same elite population and improved towards baseline at 24h post and unchanged at 48h post-match (164, 189). These findings show that MVC is a useful measure of post-match recovery in football, though the limited number of studies available potentially demonstrates the difficulty of assessing MVC in an elite environment (35).

The hip adduction squeeze test (HAST) is another example of MVC testing which is associated with groin strength, HAST has been suggested as a potential method to monitor another problem area for injury in professional football (148). The HAST has been reported as having the smallest amount of error (SEM =1.60%) when performed lying in the supine position with feet flat on a physiotherapy bench in 45_o of hip flexion (52). Despite HAST being suggested anecdotally as a valuable method to assess post-match recovery in football, previous investigations of HAST measuring the recovery profiles of players is scarce. That said, an investigation 71 healthy players competing in professional Portuguese football reported that HAST strength was lower for a group sustaining a groin injury (429.8 ± 100) when compared to those with no injury (564 ± 58.7; d = 1.58) (148). Further, it was concluded that maximal isometric adductor strength <465N increased the probability of groin injury by 72% in the same population (148). These findings may suggest that measures of HAST could be useful in monitoring a player's post-match recovery, though to date no previous research exists as evidence within an elite population.

Due to the aforementioned issues with performance testing in an elite environment, flexibility assessments may provide an alternate option that does not create further physiological stress for player's (183). However, these measures are less frequently used as physical performance markers to indicate recovery post-match in previous research (108). Active knee extension (AKE) tests have previously been reported as reliable (ICC=0.89; 95% CI: 0.81-0.94) during both active and passive testing to infer hamstring flexibility (167). When assessing knee range of motion (ROM) via AKE, it was reported that post-match reductions were present until 48h post in elite soccer players. Similarly, knee joint ROM declined 7% at both 24 and 48h post-match indicating a similar recovery profiles in elite football (144). Although flexibility assessment demonstrated a similar recovery profile to performance measures, ROM tests are suggested as most effective when used in conjunction with other recovery measures (144).

Although objective assessment of recovery with neuromuscular testing is important, availability of existing literature on elite populations is limited in professional football. As mentioned previously, this is likely a result of fatigue causing potential associated with the aforementioned testing protocols (35, 186). Further, weekly training schedules pre-and post-match are not conducive for implementing recovery testing, as limited opportunities allow for examination of recovery profiles (35). As a result, other methods of monitoring recovery are available which do not involve a performance aspect (144). Although not specific to the current thesis, due to limited research existing from elite populations on performance tests, these methods should also be considered to understand the time course of recovery post-match.

2.6.2.3 Biochemical/Hormonal and Immunological Assessment

Examination of biochemical/hormonal and immunological markers in blood plasma and saliva are commonly used to assess physiological decrements resulting from physical activity in football matches (7, 108, 144, 162). Although significant research exists, the application of biochemical/hormonal and immunological tests within professional teams is not always practical due to invasive and expensive methods (186). That said, various measures exist for identifying different physiological states, including endocrine and muscle damage responses (179).

Endocrine responses

Endocrine measures of testosterone and cortisol are useful in monitoring player response to intensified training and competition periods, which may allow practitioners to identify early signs of over-training or players in an ‘overreached’ state (153). Testosterone and cortisol measures have become increasingly popular for monitoring recovery periods in football and have been proven as useful and reliable methods for monitoring both acute and chronic responses to exercise and competition (43, 96). Testosterone and cortisol have critical roles in the regulation of protein metabolism and muscle mass and reportedly vary in opposite directions in response to exercise, producing a decreased free testosterone and cortisol ratio (T:C) when training and competitive demands are increased (70, 96). Endocrine measures, including catabolic hormones, testosterone and cortisol have previously been collected from football players immediately following a match and the days post to understand the time course of recovery (108, 147).

Testosterone is reported to reduce for up to 72h post-match in elite junior football players; however, significant increases of 44% were observed in semi-professional players immediately post-match and returned to baseline levels at 48h post (108, 177, 191). Further, an investigation in Australian football reported moderate increases to testosterone (24±18%) for players when 3-day training load increased (173). A 1 SD increase in training load above the mean also typically resulted in substantial reductions for the T:C ratio (173). An investigation of 7 semi-professional footballers also reported testosterone increased by 44% from pre to post-match ($p = 0.008$), while no change was reported for either cortisol ($p = 0.20$) or T:C ratio ($p = 0.83$) (191). In contrast, an investigation of professional Brazilian players reported non-significant changes to cortisol concentrations post-match (147). Accordingly, T:C ratios appear useful at monitoring changes or ‘spikes’ in load based on elevated measures, though profiles of recovery in professional football are underreported (35, 177).

Muscle Damage, Immunological and Inflammatory Markers

Regarding muscle damage, several indirect indicators of skeletal muscle damage following exercise have previously been reported for elite teams to determine under-recovery from training and match play (172, 182, 186). Muscle damage has been inferred via increase in the appearance of muscle proteins such as myosin heavy-chain fragments and/or myoglobin and elevated serum or plasma levels of intracellular enzymes such as glutamic oxaloacetic transaminase, lactate dehydrogenase (LDH), and creatine kinase (CK) (153). The most popular method within professional sport is monitoring of CK in the blood, which although invasive in nature has been reported as a reliable method for monitoring post-match muscle damage (186, 187). It is suggested that increased concentrations of circulating CK are typically associated with high eccentric loading and unaccustomed movement patterns, with the former resulting from explosive and high-intensity demands within football matches (141, 188). However, the exact mechanisms of CK release into the lymphatic system remains unknown, though age, ethnicity and gender appear to influence CK release post exercise (10).

Significant elevation of CK (70-250%) has been reported immediately post-match in professional European football, peaking between 24-48h post before returning to baseline values from 48-120h (7, 69, 108). Similarly, measures of CK were reported as significantly reduced throughout a 72h recovery period following matches for 10 professional outfield players (154). In agreement, an investigation of elite European footballers competing in Liga NOS and Champions league reported increased CK activity for 5 days post-match (131). Further, CK levels were significantly correlated with the number sprint efforts, sprint distance, and accelerations/decelerations in a match (194). Similarly, hard changes of direction and maximal sprints were also suggested to largely influence muscle damage (via increased CK) and ensuing recovery in EPL players (100). Collectively, these results show that measures of CK are useful in measuring the post-match recovery profile in football, which are also sensitive to external match load (108, 194).

Summary

Collectively, the previous research suggests timelines of 48-72h post-match before players have fully recovered on a variety of performance and physiological tests. Therefore, it could be assumed that matches played within typical 1 match weekly microcycles provide sufficient time to fully recovery between matches. However, during congested schedules, the time between matches is often <72h (36). The circumstances created by congested schedules, whereby players are often required to participate in acute and prolonged periods may create difficulties for practitioners to allow players to fully recovery between matches. Therefore, recovery during both acute and prolonged congested schedules should be considered.

2.6.2.4 Recovery and Congested Schedules

During congested schedules players are often required to compete in multiple matches within a week, which often results in repeat performances with less than 72h of recovery between matches. Given the post-match recovery timeline previously discussed, recent research has investigated whether reduced recovery times between matches during acute and prolonged congested schedules result in attenuated recovery times following matches (126, 144, 150, 159, 171).

When considering acute congested schedules, the effects of 3 versus 1 match weeks on recovery was investigated for 16 professional footballers competing in domestic Finnish football (126). Specifically, subjective muscle soreness and recovery, fitness (CMJ, squat jump, 10 and 20m sprint) and biochemical blood markers were assessed at 72h post-match 3 in a MM week and compared with measures at 72h post-match in a SM week (126). Moderate effects (d 1.02, CI ± 1.04) were reported for differences in muscle soreness between groups with a greater change score (1M vs. 3M) of 42% in the congested players compared with controls (126). Similarly, self-reported recovery showed a small effect ($d = 0.57 \pm 0.89$), with a 13% decrease in the congested match group (126). Despite 5 out of 7 players reporting higher CK values during the 3 match versus 1 match week (421 ± 290 vs. 316 ± 193, $p<0.05$), performance on all fitness tests remained unchanged ($p>0.05$) (126). More recently, research investigating biochemical responses following MM congested and SM weeks also reported mixed findings for 23 players competing in elite level UEFA competitions (159). Measures of CK were elevated at 24h post-match in SM weeks (CV: 45%), which were significantly higher than values at 96 (ES: 1.11, CV: 37%), and 48h (ES: 0.93, CV: 63%) post-match (159). However, no significant changes (CV: 72-141%) were reported for measures of salivary cortisol (sCORT) and salivary IgA (sIgA). When comparing between SM and MM weeks, CK levels were further elevated at 48h post-match for congested weeks (ES: 0.27, $p<0.01$) despite non-significant changes reported for sCORT and sIgA values ($p<0.01$) (159).

The effect of acute congested schedules is also highlighted in research investigating 3 matches in 11 days, whereby the second match was played 3 days post-match 1 and third match was 4 days post-match 2 (144). The study used a two-group, repeated measures design with 20 players in each the control and experimental group being assessed for measures of physical and inflammatory responses daily (144). Repeat sprint ability was reduced in the experimental group compared to control by 2-9%, with measures post-match 2 reporting the largest decrease ($p<0.05$). Further, high-intensity running was also lowest during match 2, 7-14% less when compared to match 1 and 3 ($p<0.05$). Muscle soreness was reduced (~sevenfold) when comparing the experimental ‘playing’ and control group at 48h post-match 2 (144). Further, blood markers of muscle damage peaked at 48h post for all matches, with measures collected post-match 2 exhibiting the largest differences compared to the control group (144).

In agreement with the aforementioned research, an investigation of sIgA throughout a 30-day prolonged period of fixture congestion also reported decreased sIgA ($p<0.05$) during matches that were played as MM weeks (150). The research reported sIgA for 21 professional footballers competing in the EPL, although a 7 match 30-day prolonged period was investigated, match 3, 4 and 5 within the period were played as MM weeks with <4 days of recovery (150). sIgA at 48h post-match 3, 4 and 5 were all reduced when compared to baseline ($p<0.05$), whereas measures post-match 1, 2, 6 and 7 were not significantly different ($p>0.05$), suggesting that only acute MM weeks affect sIgA (150). Interestingly, these results suggest that prolonged periods of fixture congestion may not negatively influence recovery like acute congestion (150). Despite mixed findings being reported in the aforementioned research, collectively the body of research to date on recovery during congested schedules is limited, particularly in prolonged periods where only 1 study has previously been published (150).

Summary

Collectively, recovery following a match can vary depending on the individual characteristics of the player and more importantly the external load performed during the match. Given that a 72h recovery period has previously been suggested, it could be expected that during congested schedules recovery between matches is insufficient. However, existing literature is equivocal in regard to acute and prolonged periods of congestion on recovery. Specifically, subjective measures of recovery appear to be negatively influenced, while objective and performance tests are minimally affected. The reason for mixed findings is likely a result of player rotation during congested schedules, whereby players infrequently complete >75min of match time in either MM weeks or periods of successive matches. Due to small squad sizes and depth in Australian teams, there is a decreased ability to rotate players during congested schedules. Therefore, recovery profiles should be investigated at times of increased congestion to assess the influence that these periods have on recovery in Australian football.

2.7. State of the Literature

The purpose for the current review of literature was to examine available research on professional football, firstly within normal scheduling of matches and secondly, to investigate what effect congested scheduling of matches has on injury, training load and recovery. Table 2.6 shows a high-level summary of the relevant literature and missing gaps intended to be filled by this thesis. In summary, despite significant research existing on the demands associated with football during ‘normal’ match scheduling, limited research has investigated the effects of acute and prolonged congested scheduling on injury and recovery. Importantly, no previous research has reported training load distribution throughout these periods, despite significant literature reporting a relationship between load and injury. Furthermore, no literature exists which examines the demands of congested scheduling in Australasian football competitions, where demands imposed on teams are significantly different when compared to Europe.

To date, the majority of research has focused on European competitions, though the findings reported for injuries throughout the research are somewhat mixed in their findings. These mixed findings are a consequence of the differing methodologies used throughout the previous research, which often define congested schedules differently. Further, the participants reported also vary significantly, with multiple competitions and skill levels investigated. Moreover, individual team tactics and coaching styles in the teams investigated will heavily influence the rotation of players during congested periods. Teams that have high player rotation during congested matches may report minimal effects, thus results reported from these studies will also create mixed findings.

Table 2.6: Summary of literature and identified gaps within existing research.

First Author	Title	Year	Congestion Classification	Subjects	Area to be Expanded Upon	Thesis Contribution
Ekstrand et al. (60)	A congested football calendar and the wellbeing of players: correlation between match exposure of European footballers before the World Cup 2002 and their injuries and performances during that World Cup	2004	Prolonged	n=65	- Early study which initially investigated injury during prolonged congested scheduling. - No evidence on recovery of players during these periods or associated workloads.	- Investigates the workloads associated with prolonged periods of congestion. - Further, recovery (wellness) prior to and following matches played within prolonged periods of congestion are investigated.
Dupont et al. (58)	Effect of 2 Soccer Matches in a Week on Physical Performance and Injury Rate	2010	Acute	n=23.	- The study uses external workload from matches to infer recovery between matches in 1 vs. 2 match weeks. - Lack of data on training injuries. - No external/internal workload data from training reported. - Low participant numbers and injury occurrence.	- Injury rates reported for total, match and training injuries. - Injury reported for individual MM weeks and multiple seasons with and without acute match congestion. - Training load data reported. - Objective measures of recovery reported as opposed to match external loads.
Carling et al. (36)	Match Injuries in Professional Soccer: Inter-Seasonal Variation and Effects of Competition Type, Match Congestion and Positional Role	2010	Acute	n=31±2.5 across the 4 seasons.	- Study focused on performance outcomes during acute congested schedules. - Match performance investigated across multiple positional groups during congested schedules to infer recovery rather than a direct measure of recovery. - Match injury rates only reported during acute congested schedules.	- Injury rates reported for total, match and training injuries. - Injury reported for individual MM weeks and multiple seasons with and without acute match congestion. - Training load data reported.
Carling et al. (31)	Are Physical Performance and Injury Risk in a Professional Soccer Team in Match-Play Affected Over a Prolonged Period of Fixture Congestion?	2012	Prolonged	19 (at least 1 match) – 2 completed all matches (1 GK), 6 (incomplete matches), 8 >75% total mins.	- The number of matches completed by players in the prolonged congested period are relatively low (n=8). - Match performance and recovery inferred by external load recoded during the 8 matches. - Despite training injuries being reported, no evidence provided on associated training load.	- Investigates the workloads associated with prolonged periods of congestion. - Period of congestion analysed against a matched non-congested period with the same players and same time period. As opposed to a congested period investigated vs. all 'non' congested matches. - Further, recovery (wellness) prior to and following matches played within prolonged periods of congestion are investigated.
Bengtsson et al. (16)	Muscle injury rates in professional football increase with fixture congestion: an 11-year follow-up of the UEFA Champions League injury study	2013	Acute	n=5622	- Longitudinal study focusing on injury rates during acute congested periods, though associated workloads not reported. - Given the multi-club nature of the study, specific recovery and training load data was unable to be reported. - Rotational strategies and exposure to congested weeks between clubs varied.	- Injury reported for individual MM weeks and multiple seasons with and without acute match congestion. - Training load data reported. - Objective measures of recovery reported as opposed to match external loads.

Dellal et al. (55)	The effects of a congested fixture period on physical performance, technical activity and injury rate during matches in a professional soccer team	2015	Acute	n=16 Period 1 = 5 Period 2 = 6 Period 3 = 5 3 Players in all.	- Despite reporting training related injuries, associated training loads are not reported. - Mixed findings when compared with other prolonged congested studies regarding total, match and training injury rates. Differences also exist for the reporting of injury severity. - Recovery inferred via match loads.	- Expand upon the limited literature that exists in regard to prolonged congested periods for injury and severity. - Objectively measure post match recovery. - Report training workload for measures of internal and external load. - Compare load, recovery and injury for a matches ‘non’ congested period.
Carling et al. (34)	The impact of short periods of match congestion on injury risk and patterns in an elite football club.	2016	Acute	n=25	- The actual exposure to multi-match weeks was relatively low for players as pooled data was used for comparisons. - Training loads were not reported. - Recovery was not investigated.	- Injury reported for individual MM weeks and multiple seasons with and without acute match congestion. - Training load data reported. - Objective measures of recovery reported as opposed to match external loads.
Bengtsson et al. (17)	Muscle injury rate in professional football is higher in matches played within 5 days since the previous match: a 14-year prospective study with more than 130 000 match observations	2018	Acute	n=2672	- Longitudinal study focusing on injury rates during acute congested periods, though associated workloads not reported. - Given the multi-club nature of the study, specific recovery and training load data was unable to be reported. - Rotational strategies and exposure to congested weeks between clubs varied.	- Injury reported for individual MM weeks and multiple seasons with and without acute match congestion. - Training load data reported. - Objective measures of recovery reported as opposed to match external loads.

Regarding injury, previous studies have focused on match occurrence during congested schedules, though limited research has reported training injuries. Given the prolonged duration of specific congested periods investigated, the lack of injury and load data reported is a gap within the literature that the current thesis will look to examine. Another limitation of the previous research is reduced participant numbers that exist, which is a consequence of increased player rotation meaning the extent that players are actually exposed to congested schedules in reduced (33). However, actual quantification of rotation remains absent in most literature in this area. Regardless, congested schedules present a unique challenge for Australian teams, as small squad sizes and more importantly salary caps restrict the depth available in a squad. The aim of the current thesis is to fill gaps that exist within the current literature, specifically regarding training injuries, training load distribution and recovery. Further, the thesis will expand upon current research by reporting on congested schedules in Australian football and the Asian Champions League.

Chapter 3

Study 1

As based on the publication:

Howle K, Waterson A, Duffield R. Injury incidence and workloads during congested schedules in football. *International Journal of Sports Medicine.* 2019;40(1)1-7.

3.1 Abstract

Objective: To compare the internal and external loads and injury incidence between single (SM) and multi-match (MM) weeks, and seasons with and without congested scheduling.

Methods: Measures of internal and external load (training and match), injury incidence rates and risk ratios (IRR) were determined from 42 players over 3 seasons; including 1 without and 2 with regular fixture congestion. Analyses compared players undertaking SM (n=214) and MM (n=86) weeks (>75min in both matches), whilst team data was compared between seasons with and without regular congested scheduling.

Results: Total injury rates were increased during MM (p=0.001) weeks presenting a higher risk of injury (IRR: 2.16). Injury rates were highest when congested scheduling was greatest in season 3 (4.6/1000h) and season 2 (2.9/1000h) vs. season 1 (1.78/1000h) (p=0.021). Training load was higher in weeks with SM (p=0.01), although total load (practice and match) was not different between weeks (p=0.18). External load measures were reduced in MM weeks (p<0.05). Furthermore, all internal and external training load measures were lowest in seasons with congested scheduling (p<0.05).

Conclusion: Injury rates increase whilst training load decreases during congested schedules within and across seasons. Whether injuries result from increased match exposure or the discreet match load remains to be elucidated.

3.2 Introduction

Players in successful professional football teams are often involved in multiple concurrent competitions, including Club, Champions League and International matches - with extremes of up to 50-60 matches/season reported (156). Such competitive situations result in weeks with multiple matches and thus truncated recovery periods. These occurrences are commonly referred to as congested schedules, and describe matches separated by <3 days, or multi-match weeks with 3-4 days of recovery (33, 55). Currently, mixed findings exist on the likelihood of injury or reduced performance during congested scheduling (58, 121), though a growing number of studies suggest injury risk is higher during times of fixture congestion (16, 32). The growing eminence of the Asian Football Confederation (AFC) Champions League competition, combined with small squad sizes and limited budgets in Australian teams, has increased the concern over congested scheduling in the Australian domestic competition, though evidence of its impact remains sparse.

Research on injury rates during congested schedules remains equivocal. Although total number of injuries does not differ with respect to shorter or longer between-match recovery time, (16) injury rates (based on exposure time) and the severity of injuries sustained may increase (58). For example, Bengtsson et al. (16) reported an increase in muscle injury rates with a reduced recovery time between games (<4 vs. >6 days of recovery). Further, injury rates increased in league matches with 4 days compared to 6 days recovery (29.0 v 26.6 /1000h, respectively). Dupont et al. (58) reported an increase of 4.1 to 25.6 injuries/1000 hours in matches during non-congested and congested periods (<4 days). Conversely, Carling et al. (31) reported no difference in injury rates (50.3 vs. 49.8 /1000h; n=19) in congested (<4 days) and non-congested schedules, respectively. These mixed findings may be a consequence of small sample sizes used (i.e. n=8-32) due to large squad sizes in European football allowing for increased player rotation.

Despite the equivocal findings on injury rates in congested scheduling, the training and match loads that precede injury during such periods remain unknown. Separately, research to date (31, 32, 58) reports no significant differences in distances covered in matches during or outside of congested schedules. Further, Carling et al. (32) concluded that players are able to maintain movement patterns, particularly high-intensity efforts, even with short recovery (<3 days) between matches. Despite these in-match descriptions of fixture congestion, as yet training load distribution during these periods remains to be reported. The description of internal and external loads throughout congested periods may be beneficial to give context to injury incidences given the load-injury relationships reported recently (80, 81, 169), alongside training exposure needed to maintain fitness (171).

Therefore, the present study examined injury rates sustained during single match vs. multi-match weeks and between seasons with and without congested schedules for a professional Australian club competing in domestic and AFC Champions League football competitions. Furthermore, an additional aim was to compare the respective training and match loads in single match (SM) and multi-match (MM) weeks and between seasons with and without congested schedules. It was hypothesised that MM weeks would exhibit higher injury rates than SM weeks, despite a reduction in the training loads.

3.3 Methods

Participants

The current study prospectively examined one professional football team competing over 3 seasons in the highest competitive level in Australia, the A-League. During seasons 2 and 3 the team also concurrently competed in the Asian Champions League (ACL), which consequently resulted in an increase in multi-match weeks. Data was collected from a total of 42 contracted players during this time with data included for 28 who competed in multi-match weeks, excluding goal keepers and those without match time. The players had a mean± SD age of 26.4 ± 5.1 y, stature of 181.3 ± 7.1 cm, and body mass of 74.5 ± 12.1 kg. During periods of data collection, players were participating in 3-5 football-specific field-based training sessions, 1-2 gym/recovery sessions, and 1-2 competitive matches per week. All players volunteered to participate and prior to the commencement of the study, were informed of any risk associated with their involvement and provided consent before being included. The study was approved by the institutional Human Research Ethics Committee (2014000355).

Overview

Data was collected from a total of 514 ± 111 training sessions and 106 ± 25 matches over three A-League seasons in 2012-2015 (pre-season and competition). The latter two seasons also included AFC Champions League matches (n=37), leading to regular multi-match weeks (n=40) from both seasons. A limitation of the current study was the playing group that participated over the three seasons, which included 8 players completing all three seasons, 7 completed two consecutive seasons (2013-15), while 13 only competed in 1 season (2012-13). Given the multiple definitions used, herein single match (SM) weeks include matches separated by >6 days, whilst multi-match

(MM) weeks were separated by <4 days within a 'typical' week of Monday-Sunday micro-cycle (58). Data was only included from players who completed >75 min in the same position in both SM and MM weeks to allow for direct comparison. Consequently, 214 and 86 data points were collected from players completing SM and MM weeks respectively. Further, across each season, MM weeks only occurred in seasons 2 and 3, with 18 and 22 congested schedule matches played in each season respectively. Typically weekly micro-cycles for SM weeks included a weekend match with 4 training days of varying intensity. Whereas MM weeks included 2 matches and 2-3 training sessions. External and internal markers of load were collected from all training days, except recovery/travel days or recovery days where only wellness was collected. For comparison between seasons, all players who participated in matches from season 1 (n=19), 2 (n=22) and 3 (n=31) were included with their training and match data pooled as means and used for analyses.

Markers of internal load, external load and injuries were collected from players each session within each season. However, data from global positioning systems (GPS) was not collected during matches due to Football Internationale de Federation Association (FIFA) regulations at the time. As such, comparisons between external markers of load between SM and MM weeks are from training only. Further, in season 1 insufficient GPS units were available and therefore comparisons in external load between seasons were not performed. The researchers acknowledge these limitations of the research.

Internal Load

Respective training and match loads, reported as arbitrary units (AU), were calculated by multiplying each players training or match duration (min) by their session rating of perceived exertion (sRPE) recorded approximately 30 min following each session (73).

Total loads were calculated as the sum of training (practice) and match load and reported as a mean and total weekly and season load. Training load was calculated solely on ‘practice time’ (inclusive of all drills and breaks during training) and reported as session and weekly training load. Heart rate (HR) was collected during training (T31, Polar Electro, Kempele, Finland) from all players and reported as a percentage of maximal heart rate (%MaxHR) and time greater than 85% (HR85%). Maximal heart rate for each player was obtained from pre-season VO_{2max} testing not reported here. All erroneous and missing HR data was removed from the data set prior to analysis.

External Load

During each training session, total distance (m), mean speed (m/min) and the distance covered (m) in three pre-defined categories (44); low-intensity activity (LIR) (<14.4 km.h^{-1}); high-intensity running (HIR) (>14.5 km.h^{-1}); and very-high-intensity running (VHIR) (>20 km.h^{-1}) were measured via 5-Hz (interpolated to 15-Hz) Global Positioning Satellite (GPS) devices (SPI HPU GPSports, Canberra, Australia). For each training session, players wore the same individually assigned device to reduce inter-device reliability issues. Devices were worn between the scapulae in a customized harness and data was subsequently analysed using device specific software (Team AMS, GPSports, Canberra, Australia). The GPS units in this study have been reported to have an acceptable level of accuracy and reliability for measures of total distance (interclass correlation [ICC], r<0.53; coefficient of variation [CV] 5– 15%) (195). However, in contrast to the previous research GPS units have reduced reliability when measuring very high-intensity movements (113). Additionally, a 100Hz accelerometer with a 16G tri-axis summing body movement in three planes of motion was embedded in the units to calculate body load (AU) (86).

Injury

The club physiotherapist recorded all injuries in consultation with medical and conditioning staff. Two different physiotherapists and doctors were employed by the club during the period of this study, with one physiotherapist and doctor completing the whole of season 1, whilst the others completed both season 2 and 3 – though all complied with club injury reporting system as part of the National Federation requirements. An injury was defined as 'any physical compliant sustained from a match or training session resulting in partially completed or unavailability for training and match' (77) as dictated by the governing national body. Injury rates per 1000 hours (for training and matches respectively) were calculated as per other research (34). Injury rates were calculated as a group mean for the match context (SM vs. MM weeks) and squad means for comparison between seasons, which is similar to other research (34, 36, 55) that has used squad injury rates i.e. total injuries for the squad and mean exposure duration. Contact injuries were defined as an injury that was direct result of impact (either opposition or teammate), which included both soft tissue and structural injuries. Non-contact injuries were defined as injuries without any impedance from another object, while match and training injuries were recorded based on which session type they occurred (55). Finally, an injury that was sustained on match day or in the 4 days following was assigned to SM or MM week group accordingly.

Statistical Analysis

Data are presented as a mean ± standard deviation (SD). Respective one-way repeated measures analysis of variance (ANOVA) determined differences in all load variables between SM and MM weeks and also between seasons. Statistical significance was set at $p<0.05$ and post-hoc tests (Tukey) were used to determine differences between seasons. The Statistical Package for Social Sciences (SPSS v22.0, Chicago, IL) was used to perform all statistical analyses. Further, injury rates (/1000h) and injury counts were used to calculate an Incidence Rate Ratio (IRR) to determine whether there was higher injury risk in SM or MM weeks and between seasons, with 95% confidence intervals (CIs) calculated using z-statistics and ensuing p values (34).

3.4 Results

The mean number of sessions per week and total session duration were significantly higher in SM weeks ($p=0.0001$), despite session duration not being significantly different between SM and MM weeks ($p=0.77$). All measures of internal training load (per session and weekly) were significantly greater during SM weeks ($p=0.001$; Table 3.1). However, total load per week was not significantly different between conditions ($p=0.18$). Training-based HR responses indicated % max HR ($p=0.002$) and HR85% max ($p=0.0001$) were both higher for SM weeks. For external load markers, session and weekly total distance and mean speeds were significantly greater in SM than MM weeks ($p=0.005$; Table 3.1). Total distance and distance within speed zones were lower in MM weeks, with lower session LIR, HIR and VHIR ($p=0.001$).

Total injury rates (relative to training and match duration) were significantly greater during MM weeks ($p=0.001$; Table 3.2). Further, incidence rate ratios (IRR) showed that a higher risk of total injury exists in MM weeks (IRR: 2.16 [95% CI: 0.8-5.8]; $p<0.05$). Furthermore, training (IRR: 2.52 [95% CI: 0.4-15.1]; $p<0.05$) and match related injuries (IRR: 1.12 [95% CI: 0.3-3.6]; $p<0.05$) were higher during MM weeks for both risk and incidence.

Table 3.1: Mean ± SD and 95% Confidence Intervals (CI) for descriptive, internal and external training and match loads for Single Match (SM) v Multi-Match (MM) weeks.

Variable	**SM (n=214)**	**95% CI**	**MM (n=86)**	**95% CI**
Descriptive				
Number of Matches (n)	37	-	40	-
Number of Sessions/Week (n)	5.0 ± 0.7	[4.9 - 5.0]	3.5 ± 0.9 *	3.3 - 3.6
Session Duration (mins)	58.8 ± 7.3	[57.8 - 59.8]	50.4 ± 6.7	49.0 - 51.8
Total Session Duration (mins)	294 ± 56	[286 – 301]	179 ± 44 *	170 - 189
Internal Loads				
Session Training Load (AU)	229 ± 65	[220 – 238]	125 ± 41 *	[116 – 134]
Weekly Training Load (AU)	1186 ± 416	[1130 – 1240]	436 ± 153 *	[404 – 468]
Weekly Total Load (AU)	1938 ± 425	[1880 – 1990]	1947 ± 251	[1890 – 2000]
Match RPE (AU)	8.5 ± 0.7	[8.4 - 8.6]	8.4 ± 1.2	[8.1 - 8.6]
Training HR$_{\%max}$ (%bpm)	72 ± 6	[71.1 – 72.6]	70 ± 4 *	[69 - 71]
Training Total HR$_{85\%}$ (min)	37 ± 27	[33 - 40]	9 ± 10 *	[6 - 11]
External Loads				
Session Distance (m)	3618 ± 797	[3510 - 3730	2345 ± 295 *	[2280 – 2410]
Weekly Distance (m)	18131 ± 3391	[17700 – 18600]	11583 ± 2801 *	[11000 – 12200]
Mean Speed (m/min)	64.3 ± 5.8	[63.5 - 65.1]	59.1 ± 3.6 *	[58.3 - 59.9]
Session LIR (m)	3176 ± 607	[3090 – 3260]	2100 ± 270 *	[2040 – 2160]
Weekly LIR (m)	15730 ± 2786	[15400 – 16100]	10387 ± 2576 *	[9840 – 10900]
Session HIR (m)	436 ± 192	[410 – 462]	181 ± 39 *	[173 – 189]
Weekly HIR (m)	2116 ± 797	[2010 – 2220]	890 ± 255 *	[836 – 944]
Session VHIR (m)	101 ± 63	[92 – 109]	42 ± 21 *	[37 - 46]
Weekly VHIR (m)	482 ± 280	[445 – 520]	202 ± 103 *	[180 – 224]
Session BodyLoad (AU)	113 ± 42	[107 – 119]	76 ± 26 *	[70 - 81]
Weekly BodyLoad (AU)	554 ± 189	[529 – 579]	377 ± 141 *	[347 – 407]

* Represents significantly different to SM ($p<0.05$)

Table 3.2: Total, training and match injury and incidence rates with 95% Confidence Intervals for Single Match (SM) v Multi-Match (MM) weeks (within-player) and across multiple seasons with and without congested schedules (between squads).

All injuries rates were calculated as: (number/1000)*Exposure Time, and reported per 1000 hours (and 95% confidence intervals)

Variable (no of matches) (no of congested schedules)	**SM** n=37 n=0	**MM** n=40 n=40	**Season 1** n=29 n=0	**Season 2** n=37 n=18	**Season 3** n=40 n=22
Injury					
Total Injury (n)	6	12	18	36	46
Total Injury Rate (/1000h)	15.6 (10.8-20.4)	33.7 (25.1-42.3) *	1.78 (0.1-3.46)	2.9 (0.4-5.4) ^	4.6 (0.7-8.5) ^#
Match Injury (n)	4	9	13	21	20
Match Injury Rate (/1000h)	44.8 (33.1-56.5)	50.3 (44.1-56.5) *	6.3 (2.3-10.3)	10.5 (8.1-12.9) ^	13.6 (11.2-16.0)^#
Training Injury (n)	2	3	5	15	26
Training Injury Rate (/1000h)	6.7 (4.0-9.4)	16.9 (11.7-22.1) *	0.74 (0.1-1.38)	1.2 (0.3-2.1)	3.0 (0.3-5.7) ^#
Contact Injuries (n)	3	4	6	12	7
Non-Contact Injuries (n)	3	8	5	24	39

* Represents significantly different to SM week
^ Represents significant different season 1 ($p<0.05$)
# Represent significantly different to season 2 ($p<0.05$).

Table 3.3: Mean±SD and 95% Confidence Intervals (CI) for descriptive and internal loads across multiple seasons with and without congested schedules.

Variable	**Season 1**	**95% CI**	**Season 2**	**95% CI**	**Season 3**	**95% CI**
Descriptive						
Number of Matches (n)	29	-	37	-	40	-
Number of Congested Schedule Matches (n)	0	-	18	-	22	-
Number of Sessions	183 ± 27	[171 – 195]	195 ± 44	[177 - 213]	136 ± 55 *#	[117 – 155]
Weekly Session Duration (mins)	323 ± 20	[314 – 332]	284 ± 15 *	[278 – 290]	245 ± 34 *#	[233 – 257]
Total Session Duration (hours)	204 ± 33	[189 – 219]	199 ± 47	[179 – 219]	141 ± 59 *#	[120 – 162]
Internal Load						
Weekly Training Load (AU)	1617 ± 173	[1540 – 1690]	1365 ± 131 *	[1310 – 1420]	1134 ± 218 *#	[1060 – 1210]
Season Training Load (AU)	60770 ± 12409	[55200 – 66400]	57583 ± 15110	[51300 – 63900]	39106 ± 17040 *#	[33100 – 45100]
Weekly Total Load (AU)	1088 ± 101	[1040 – 1130]	989 ± 73 *	[959 – 1020]	888 ± 116 *#	[847 – 929]
Season Total Load (AU)	75374 ± 14564	[68800 – 81900]	73292 ± 18477	[65600 – 81000]	51100 ± 21006.9 *#	[43700 – 58500]
Match Load (AU)	559 ± 140	[496 – 622]	614 ± 141	[555 – 673]	642 ± 200	[572 – 712]
Total season Match Load (AU)	14603 ± 6355	[11700 – 17500]	15709 ± 6620	[12900 – 18500]	11994 ± 7592	[9320 – 14700]
Match Duration (min)	70.3± 18.5	[62 – 78]	77.3 ± 15.0	[71 – 83]	79.1 ± 21.4	[71.6 - 86.6]
Total Match Duration (min)	1824 ± 738	[1490 – 2160]	1994 ± 817	[1650 – 2340]	1469 ± 912	[1150 – 1790]

* Represents significant difference to Season 1 (p<0.05)
# Represents significant different to season 2 (p<0.05)

For between-season analyses, the number of training sessions completed in season 3 was significantly lower than season 1 (p=0.002) and 2 (p=0.0001; Table 3.3). Weekly session duration was reduced across each season, with season 1 significantly higher than both season 2 and 3 (p=0.002 respectively; Table 3.3), while season 2 was significantly higher than season 3 (p=0.001; Table 3.3). Internal training loads were significantly reduced in season 3 and 2 compared to 1 (p=0.005; Table 3.3). Total weekly load was significantly lower in both seasons 3 and 2 when compared to season 1 (p=0.003); though not significantly different between seasons 2 and 3 (p=0.12). Regardless of congested scheduling, match loads and durations did not significantly differ between seasons (p=0.09).

Significant differences existed between seasons 1 and 2 for total (IRR: 0.61 (95% CI: 0.3-1.1, p<0.05), match (IRR: 1.67 [95% CI: 0.8-3.3]; p<0.05) and training injury risk (IRR: 1.62 [95% CI: 0.6-4.5]; p<0.05). Similarly, significant differences were also evident between seasons 1 and 3 for the total (IRR: 2.58 (95% CI: 1.5-4.5, p<0.05), match (IRR: 2.16 [95% CI: 1.1-4.3] p<0.05) and training injury (IRR: 4.05 [95% CI: 1.6-10.6]; p<0.05). Significant differences also existed between season 2 and 3 for total, match and training injury rates (p<0.05; Table 3.2). Comparisons with IRR analyses showed no significant difference for total injury rates between seasons 2 and 3 (IRR: 0.63 [95% CI: 0.4-1.0]; p<0.05). However, match injuries were significantly increased in season 3 compared to 2 (IRR: 1.30 [95% CI: 0.7-2.4]; p<0.05), while training injury rates (IRR: 2.5 [95% CI: 1.3-4.7]; p>0.05) were not significantly different between seasons 2 and 3.

3.5 Discussion

The current study represents a novel examination of the influence of fixture congestion within and between seasons on training loads and injury in football, within the context of the AFC Champions League. The main findings were that injury rates were highest during MM weeks, which was evident on direct comparison between SM vs. MM weeks and between seasons with and without congested scheduling demands. Not surprisingly, total loads were not significantly different between SM vs MM weeks, despite training loads being lower in MM weeks. Similarly, external training load measures were also reduced in MM weeks, and reduced in seasons with more congested fixtures. Accordingly, the nature of congested schedules resulted in reduced training loads and increased match loads, and concomitantly resulted in increased injury occurrence. Despite the finding of the current research the reason for the observed injury prevalence remains unknown.

Injury in congested and non-congested weeks

Previous research reports increased injury rates in professional UEFA football players competing in domestic and Champions League competitions (58), and French Division 1 players (36, 55) in 2 vs. 1 week matches (IRR: 2.0 (95% CI: 1.1 to 3.8). In agreement, the current research also suggests increased injury rates during MM vs. SM weeks for an Australian team competing in the AFC Champions League. As a further explanation of this increased injury rate, injuries increased due to match-based, non-contact injuries; which again concurs with previous observations in multi-match UEFA Champions League football injuries (58). Consequently, an increased risk of injury in MM weeks is evident, predominantly via increased match exposure.

Injury in seasons with and without fixture congestion

Increased injury rates were also evident in seasons with increased fixture congestion in the current study. Whilst previous studies report increased injury rates in multi-match weeks from pooled team data sets in congested periods (36, 55, 58), this is the first study to report increased injury rates in seasons with and without congested scheduling. Regardless, similar injury rates were evident without congested scheduling in the current study to those reported in professional Dutch footballers of 6.2 (5.5-7) injuries/1000h (15). The injury rates reported in the current study during times of fixture congestion are lower than previous research, however, the playing squad in the current study is considerably smaller than those available in Europe (15). In the current study, injury rates and the risk of injury increased in seasons with fixture congestion, which also compares favourably with existing research reporting injury rates across 27 European football clubs in UEFA Champions League across multiple seasons (16). As further explanation of this increased injury rate, increased match-based injuries were present in seasons with regular fixture congestion. Such a finding concurs with the findings of match-based injuries in a team competing in the UEFA Champions League (121). However, a novel finding of the present study showed significant increases of training-based injuries during multi-match seasons, despite reduced training loads in these seasons. That said, injuries for seasons with extensive fixture congestion were predominantly related to non-contact muscular injuries. Accordingly, these findings are in agreement with other research that also shows significant increases to match and training injuries during seasons with increased match demands resulting primarily from non-contact match injuries (58).

Internal training loads in congested and non-congested schedules

Recently the influence of training loads as a precursor to injury occurrence have received growing research attention (80, 81). For example, higher total training loads and the rate of increase in load are related to higher overall injury incidence in players of various football codes (78, 80). Intuitively, coaches will adjust training loads during congested schedules, though changes to this profile given the knowledge of the training load – injury paradigm remains to be reported. Accordingly, total loads reported in the current study did not differ; however, the reductions in training load that occurred in MM weeks were offset by the increased match load. Interestingly however, weekly training and total loads (including match load) were both significantly reduced in seasons with increased congested scheduling, with the lowest total loads reported in season 3 inclusive of the highest number of matches. Previous research (171) on sub-elite university footballers has shown reduced training loads result from MM weeks in turn directly reduces physical capacity over a 6 week period. Furthermore, high match loads with regular MM weeks (i.e. 3+ matches with < 3 days recovery) appear to increase the risk of accumulative fatigue in both sub-elite and professional football players (15, 171). Recently, research (5) on training load distribution in 2 and 3 match weeks reported a decrease in training duration as the frequency of matches within a week increases. Alongside these findings, the current study provides evidence that in this case study of one team, no difference in total sRPE load was evident, and that loading in multiple matches is unlikely to be the cause of injury *per se.*

External loads in congested and non-congested schedules

The majority of research on congested schedules relating to external load has focused on the physical demands during matches (31, 32, 55, 121, 156). The current study represents a novel report of the distribution of external loads during training across multiple seasons with fixture congestion. External load measures were all significantly reduced during weeks with congested matches, although a limitation here is that external match demands are not reported in the current study, which is likely to be a factor in injury occurrence (34). The total (3717 ± 797m) and high speed running distance (436 ± 192m) recorded in the current study for 1 match weeks is similar to those previously reported for EPL players (e.g. daily total 3-4km and high speed running distance (285-442m) (83). Despite total and high-speed running in the current study for SM weeks being somewhat similar to those previously reported (83, 130). MM weeks had significant reductions for total distance, HIR and VHIR. Although the current study did not report external load for matches, the current findings show that training sessions are altered to accommodate for the increased match load of MM weeks. Similarly, weekly total distances for EPL players supports the current research, reporting significantly less distance during training in weeks with multiple matches compared with SM weeks (5). However, in contrast, the aforementioned research (5) included the running demands of matches within their study via semi-automated Prozone system. Accordingly, MM weeks, which include both 2 and 3 matches reported higher total, and zone-relevant running distances, highlighting a limitation of the external load data of the present study.

3.6 Conclusions

The present study examined fixture congestion within and between seasons in Australian domestic and Champions League football to determine the effect on training loads and injury. The main findings showed that total training and match injury rates increased as a result of fixture congestion within and between seasons. However, it is unclear whether the increase in total injury rates, which were largely due to increases in match injuries, were predominately a result of increased match exposure rather than an increased injury risk. Given the limited number of players within the squad for the team investigated, difficulties existed for player rotation which may have helped to reduce this injury risk. Internal and external markers of load were also significantly reduced during congested weeks and seasons, though despite these reductions, the risk of injury was still increased during fixture congestion. Although measures of fitness and fatigue were not assessed as part of the current study, it would be of interest to see if the reductions in external and internal load reported here had any corollary effect. Future research may be able to assess these relationships, which might also include a marker of external load during matches.

3.7 Practical Applications

- Injury prevalence during fixture congestion is increased within and between seasons.
- Rotation of players can be considered during increased fixture congestion dependent on squad quality and availability.
- Quantifying match loads is important to assist in understanding athlete loading during congested periods.

Chapter 4

Study 2

As based on a paper submitted:

Howle K, Waterson A, Duffield R. Prolonged periods of fixture congestion in Australian soccer; effects on training load distribution, recovery and injury. *Journal of Sports Sciences*

4.1 Abstract

Objective: To investigate the effect of a period of prolonged fixture congestion on training load distribution, perceived wellness (for recovery) and injury in an Australian team in the Asian Champions League.

Methods*:* A 36-day congested schedule was compared to a matched duration non-congested period for 20 outfield players. Daily measures of internal load (session-Rating of Perceived Exertion (sRPE) x duration for training/match load, Acute:Chronic Workload Ratio (ACWR) and % maximal heart rate) and external load (total, low-, high-, and very high-intensity running distances) alongside perceived wellness were measured. Further, injury incidence rates (/1000h) and risk ratios (IRR) were calculated based on recorded injury occurrence.

Results: All internal and external measures of load were lower during the congested period ($p<0.05$), except for increased mean and total match loads for the congested period ($p<0.05$). The ACWR was not significantly different between respective periods ($p=0.21$), despite significantly higher sRPE match loads for the congested period ($p=0.001$). Mean daily wellness was not different between periods ($p=0.61$), although was reduced during the congested period at 24h pre-match ($p=0.01$) and 48h post-match ($p=0.02$). Injury rates significantly increased in the congested period for total ($p=0.01$), match ($p=0.001$) and training injuries ($p=0.001$).

Conclusion: Similar total load, reduced training load and comparable ACWR existed between periods as would be expected due to the increased match exposure, despite increased injury rates during this case study of prolonged congestion. Perceived wellness was suppressed at 48h post and 24h pre matches, suggesting acute reductions in perceived recovery from congested scheduling.

4.2 Introduction

As with all continental football (soccer) competitions, Australian teams contesting the Asian Champions League (ACL) have an increased number of matches resulting from concurrent competitions. These increased match demands result in both acute and prolonged periods of fixture congestion, whereby players are required to play successive games separated by ≈3 days, in turn reducing recovery and preparation time (16, 32, 55). As a consequence, reduced recovery periods and exacerbated match exposure is presumed to result in reduced match performances and increased injury rates (55, 62). However, evidence exists from European-based research to support the notion that congested schedules do not reduce physical or technical performance in consecutive matches, suggesting players can tolerate repeated match exposures separated by 72h (31). That said, a potential confounding issue in the interpretation of these results is that discreet congested matches i.e. two consecutive matches within 96h are pooled from multiple different time points, including different seasons (16, 31, 36, 58). Such pooling of data may mask the effects of prolonged exposure to congested schedules on recovery (16, 31, 36, 58). Thus, the effect of congested fixtures may be heightened during prolonged periods of repeated match exposure.

When considering match loads during prolonged congestion, no significant changes are evident in match distance or speed within 6-8 consecutive matches with respective 96h recovery periods, suggesting no undue effect of fatigue on match physical performance (Dellal et al., 2015; Carling et al., 2012; Bengtsson et al., 2018; Carling et al., 2015). However, physical activity profiles within matches were used to infer recovery as opposed to objective measures. Research that has objectively measured post-match recovery show mixed findings depending on the recovery parameter, though markers of physical performance and biochemical measures and seem unaffected (Owen et al., 2019; Mohr et al., 2016; Lundberg et al., 2017; Morgans et al., 2014). However, these findings were reported from acute post-match timeframes in multi-match weeks and do not represent prolonged congested schedules.

Despite previous studies investigating match loads and performance during prolonged congested schedules, few studies report training load distribution (5, 150). For example, reduced training loads were observed in starting players vs. non-starters in an English Premier League side playing 7 games in 30days (149). Understanding how training load distribution during congested schedules may differ from normal scheduling can inform the load-injury relationships that have gained recent popularity (80). In particular, the stochastic nature of load is potentially reported by the Acute:Chronic Workload Ratio (ACWR) and despite growing limitations (142, 202), is widely reported within professional football during microcycles without congested scheduling of matches (110). Therefore, whether the distribution of training load during prolonged congested schedules effects ACWR remains to be established.

Research on prolonged periods of fixture congestion are varied in regard to the time frames investigated, although the majority focus on 4-5 week periods (16, 31, 55, 62). From these prolonged periods, both increases and decreases in total and match related injuries are reported (31, 55). For example, multiple congested periods of 6 matches separated by 3 days showed increased match injury rates when compared to non-congested periods for 16 players (55). In agreement, research over an 11-year period investigating multiple teams in UEFA competitions also found that match injury rates increased when 6 matches were played in ≈30 days. Conversely, Carling et al. (31)

determined that total injury rates remained unchanged when comparing a congested period of 8 matches in 26 days vs. a non-congested period (50.3 vs. 49.8/1000h, respectively; p=0.940). The reason for mixed findings in the aforementioned research is likely due to different methodology between studies, though recovery between matches and training load distribution were not considered. Accordingly, a greater understanding of recovery throughout prolonged periods, alongside the match and training load distribution may provide insight into player responses to congested schedules. Therefore, the aim of the current research is to investigate the effect of a period of prolonged congested scheduling on training load distribution, perceived wellness (as a proxy for recovery) and injury rates for one Australian club competing in the ACL.

4.3 Methods

Participants

A within-player comparison of data collected from 20 contracted players was undertaken during a prolonged 36-day congested period and a matched duration non-congested period, excluding goal keepers and those without match time. The players had a mean ± standard deviation (SD) age of 27.9 ± 5.8 y, stature of 182.1 ± 7.6 cm and body mass of 73.8 ± 11.8 kg. During periods of data collection, players were participating in 3-5 football-specific field-based training sessions, 1-2 gym/recovery sessions, and 1-2 competitive matches per week. All players volunteered to participate and prior to the commencement of the study, were informed of any risk associated with their involvement and provided consent before being included. The study was approved by the institutional Human Research Ethics Committee (2014000355).

Overview

The current study examined one professional football team competing in the highest competitive level in Australia (A-League). During the 2014/15 season, the team competed in the ACL, which resulted in increased periods of fixture congestion. Specifically, a prolonged 36-day period resulting in 11 matches being played from the 21st of February 2015 – 28th March 2015. Each week during this period had a minimum of 2 matches, with an average of 3.4 ± 0.9 between matches. Travel demands were also higher throughout this period, with 4 international flights (Japan and Korea) of ~ 10 h duration and 6 domestic flights >2.5h. Internal and external markers of load from training and matches, as well as injury and perceived wellness data were collected during this period. This data was compared with a 36-day period deemed to be 'non-congested' from within the same season (10th of October 2014 – 15th November 2014), with 7.7 ± 2.1 days between matches, which fits the suggested profile of a normal fixture profile (121). Only two flights were taken during this period, both of which were <2.5h. There were 6 A-League and 5 ACL matches played in the prolonged congested period, with 7 matches played at home and 4 played away (2 of which were played in Asia). All matches in the non-congested period were in the A-League, with 3 at home and 1 away. Data was only included for players who completed >75 min of match time in the same position and included for analysis as per Carling et al. (33). Data was collected from a total of 19 ± 3 training sessions and 4 ± 1 matches during the non-congested period and 6 ± 1 training sessions and 11 ± 1 matches in the prolonged congested period.

Internal Load

Internal training loads were calculated for both training sessions and matches by multiplying each players training or match duration (min) by a 30min post-session rating of perceived exertion (sRPE) and reported as arbitrary units (AU) (73). Mean total training loads were calculated as the sum of respective training and match loads. The Acute:Chronic Workload ratio (ACWR) was calculated based on sRPE (184). ACWR has been suggested as a method of monitoring changes in workload (132); though research has argued that monitoring loads using rolling averages via ACWR fails in quantifying the extent that fatigue and reductions in fitness have over time (142, 202). Daily ACWR was calculated for both congested and non-congested periods by dividing the acute workload (previous 7 day average) by the chronic workload (previous 28 day average) and reported as the mean acute, chronic and ACWR (low – high) for the duration of each respective period. Internal load was also determined via heart rate (HR) response in training (T31, Polar Electro, Kempele, Finland) from all players and reported as a percentage of maximal heart rate ($HR_{\%max}$) and time greater than 85% of max HR ($HR_{85\%}$). Maximal heart rate used in calculations for percentage of maximal HR were obtained during pre-season VO_{2max} testing, which is not reported here.

External Load

During each training session, total distance (m), mean speed (m/min) and the distance covered (m) in three pre-defined categories; low-intensity activity (<14.4 $km.h^{-1}$); high-intensity running (>14.5 $km.h^{-1}$); and very high-intensity running (>20 $km.h^{-1}$) were measured via 5-Hz (interpolated as 15-Hz) Global Positioning Satellite (GPS) devices (SPI HPU GPSports, Canberra, Australia) (44). As per previous research, participants wore the same GPS device in each training session to limit the effect of inter-unit variability (44, 195). Units were worn between the scapulae in a customized harness and data was subsequently analysed using device specific software (Team AMS, GPSports, Canberra, Australia). The GPS units used in the current study have been proven to have an acceptable level of accuracy and reliability for measures of total distance (interclass correlation [ICC], r<0.51; coefficient of variation [CV] (1.3 – 1.9%) (113).

However, reduced reliability exists with high-speed running distance (CV: 4.0 – 5.8%) and is poor when measuring very high-speed running distance (CV: 9.0 – 12.5%) (163). A limitation of the current research was that external match demands were not collected due to restrictions at the time in the use of GPS by the Football Internationale de Federation Association (FIFA).

Perceptual Wellness

A perceived wellness questionnaire based on previous recommendations (138) was used to assess player wellness and infer post-match perceived recovery. All players had extensive familiarity with the questionnaire prior to the data collection period. The questionnaire comprised of 5 questions relating to perceived fatigue, sleep quality, general muscle soreness, stress levels and mood with each question scored on a five-point Likert scale (values of 1–5 with 0.5 point increments) with ratings starting at poorest (0.5) – (5.0) greatest (42). Total perceptual wellness was then determined by summing the 5 questions together for a score out of 25 (42, 138). Ratings of wellness were collected from players in the morning or upon arrival at training or match each day using a customised excel spreadsheet. Overall mean wellness was reported for respective congested and non-congested periods. Further, mean wellness 24h pre, 24h and 48h post-match were pooled with a mean reported from each match during respective periods to infer post-match perceptual recovery.

Injury

The same club physiotherapist recorded all injuries in consultation with medical and conditioning staff during both periods. An injury was defined as ‘any physical complaint sustained from a match or training session resulting in partially completed or unavailability for training and match’ (77), as dictated by the governing national body. Injury rates per 1000 hours (for training and matches respectively) were calculated (138). Contact injuries were defined as an injury that was a direct result of impact (either opposition or teammate), which included both soft tissue and structural injuries. Non-contact injuries were defined as injuries without any impedance from another object, while match and training injuries were recorded based on which session type they occurred (77). Further, the club physiotherapist determined severity of injury based on slight (1-3 days), minor (4-7 days), moderate (8-28 days), and major (>28 days) definitions (55). It is acknowledged that a limitation of the current study exists given the duration of the time period investigated, i.e. 36 days. As a result, the actual injury numbers reported are considerably low which effects the significance of the results reported; though, represent a unique case study in Australian soccer and are not without precedent in European-based research (31).

Statistical Analysis

Data are presented as a mean ± standard deviation (SD). Respective one-way analyses of variance (ANOVA) were performed on log transformed data to determine differences in all load variables between non-congested and congested periods with statistical significance set at $p<0.05$. Two-way ANOVA was also used to determine whether differences existed for mean wellness match profiles (condition x time), along with one-way ANOVA to assess overall mean wellness and ACWR between the prolonged and congested periods. The Statistical Package for Social Sciences (SPSS v22.0, Chicago, IL) was used to perform all statistical analyses. Further, injury (/1000h) counts and severity were recorded to determine whether there was higher injury risk in prolonged vs. non-congested periods, with 95% confidence intervals (CIs) calculated using z-statistics and ensuing p values (32). Further, Cohens's d effect sizes (ES) were also calculated to determine the magnitude of difference for performance and recovery variables between respective periods. The ES was classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) and very large (>2.0-7.0) (Batterham and Hopkins 2006).

4.4 Results

As shown in Table 1 and Figure 1, the mean number of matches played during fixture congestion was significantly greater than the non-congested period (p=0.002, ES: 2.2 [95% CI: 1.6, 2.8]). The mean number of training sessions/week (p=0.001, ES: 1.65 [95% CI: 1.41, 1.90]), total training duration (p=0.003, ES: 5.1 [95% CI: 4.4, 5.8]) and mean training duration (p=0.001, ES: 2.2 [95% CI: 1.4, 3.0]) were all significantly higher in the non-congested period. Further, all measures of mean and total internal training load were significantly greater during the non-congested period (p=0.001), whilst mean match loads were higher in the congested period (p=0.001, ES: 0.3 [95% CI: 0.1, 0.4]). For external load measures, total training distances and mean speed were significantly higher during the non-congested period (p=0.001, ES: 2.7 [95% CI: 1.8, 3.7]; p=0.001, ES: 2.5 [95% CI: 1.9, 3.1]; respectively), as were distances in all respective speed zones (LIR p=0.002, ES: 1.6 [95% CI: 0.8, 2.3]; HIR p=0.001, ES: 3.3 [95% CI: 2.4, 4.2]; VHIR p=0.001, ES: 2.4 [95% CI: 1.9, 2.9]). The mean daily ACWR was not significantly different between congested and non-congested periods (0.96 ± 0.1 vs. 0.97 ± 0.2; p=0.21, ES: 0.06 [95% CI: -0.0, 0.12]; Table 1).

Perceived measures of wellness throughout the prolonged and non-congested periods are shown in Figure 1A and 1B. Overall mean perceived wellness for the congested period was not significantly different to the non-congested period (17.5 ± 1.7 vs. 17.3 ± 2.1; p=0.61, ES: 0.3 [95% CI: 0.0, 0.5]). However, when pooled per match within these scheduling periods, wellness was significantly reduced at 24h pre and 48h post-match in congested vs. non-congested (p=0.02, ES: 1.8 [95% CI: 1.5, 2.0], and p=0.01, ES: 0.9 [95% CI: 0.6, 1.1], respectively; Figure 2), but not significantly different at 24h post-match (p=0.45, ES: 0.4 [95% CI: 0.1, 0.6], Figure 2).

As shown in Table 2, injury rates/1000 h were significantly increased in the congested period for total (p=0.01), match (p=0.001) and training injuries (p=0.001) compared to the non-congested period. Similarly, the absolute number of injuries sustained were higher for all classifications of injury severity during the congested period (Table 2). Further, the mechanism of injury was also greater for non-contact and contact injuries during the congested period.

Table 4.1: Mean ± SD descriptive, internal and external training and match loads for extended period of fixture congestion v non-congested period (36 days).

Variable (no of matches)	**Congested Period** **(n=11)**	**Non-congested Period** **(n=4)**
Descriptive		
Number of Matches (n) (% of matches played)	9 ± 3 (87 ± 6)	4 ± 1 * (88 ± 9)
Number of training sessions (n)	15 ± 4	22 ± 4 *
Total training duration (min)	794 ± 70	1588 ± 206 *
Mean session training duration (min)	52 ± 6	76 ± 14 *
Internal Loads		
Mean Training Load (AU)	174 ± 43	344 ± 75 *
Mean Match Load (AU)	547 ± 185	484 ± 166 *
Total Match Load (AU)	3251 ± 2071	1480 ± 797 *
Mean Total Load (AU)	5513 ± 1866	8943 ± 1494 *
Mean Training $HR_{\%max}$ (%bpm)	73 ± 7	77 ± 9 *
Mean Training $HR_{>85\%}$ (min)	9 ± 2	16 ± 5 *
Mean Acute Workload (AU)	303 ± 41	323 ± 84
Mean Chronic Workload (AU)	313 ± 14	330 ± 12
Mean ACWR (AU) (Low-High)	0.96 (0.69 - 1.19)	0.97 (0.65 - 1.49)
External Loads		
Mean training distance (m)	2899 ± 691	4345 ± 295 *
Mean Speed (m/min)	64.3 ± 6.1	84.1 ± 9 *
Mean training LIR (m)	2526 ± 510	3791 ± 977 *
Mean training HIR (m)	293 ± 87	913 ± 244 *
Mean training VHIR (m)	77 ± 22	239 ± 89 *

* Represents significantly different to congested period ($p<0.05$)

Table 4.2: Total, training and match injury and incidence rates for period of fixture congestion v non-congestion (36 days).

Variable (no of matches)	**Congested Period** n=11	**Non-Congested Period** n=4
Injury		
Total Injury (n)	11	2
Total Injury Rate (/1000h)	45.3 (32.2-51.6)	13.4 (8.6-11.9) *
Match Injury (n)	10	1
Match Injury Rate (/1000h)	64.9 (53.2-73.6)	23.1 (14.2-26.3) *
Training Injury (n)	1	1
Training Injury Rate (/1000h)	24.8 (18.0-27.4)	6.2 (3.7-7.2) *
Severity		
Slight (n)	1	0
Minor (n)	2	1
Moderate (n)	4	1
Major (n)	4	0
Mechanism		
Contact Injuries (n)	4	1
Non-Contact Injuries (n)	7	1

All injuries rates were calculated as: (number/1000)*Exposure Time and reported per 1000 h.

* Represents significantly different to congested period ($p<0.05$).

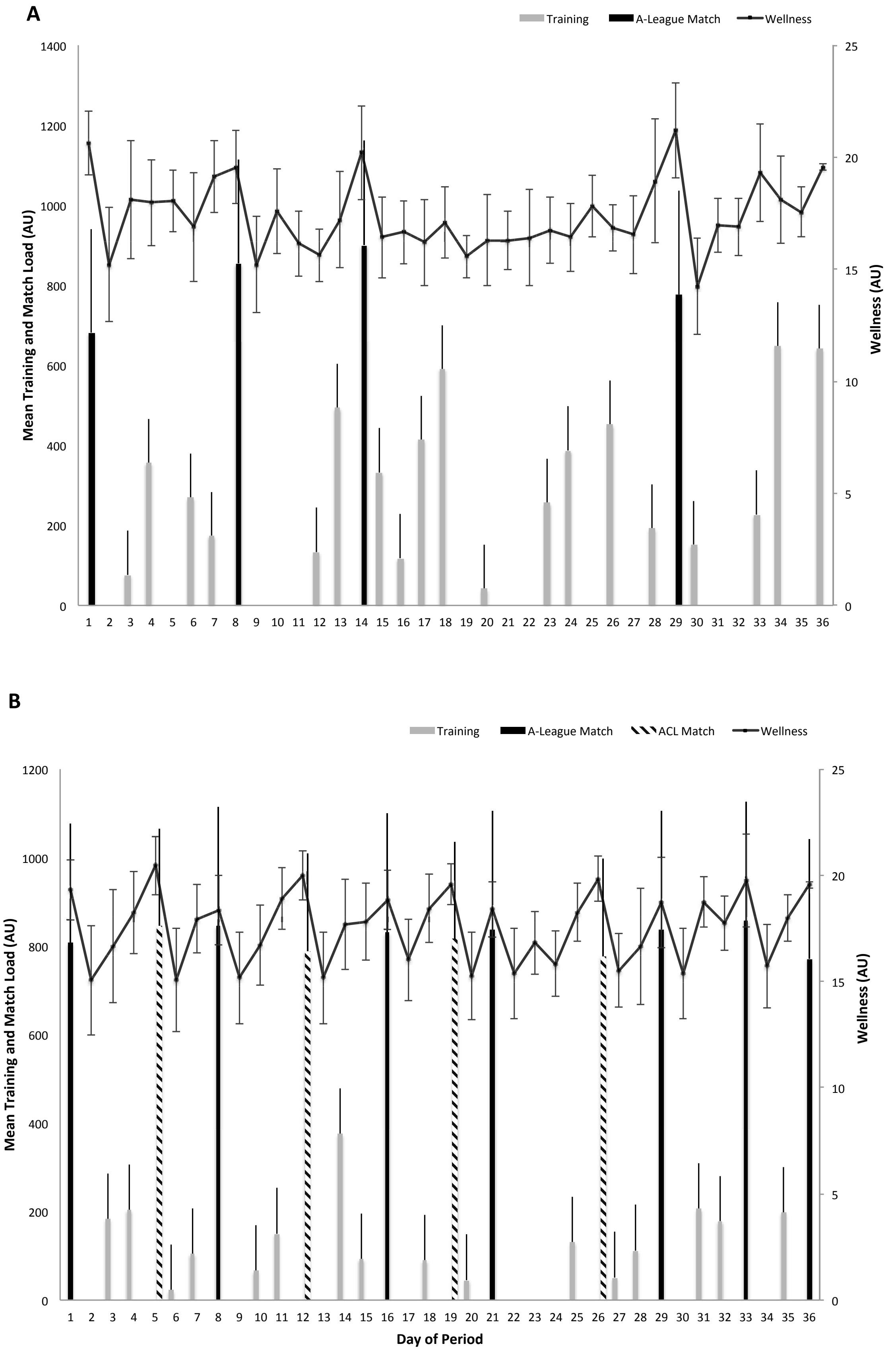


Figure 4.1: Mean ± SD wellness and training and match loads throughout (A) non-congested and (B) extended period of fixture congestion.

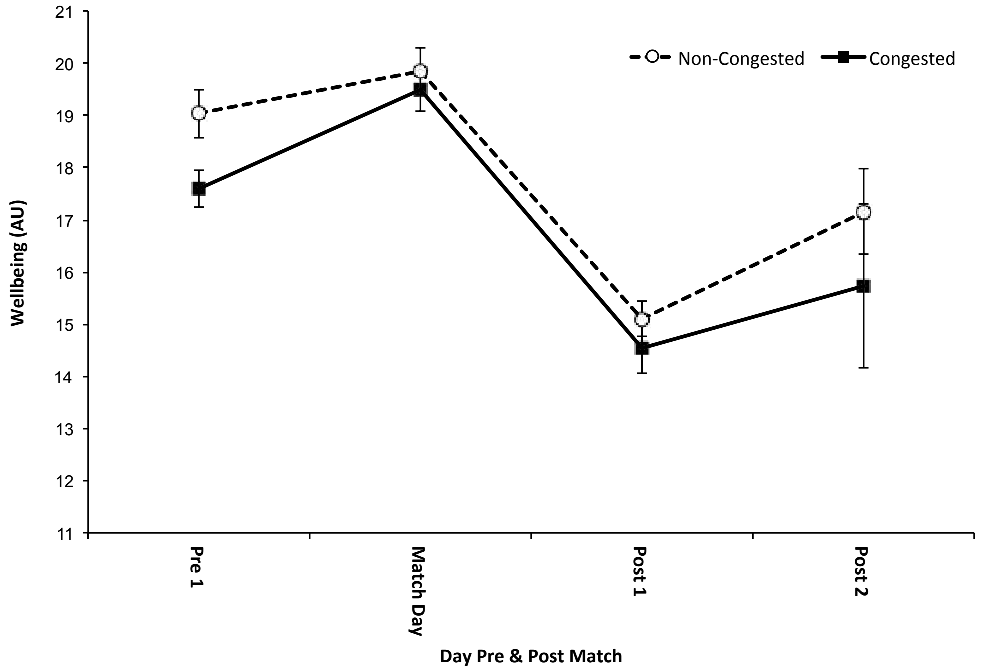


Figure 4.2: Mean ± SD total wellness pre- and post-match in congested v non-congested schedules.

Represents significantly different to congested period ($p<0.05$).

As shown in Table 4.2, injury rates/1000 h were significantly increased in the congested period for total (p=0.01), match (p=0.001) and training injuries (p=0.001) compared to the non-congested period. Similarly, the absolute number of injuries sustained were higher for all classifications of injury severity during the congested period (Table 4.2). Further, the mechanism of injury was also greater for non-contact and contact injuries during the congested period.

4.5 Discussion

The current study represents a novel examination of a case study of training load distribution, recovery (via perceived wellness) and injury rates for an Australian soccer team during a prolonged congested schedule throughout the ACL. Mean and total internal and external training loads were reduced during congested periods, even though match loads were increased. Further, the ACWR was not different between respective periods, despite the reduced training loads during the congested period. Representing perceived recovery, mean wellness did not differ between respective competitive periods, although 24h pre and 48h post-match wellness was reduced in the congested period, suggesting reduced perceived post-match recovery. Further, despite the limited size of this case study data, injury rates were higher during the congested period for total, match and training injuries.

A novel aspect of this study was the reporting of training load distribution during congested periods, showing total load (training + match load) was significantly higher during the non-congested period. These results suggest a significantly decreased training volume and intensity during periods of congestion, though it is unclear what specific influence these decreased loads had on either performance or injury.

Furthermore, despite significant increased exposure and match loads in the congested period, the mean ACWR remained similar between periods; hence, placing some doubt over the use of ACWR to represent the subtleties of load in the context of congested schedules. Although speculative, previous research suggests that ACWR's between 1.00 – 1.25 result in a reduced risk of injury in professional footballers (132). Given the mean ACWR reported here (0.8 - 1.2) throughout the congested period, such distribution and potential for spikes do not appear to fit with any explanation of increased injury rates observed in congested periods. As such, a further understanding of load and its effect on injury and recovery throughout these periods may be needed using larger data sets from multiple clubs and leagues.

Markers of external load during the non-congested period were all increased compared to the congested period. It is acknowledged that a significant limitation to the current study is the absence of GPS data from matches, which makes comparison between respective periods difficult and tenuous given the assumption external load was likely higher in congested periods. Limited research exists on external load throughout prolonged congested periods, with only one previous study describing load for both training and matches during an intensified period of congestion for starters and non-starters (150). Starting players recorded mean training session distances of 2973 ± 1091m and 59 ± 41m at >19.8 km/h, which is similar to that reported in the current study (150). Despite such similarities, during multi-match weeks (5), player's loads were included for analysis when only completing >50% of match time in 5 matches throughout the intensified period. In contrast, although speculative, the higher match exposure for players within the current study (>75min) may be a result of less frequent player rotation. When considering external training loads were similar to the aforementioned research, reduced player rotation may help to explain the increased injury rates reported in the current research.

A novel aspect of the current research was the collection of perceived wellness throughout the prolonged period of congestion to infer perceptual recovery. No differences were evident for mean wellness between respective 36 day congested and non-congested periods, which may suggest that reduced mean training loads and a focus on recovery throughout congested periods assists moderate perceived wellness in the context of higher match loads. In contrast, discreet wellness responses at 48h post and 24h pre match were lower during the congested period. No comparable literature exists, though previous findings report reduced salivary IgA response following matches during intensified congested periods for English Premier League players and the authors suggested slowed recovery following congested matches (150). In the current study, the 24h post-match wellness response was unchanged between the congested and non-congested periods and may relate to the presence of extensive travel in the current competition at this time point. For example, prolonged international travel results in reductions to perceptual wellness at 24h post-travel (75). In agreement, the current research also shows similarly reduced wellness at 24h post-match for both periods, which may have been exacerbated by the act of prolonged travel at 48h post-match in the congested period. Further, these prolonged reductions in wellness, potentially as a result of travel, are also highlighted by reduced wellness at 24h pre-match, which suggests that recovery timelines are delayed following two when compared to one match weeks. Therefore, in the current study suppressed wellness may highlight the adverse effect of travel, whereby long flight and transit times prolong perceived recovery, and is of particular concern during congested schedules in the ACL.

Whilst acknowledging the case study context and low injury count, match injury rates were increased during 36-day fixture congestion as part of the ACL; which, concurs with previous findings for professional French footballers during congested vs. non-congested periods (43.3 vs. 18.6 injuries/1000 h) (55). Conversely, Bengtsson et al. (16) reported that match injury rates remained similar with >3 vs. <3 days of recovery across multiple concurrent European competitions. Total injury rates within the current research were also significantly increased, which is in contrast to previous findings throughout prolonged periods of congestion (16, 31, 55). Specifically, Dellal et al. (55) reported no change between overall injury rates (match + training) for a congested v non-congested period (14.4 v 15.6/1000h). In agreement, Carling et al. (31) showed total injury rates remained unchanged during a period of 8 matches within 26 days (50.3 vs. 49.8 / 1000 hours, for prolonged and non-congested periods, respectively). Despite significantly higher match injury rates reported previously (55), the training injury rates within these studies was very low (4.6/1000h), which led to the reduced total injury rates reported. Research has proposed an explanation for the reduced training injury rates observed in Europe may be due to the rotational strategies used by teams to reduce physical loads during training or in microcycles (55). In contrast, the higher training (and match) injury rates observed within the current research, suggest greater challenges for Australian teams competing in prolonged congested periods, particularly if squad rotation is not as feasible for Australian teams in the ACL.

It should be acknowledged that potential limitations for the current study exist. Firstly, the comparison of the congested period v non-congested period obviously occurred at different time points in the season. However, a novel aspect of the study is that data was collected from the same 20 players in each period for comparison, rather than simply comparing the starting players v non-starting players throughout the congested period. A further limitation is the use of players completing >75min of match time for analysis and not players completing a full 90min match. During increased periods of fixture congestion players are frequently rotated and have their playing times reduced, as a consequence participant numbers for comparison between periods would have been too low. Lastly, as previously mentioned external match demands were not available due to restrictions at the time in the use of GPS by FIFA. As a further consequence of this limitation, differences in injury rates during training and matches is difficult to interpret. Due to the potential causative effect of load on injury, the absence of external load in matches would mean that any rationale for these differences in injury would be speculative.

4.6 Conclusions

The present study is a novel examination into the effect that a prolonged period of fixture congestion has on training load distribution, wellness as a proxy for recovery and injury rates. Despite a significant reduction in internal and external loads and no differences in the ACWR, total, match and training injury rates were significantly increased during the prolonged period of congestion. A significant reduction in wellness at 24h pre and 48h post-match was also present during congested fixtures, highlighting reduced acute recovery. Thus it appears increased injury rates and reduced perceived recovery exist during prolonged congested schedules resulting from the

ACL. However, the exact cause for heightened injury rates during ACL remains unclear given multiple factors such as travel, external match load and recovery measures from matches have not been explored here. These factors may be considered for future research exploring these demands when competing in congested scheduling of matches.

4.7 Practical Applications

- Quantifying external load from matches is important to understand the loads imposed on players.
- A focus on recovery between matches may help facilitate improved readiness for matches and tolerance to load.
- Rotation of players should be considered (where appropriate) during congested periods in order to reduce physical load and enhance recovery.

Chapter 5

Study 3

As based on the publication:

Howle K, Waterson A, Duffield R. Recovery profiles following single and multiple matches per week in professional football. *European Journal of Sport Science.* 2019;19(10)1-9.

5.1 Abstract

Objectives: To investigate player responses 48h post-match in single (SM) and multi-match (MM) weeks on perceptual and objective outcome measures to infer recovery status.

Methods: From 42 professional players over 2 seasons, outcome measures relevant to recovery status were collected 48h following matches, as well as during pre-season training weeks as a comparative baseline. These included 1) 5-item subjective wellness questionnaire, 2) total quality recovery (TQR) scale, 3) hip adduction squeeze test, 4) ankle knee to wall (KTW) test, and 5) active knee extension (AKE) flexibility test. These measures 48h post-matches were compared in SM (n=79) and MM (n=86) weeks where players completed >75 min of match time in one (SM) or where both matches were played with <96h recovery (MM). Internal match load was collected from each match based on session rating of perceived exertion (sRPE) multiplied by match duration.

Results: Subjective wellness (specifically fatigue, sleep and soreness), TQR and hip adduction squeeze test were all significantly reduced at 48h following match 1 post for both SM and MM ($p<0.05$), and further reduced following match 2 in MM ($p<0.05$), while SM returned to baseline at the same time point. No other outcome measures to infer recovery showed significant differences ($p>0.05$) within or between-conditions.

Conclusions: Subjective wellness, TQR and hip adduction strength showed further reductions 48h post-match in congested schedules, but not in single matches. Therefore, congested schedules supress recovery, and such measures may be of use to assess readiness to compete during these schedules.

5.2 Introduction

Congested scheduling has been defined as matches played with <3 days of recovery, or multi-match weeks with <4 days of recovery between matches (36). Professional football within Europe often requires players to compete in multiple concurrent competitions, including both domestic and champions leagues (121). The scheduling consequences of dual competitions can result in multiple matches whereby players experience short recovery periods (8, 55 58). The actual extent that players are exposed to these periods has been suggested to be less than initially perceived, and hence why players seemingly can recover to maintain physical match performance (32). However, in Australian football (soccer), small squad sizes and reduced salary caps create difficulties for teams competing in a congested schedule and often results in players being exposed to frequent multi-match weeks.

Previous evidence suggests that 72h is the minimal timeframe for post-match recovery (153); though not all studies report 72h post-match as long enough to completely restore homeostatic balance (177). Despite these mixed findings, the concern with congested schedules is the reduced recovery that may be caused by successive matches (31), which may result in an increased injury risk. For example, increased non-contact injuries have been reported during congested schedules of 2 vs. 1 match weeks in professional French football players (58). Further, total injury rates were 25.6 vs 4.1 injuries per 1000 hours for 2 vs. 1 match weeks, suggested to result from the reduced recovery time between matches (31, 58). Regardless, whilst congested schedules are suggested to heighten the risk of injury (121), the explicit effects of multiple matches on post-match recovery remain unknown.

With recovery central to above theories regarding the effect of congested schedules; recovery is considered to have occurred when a player is able to reach, if not exceed, a particular benchmark related to performance or physiological and perceptual states following training or matches (98). Appropriate recovery from a match is suggested to require ≈72h, with exercise-induced inflammatory responses and reductions in physical performance apparent for ≈72-96h (139). However, such timelines represent single rather than consecutive matches, and thus the effect of an ensuing match within that 96h window on recovery remains to be reported in professional players. In youth players undertaking 7 matches within 7 days, a significant decrease in the salivary concentration of both testosterone and Salivary IgA was observed without changes in cortisol between the start and end of the schedule (150). However, no contextual or a baseline non-playing comparison group was reported and such a schedule in youth players does not represent the demands of professional football. Recent research (204) on hamstring strength, pain and lower limb flexibility has shown that measures remain suppressed following 48h post-match during congested schedules in elite youth athletes. Thus far no study has explicitly examined perceptual (i.e. wellness, total quality recovery) or outcome measures (joint mobility, muscle strength) of recovery at a standardised timeframe following single or multiple matches in a weekly microcycle in professional football (108). Consequently, the aim of this study was to examine the 48h post-match recovery profile between the 1st and 2nd match of a week during congested scheduling and similar timeframes in a single match week in professional footballers. It was hypothesised that multiple matches per week would reduce the recovery profile of player's 48h following the 2nd match.

5.3 Methods

The current study examined an Australian professional football team competing concurrently in the domestic A-League competition and Asian Champions League (ACL). Data was collected from a total of 42 contracted players during this time, excluding goal keepers and those without match time. The players had a mean and standard deviation (SD) of age of 26.4 ± 5.1y, stature of 181.3 ± 7.1cm, and body mass of 74.5 ± 12.1kg. During periods of data collection, players were participating in 3-5 football-specific field-based training sessions, 1-2 gym sessions, 1-2 recovery sessions, and 1-2 competitive matches per week. All players volunteered to participate and prior to the commencement of the study were informed of any risk associated with their involvement and provided consent before being included. The study was approved by the institutional Human Research Ethics Committee (2014000355).

Data was collected as a prospective cohort study over two A-League seasons from 2013-2015 (pre-season and competition). Both seasons included Asian Champions League (ACL) matches (n=37), leading to regular multi-match weeks (n=40). Multi-match weeks were frequent during these seasons with regular acute periods of fixture congestion occurring from February – May 2013, August – November 2014 (including ACL final), December – January 2015 and February – May 2015. Multi-match weeks were defined as weeks with 2-matches separated by <4 days (96h) of recovery (121). A 'typical' week was considered as Monday-Sunday throughout the duration of the study. Therefore, multi-match weeks consisted of a mid-week game (e.g. Wednesday) followed by another (<4 days) over the weekend typically between 72 and 96h post-match 1. Data were only included from players who completed >75 min in a comparable single-match (SM) or multi-match (MM) to compare the 48h post-match outcome measures. Specifically, outcome measures included 1) 5-item subjective wellness questionnaire, 2) total quality recovery (TQR) scale, 3) hip adduction squeeze test, 4) ankle knee to wall (AKW) test, and 5) active knee extension (AKE) flexibility test.

The outcome measure profiles of SM and MM players were compared 48h following each match and compared to a pre-season training baseline to further understand the recovery profile in the presence (MM) and absence (SM) of the consecutive weekly match load. Consequently, 86 data points were collated for MM whereby players had 48h post-match recovery measures from the two matches in the same week with >75min playing time in both matches. Similarly, SM had 79 data points where players completed >75min in the 1st match within the week and did not compete in the 2nd match. Furthermore, as a proxy for a comparable baseline, the same outcome measures were collected from the first session of the week during pre-season training weeks where no training or match had occurred within the previous 48h i.e. first session of the week following a recovery day (n=19 ± 5 weeks from 2 seasons). A mean value for each individual player for each measure was used as a baseline per player to then compare to measures 48h following 1 and 2 matches within a week. All outcome measures were collected at a standardised time in the morning at the first designated training session 48h following each respective match.

Internal match loads, reported as arbitrary units (AU), were calculated by multiplying each player's match duration (min) by their session rating of perceived exertion (sRPE) using a 0-10 scale and recorded approximately 30min following each match (73). A 5-item psychometric questionnaire, based on previous recommendations (138) and with which players had extensive familiarity, was used to assess player wellness. The questionnaire comprised of questions relating to perceived fatigue, sleep quality, general muscle soreness, stress levels and mood with each question scored on a five-point Likert scale (values of 1–5 with 0.5 point increments - 1 and 5 representing anchor points relating to poor and very good ratings, respectively). Total wellness was determined by summing the 5 questions together for a score out of 25 (99). Subjective ratings of wellness were collected from players upon arrival at training or matches each day. Although these scores were collected from players each day during the study period, only questionnaires completed at 48h post-match at the first training session of the week were used for analysis. A visual analogue scale (VAS) was also used to determine perceived total quality recovery (TQR) using a 1 – 10 scale, with 1 being the worst possible recovery and 10 being the best possible recovery following the match (122, 158).

Objective outcome measures from matches were assessed 48h post-match, which was the commencement of the first returning post-match training session. These measures included: 1) hip adduction squeeze test, 2) ankle knee to wall (KTW) test, 3) active knee extension (AKE) flexibility test and 4) sit and reach. These tests were part of the club recovery and rehabilitation inventory, and all players had extensive familiarity and practice with the test battery. It should also be noted that players were sufficiently warmed up prior to performing each test after completing the club’s prehab protocol. All measures were collected throughout the duration of the study by the principal investigators, thus minimising variation from multiple testers. Specifically, the hip adduction squeeze test and AKE flexibility test were performed by the club’s physiotherapist on all occasions for each athlete. While all testing for the ankle KTW test and sit and reach across each participant were performed by the sports scientist. Hip adduction squeeze was assessed with the player lying in the supine position with feet flat on a physiotherapy bench in 45_{o} of hip flexion. Previous research (52) suggests that this position for the test has the smallest amount of error (SEM =1.60%). Player's hands were crossed against their chest, and head flat against the bench and performed multiple warm up efforts. Following these 'warm up' efforts, players produced a single maximum adductor squeeze on a commercially available aneroid sphygmomanometer (Code 4549, Astir, Australia) with peak pressure recorded to the nearest mmHg (123). While not a direct replication of the procedures of previous research, such warm-up and single effort procedure fit with the constraints of testing within club environments to improve efficiency and player compliance (123). Unlike previous research (148), the current study did not have any participants in the data set who reached the maximal reading on the sphygmomanometer.

Ankle KTW test was used to determine maximal ankle dorsiflexion range of motion (ROM) (118). Measures of ankle dorsiflexion are used to assess calf ROM (72), given previous research suggesting that reduced calf ROM is related to an increased risk of injury (180). A weight-bearing lunge was performed in a standing position with the player's heel in contact with the ground, the knee in line with the second toe, and the great toe starting 10cm away from the wall. The foot was progressively moved away (or toward) from the wall 1cm at a time until they are unable to touch the wall with their knee and without lifting the heel from the ground. Player's final position was determined using a metric tape affixed to the floor with 0.1 cm increments. Ankle KTW measures using a tape measure are shown to have intra-rater reliability of r=0.98 and 0.99 for the right and left foot respectively, with SEM ranging from 0.4 - 0.6cm and minimal detectable change (MDC) between 1.1 and 1.5cm (118). This method is also proven to be a reliable measure of ankle dorsiflexion when compared to other methods such as goniometer and inclinometer (72).

AKE flexibility test measures were obtained using a commercially available digital inclinometer (Acumar, Lafayette, IN, USA). AKE testing has previously been reported as an accurate method to assess hamstring flexibility (ICC) r=.96, (SEM=1.82) for intra-tester reliability (206). Players were tested while lying in a supine position before raising their leg to a 45$_0$ angle flexing at the hip. From this position, the players straightened their leg from the knee until reaching full extension. Players were given 3 attempts to reach full extension before the angle of their leg was assessed using the inclinometer. While holding position at maximal extension, the principal investigator placed the inclinometer at the anterior crest of the tibia to measure the obtuse angle between the lower leg and knee (206) to determine the angle of knee extension.

Finally, the sit and reach test was used to assess hamstring flexibility (135), with research indicating moderate mean criterion-related validity for estimating hamstring extensibility (r = 0.46-0.67), but low association with lumbar extensibility (r = 0.16-0.35) (135). The ‘modified’ sit and reach testing protocol was used to remove bias, as all players started from individual zero marks. Sit and reach was obtained using a Flex-Tester box (Power systems, Knoxville, TN, USA), which required players to be seated with legs fully extended. Players started in a position with their head and back flat against a wall before extending the arms fully (without stretching) to determine a zero mark. Shoes were removed and feet placed flat against the measurement device, after several warm-up attempts the players reached out flexing at the hip joint with both hands pushing the device forward from a zero starting mark.

Statistical Analysis

Data are presented as a mean ± standard deviation (SD). Respective two way analysis of variance (ANOVA) were performed on log transformed data to determine within-player differences in all objective and subjective recovery measures between a mean of baseline measures (i.e. 48h recovery during pre-season) and 48h following 1 and 2 matches within the same week (for >75min match time). Post-hoc Tukey tests were performed to determine the location of significance. Statistical significance was set at $p<0.05$ and the Statistical Package for Social Sciences (SPSS v22.0, Chicago, IL) was used to perform all statistical analyses. Effect sizes (ES) and 95% confidence intervals were also calculated to determine the magnitude of difference between respective 48h post-match recovery. The ES was classified as trivial (<0.2), small (>0.2-0.6), moderate (>0.6-1.2), large (>1.2-2.0) and very large (>2.0-4.0), based on classification provided by Batterham and Hopkins (14).

5.4 Results

As presented in Table 5.1, match duration between SM and MM for match 1 (p=0.61) were not significantly different (ES: −0.05 [95% CI: −0.12, .01], trivial), nor were durations different between match 1 and 2 for MM (p=0.56, ES: −0.02 [95% CI: −0.09, .02], trivial). No significant differences existed for match RPE between SM and MM in match 1 (p=0.70, ES: 0.10 [95% CI: −1.3, .42], trivial) or between match 1 and 2 for MM (p=0.63, ES: −0.10 [95% CI: -1.12, .66], trivial). Accordingly, match loads also did not significantly differ between groups for match 1 (p=0.72, ES: 0.70 [95%

CI: −0.78, .16], moderate) or between match 1 and 2 in MM (p=0.62, ES: −0.90 [95% CI: −0.22, .09], moderate).

Total wellness was significantly reduced compared to baseline following match 1 in both SM and MM (p=0.02, ES: 0.90 [95% CI: −0.82, 3.11], moderate), without significant differences between groups (p=0.68, ES: −0.03 [95% CI: −0.12, .43], trivial). Following match 2, Total wellness was further reduced in MM compared to Baseline (p=0.001, ES: 1.54 [95% CI: −0.97, 3.87], very large), match 1 (p=0.01, ES: −1.12 [95% CI: -1.12, 1.96], large), and non-playing SM match 2 (p=0.01, ES: −0.10 [95% CI: -1.78, 3.11], trivial). However, wellness following match 2 for non-playing SM returned to Baseline values (p=0.10, ES: −0.23 [95% CI: -0.21, .10], small).

In explanation, the above pattern of a significant reduction from Baseline following match 1 in SM and MM (p<0.05) and a further reduction following match 2 in MM (p<0.05), but not SM (p>0.05), was evident for ratings of fatigue, sleep and soreness. However, significant differences were not evident for stress and mood when comparing between Baseline, match 1 (p=0.71, ES: 0.09 [95% CI: 0.14, 0.89], moderate) and match 2 (p=0.69, ES: 0.07 [95% CI: -0.70, 0.56], trivial) for SM week players. Conversely, following match 2 both stress and mood were reduced when compared to Baseline (p=0.001, ES: 0.82 [95% CI: -0.23, 2.16], moderate) and non-playing SM match 2 (p=0.001, ES: 1.14 [95% CI: 1.19, 2.11], large) in MM player’s. For the TQR score (Table 5.2), following match 2 in MM there was a significant reduction compared to Baseline (p=0.01, ES: 0.91 [95% CI: 0.89, 2.16], large) and non-playing SM match 2 (p=0.02, ES: 1.34 [95% CI: 1.10, 3.54], very large).

Table 5.1: Mean ± SD Match and Load data from single and multiple matches.

Variable	**Single match**	**Multiple match**	
	Match 1 (n=79)	**Match 1 (n=86)**	**Match 2 (n=86)**
Match Duration	90 ± 12	90 ± 14	89 ± 12
RPE	8.4 ± 0.9	8.4 ± 0.7	8.4 ± 0.8
Match Load	758 ± 140	759 ± 140	749 ± 128

Note: no significant differences between or within conditions.

Table 5.2: Mean ± SD perceived wellness and total quality recovery 48h following matches for group pre-season baseline, and the 1st and 2nd match in a week for players who only played the 1st, and players who played both matches within congested weeks.

Variable	**Baseline (n=19)**	**Single match**		**Multiple matches**	
		Post-match 1 (n=79)	**Post-match 2 (n=79)**	**Post-match 1 (n=86)**	**Post-match 2 (n=86)**
Fatigue (AU)	3.9 ± 0.5	3.1 ± 0.7*	3.8 ± 0.5#	3.0 ± 0.5*^	2.6 ± 0.5*#^**
Sleep (AU)	3.8 ± 0.3	3.1 ± 0.9*	3.6 ± 0.8#	3.1 ± 0.8*^	2.6 ± 0.7*#^**
Soreness (AU)	3.8 ± 0.4	2.9 ± 0.8*	3.6 ± 0.5#	3.0 ± 0.5*^	2.5 ± 0.5*#^**
Stress (AU)	3.9 ± 0.8	3.8 ± 0.4	3.8 ± 0.6	3.7 ± 0.5	3.3 ± 0.5*#^**
Mood (AU)	3.9 ± 0.4	3.8 ± 0.5	3.9 ± 0.8	3.8 ± 0.5	3.5 ± 0.6*#^**
Total Wellness (AU)	19.1 ± 0.9	16.8 ± 1.7*	18.3 ± 2.1#	16.6 ± 1.9*^	14.6 ± 1.8*#^ **
TQR (AU)	8.2 ± 1.1	7.6 ± 1.2^	7.9 ± 1.1	7.5 ± 0.9*	6.2 ± 1.3*#^**

TQR = Total Quality Recovery.

*Represents significantly different to Baseline ($p<0.05$)
#Represents significant difference to SM Match 1 ($p<0.05$)
^Represents significant difference to SM Match 2 ($p<0.05$)
** Represents significant difference to MM Match 1 ($p<0.05$)

Table 5.3: Mean ± SD Outcome measures 48h following matches for group pre-season baseline, group 1 playing in the 1st match within a week and group 2 playing a 'multi-match' week.

Variable	**Baseline (n=19)**	**Single match**		**Multiple match**	
		Post-match 1 (n=79)	**Post-match 2 (n=79)**	**Post-match 1 (n=86)**	**Post-match 2 (n=86)**
HAST (mmHg)	274 ± 34	266±35*	272 ± 29#	263 ± 30*	249 ± 34*#^**
KTW (L) (cm)	10 ± 3	9 ± 2	10 ± 2	10 ± 2	10 ± 2
KTW (R) (cm)	10 ± 3	9 ± 3	10 ± 2	10 ± 2	10 ± 2
Sit and Reach (cm)	11 ± 6	10 ± 1	10 ± 2	10 ± 2	10 ± 2
AKE (L) (degrees)	81 ± 8	84 ± 7	82 ± 7	82 ± 9	79 ± 6#
AKE (R) (degrees)	82 ± 7	84 ± 7	84 ± 6	82 ± 9	80 ± 6#

HAST = Hip Adduction Squeeze Test; KTW (L) = Knee to Wall Left; KTW (R) = Knee to Wall Right; AKE (L) = Active Knee Extension Left; AKE (R) = Active Knee Extension Right.

*Represents significantly different to Baseline (p<0.05)
#Represents significant difference to SM1 Match 1 (p<0.05)
^Represents significant difference to SM Match 2 (p<0.05)
** Represents significant difference to MM Match 1 (p<0.05)

However, no significant differences were evident when comparing TQR scores between Baseline and SM match 1 (p=0.77, ES: -0.64 [95% CI: 0.19, 0.91], moderate) or match 2 (p=0.61, ES: -0.27 [95% CI: 0.15, .69], small).

Hip adduction squeeze test was significantly reduced compared to Baseline following match 1 in both SM and MM (p=0.01, ES: 1.37 [95% CI: -1.26, 3.69], very large; p=0.01, ES: 1.22 [95% CI: -1.17, 3.23], very large; Table 5.3), without significant differences between groups (p=0.60, ES: -0.07 [95% CI: 0.25, .72], trivial). Following match 2, hip adduction squeeze test was further reduced in MM match 2 when compared to baseline (p=0.01, ES: 1.81 [95% CI: -1.76, 2.72], very large), match 2 non-playing SM (p=0.02, ES: 0.87 [95% CI: -1.76, 1.92], moderate) and match 1 MM (p=0.01, ES: 1.09 [95% CI: -0.91, 1.99], large). In contrast, no significant differences were evident in hip adduction squeeze test for non-playing match 2 SM when compared to Baseline (p=0.01, ES: -0.21 [95% CI: -0.76, .13], small). No significant differences were evident for KTW (L), KTW (R) and Sit and Reach when comparing between or within SM, MM and Baseline (p<0.05). AKE (L) and (R) were significantly reduced when comparing between MM match 2 and SM match 1, however when comparing SM and MM to Baseline no significant differences were evident (p>0.05).

5.5 Discussion

This study is the first to examine the 48h post-match recovery of subjective wellness, TQR and selected outcome measures of hip adduction squeeze test, ankle KTW test, and AKE flexibility test for elite Australian footballers (soccer) during periods of fixture congestion. Not unexpectedly, multiple matches with <96h recovery results in suppressed 48h post-match subjective wellness and TQR, along with reductions in hip adduction squeeze test. Conversely, all other outcome measures and the majority of subjective wellness measures (except fatigue and soreness) demonstrated a return to baseline for players who didn't play in a second match within a week.

Given recovery is related to the imposed load, it is important to recognise the match loads of players when interpreting recovery state. Accordingly, no differences existed in match duration or internal match loads between the first and second match in a multi-match week who had >75min playing time in both. Whilst internal match loads and match duration were comparable, it is acknowledged the lack of external load measures are a limitation to the interpretation of the current recovery data. Given international football regulations at the time prevented use of in-match monitoring systems at the time of collection, no external load variables were available, and this is duly acknowledged as an unavoidable limitation. However, in support, running-based movement variables do not change between matches within congested schedules (8). For example, whilst acceleration profiles are altered throughout congested schedules, no differences for total or mean distance, high-intensity running or peak running speed are evident (8). Consequently, the lack of difference between matches in congested schedules for external load in previous studies, and similar internal load responses in the current study, suggest comparable match loads with which to then contrast the 48h post-match recovery profile.

Measures of subjective wellness provide an insight into the internal response and are known to be responsive to training load (28, 82 ,108, 191). In the present study, subjective wellness was reduced 48h following the first match in both groups, but was further reduced following match 2 in MM. Previous research (190) demonstrates wellness to be reduced 48h post-match compared to pre-match values for English Premier League players in a 'standard' 1 match week. Furthermore, wellness has been shown to recover to pre-match values by 96h post-match in Australian rules football players (42). Despite similar trends observed here for SM players, those competing in MM showed further reductions in subjective wellness following the 2nd match. Such responses suggest that the congested scheduling exacerbates the (poorer) recovery state in the context of maintained match loads. More specifically, the sub-components of subjective wellness most responsive to these match loads were fatigue, sleep and soreness, which have also shown responsiveness in Australian rules footballers (42). In the present study, these responses are likely explained by the engagement in repeated match demands and predominant night fixtures disturbing sleep patterns and possibly air travel (75). Collectively, these findings show the usefulness of subjective wellness to monitor post-match recovery, particularly fatigue, sleep and soreness.

Perceived recovery via TQR values in the current study remained unchanged compared to Baseline 48h following the 1st match of both SM and MM, and then decreased only after MM match 2. Previous research (84) using TQR in response to total load (session and match) has also been primarily used for acute time periods of 4 weeks in youth (84) and following 1 match in elite Brazilian soccer players (158). However, Gjaka et al. (84) recently reported TQR scores were unchanged in youth soccer players participating in either 1 or 2 matches/week over a 4-week period, regardless of differences in match loads. The lack of change in TQR following matches reported here could suggest this scale is less responsive than wellness measures. However, the reductions in TQR following MM match 2 could suggest players only start to perceive suppressed recovery when multiple matches have occurred. Consequently, perceived recovery tools such as TQR can be useful to monitor recovery during congested schedules.

Hip adduction squeeze test was the only objective outcome measure of strength or range of motion to show responsiveness to either a single or multi-match schedule. Specifically, hip adduction was reduced following match 1 in both SM and MM players and match 2 in MM but not SM. Previous evidence suggests a time course of post-match muscle damage and functional impairments to be 72 – 96h, and the current data supports such propositions (153, 179). The further addition of another match within 96h of the first match may explain the further reduction in hip adduction reported here; likely due to the physical match demands placed upon a muscle group (adductors) thought to be weaker in a region dominated by larger muscle groups of the hip/gluteal region (158). Comparable data in the literature is scarce, though recent research (205) reports congested football in youth players reduced hip adduction with varying individual magnitudes, as some players show peak force reductions of up to 40% throughout a 7 match tournament. The authors also observed that peak force resulting from the hip adduction squeeze test was reduced for every 100 unit increase in match load (204). When considering these results and the findings of the current study, it appears that a simple hip adduction squeeze test may be a useful assessment to monitor player recovery during times of increased match scheduling.

Although the hip adduction squeeze test showed post-match reductions in the current study, ankle KTW, AKE flexibility test and sit and reach tests were unchanged 48h post-match. At present, limited research exists on the use of ankle KTW tests to assess post-match recovery of ankle dorsiflexion (205); rather, studies have focused on identification of risk factors for lower body injuries (180). Knee extension tests have shown (108) joint ROM was suppressed for 96h post-match in elite soccer players compared to a non-playing control group. The present study did not observe any change in AKE flexibility, though the context of testing time points may have resulted in such findings. Similar findings were also recently reported (39), which suggested that despite hamstring flexibility being reduced post-match in semi-professional Australian rules football players, reductions were not clinically meaningful. Finally, sit and reach tests did not show any significant differences from Baseline or between matches in the current study. Previous research (51) in Australian rules football investigated different post-match recovery modalities and also reported equivocal changes in post-match sit and reach tests. Consequently, despite the regular use of AKE flexibility and other flexibility tests in football, these measures were unresponsive when measured 48h post-match during congested scheduling in professional soccer.

It should be acknowledged that a potential limitation of the current study is the use of ‘pre-season’ outcome measures as a baseline. This was used as a proxy given the inability to collect pre-match measures within ecological environments of professional football. Whilst not ideal due to the potential for higher training loads during pre-season weeks; it is likely players had the best chance at a “trained”, yet fully recovered state to use as a comparative baseline. A further limitation is the use of players completing >75min of match time for analysis and not players completing a full 90min match. As some justification, during increased periods of fixture congestion players are frequently rotated and have their playing times reduced, as a consequence participant numbers for players completing 90mins would be extremely low.

5.6 Conclusion

This study examined the 48h post-match recovery profile of single and multi-match weeks in professional footballers. The findings show that congested schedules result in reduced self reported subjective measures of wellness (particularly fatigue, sleep and soreness), and TQR, as well as hip adduction squeeze test for players who accumulate >75min of match-play time in both matches. Comparably, outcome measures for players who only undertook one match returned to baseline values at 48h following the 2nd match in which they did not play. Therefore, the current research suggests that congested scheduling resulting in MM weeks impacts on players post-match recovery by prolonging the duration for return to baseline.

5.7 Practical Applications

- Players competing in congested schedules exhibited reduced hip adduction squeeze peak pressure and TQR at 48h following the 2nd match within a week compared to players competing in 1 match per week.
- Athlete monitoring could use subjective (fatigue, sleep, soreness) and objective (hip adduction squeeze) measures in the identification and management of players with reduced function [due to fatigue] and possibly health during congested match schedules.

Chapter 6

Discussion

6.1 Introduction

Professional football teams are presented with unique challenges during congested scheduling, as reduced recovery times and interrupted preparation create a potential for sub-optimal match outcomes (61, 71). Understanding the influence that congested schedules have on injury, training loads and recovery assists teams to make informed decisions on player selection, training loads and recovery during these demanding periods (55). This is particularly the case in Australia where the Asian Football Confederation Champions League (ACL) creates difficult scheduling issues, including increased match exposure, reduced recovery time and frequent long-haul travel. Much of the current literature on congested scheduling is European-centric, and no such research exists on these demands in Australia (17, 31, 55). This differing context is important as, in Australian football (soccer) smaller squad sizes, reduced budgets and increased travel demands create greater complexities for teams competing in congested schedules and requires further investigation.

Given the above, this thesis presents three studies attempting to improve the current understanding of congested scheduling within professional football with an Australian focus. Specifically, assessing what influence acute (study 1) and prolonged (study 2) periods of match congestion have on injury, training load distribution and recovery (study 3) in professional Australian domestic football as a result of competing in the ACL. In this final section of the thesis, key findings from all studies will be discussed in context of relevant research to understand congested scheduling as applied to Australian football, with particular focus on congested schedules and 1) Injury, 2) Training Load and 3) Recovery.

6.2 Injury in Acute and Prolonged Congested Schedules

As a result of the combined demands of training and match play, modern football players individually sustain ≈2.0 injuries per season or 4.8/1000h (95% CI: 4.6 to 5.0) (18, 61). Overall, injuries are primarily a result of match exposure, with 57% and 43% occurring in matches and training, respectively (61). Match injury rates have been reported to range from 24.6 - 88.7/1000h, whereas training injuries range from 4.1 - 14.6/1000h, depending on the team and competition investigated (55, 91). Increased scheduling of matches resulting from club, continental and international competitions often results in excess of 60 matches per season for teams in Europe (31). Therefore, as a result of significantly increased match exposure and potentially reduced recovery between matches during congested schedules, it could be assumed that total and match related injury rates are increased (31, 55, 58). However, due to the different contexts between studies, mixed findings exist for total, match and training injuries during acute and prolonged congested periods (17, 31, 55). Hence, the subsequent section will discuss and compare the current findings on the effects of acute and prolonged periods of fixture congestion (i.e. SM vs. MM weeks) for total, match and training injuries.

6.2.1 Total Injury rates in Congested Schedules

From an acute perspective, the current thesis (study 1) reported a significant increase for total injury rates during acute MM periods of congestion and for seasons with greater scheduling of acute MM weeks. Previous research with similar methodology (i.e. one team comparing different SM vs. MM weeks) also reported increased total injury rates during 2 (25.6/1000h) versus 1 (4.1/1000h) match weeks across 2 seasons of Scottish Premier League football (58). The authors postulated that increased injury rates were a consequence of the 2 – 3 days less recovery between matches compared to

SM weeks (58). However, in contrast, when <3 (25.2/1000h), 4 (25.0/1000h), 5 (24.3/1000h), 6 (23.7/1000h) and 7-10 (23.9/1000h) days of recovery exist, short-term match congestion did not affect injury rates from over 65,000 UEFA match observations (17). Reasons for the discrepancy in findings are likely related to the methodologies used, most notably, in single team studies inclusion criteria for participants is perhaps more defined i.e. completing >75mins of match time (55). In addition, multi-club and multi-competition investigations rely on data collection from multiple teams that may have very different rotation and recovery strategies (17). In addition, an increased number of staff within teams contributing to data collection may result in a lack of consistency (17). Therefore, these methodological factors may significantly affect the interpretation of the results, particularly when considering longitudinal multi-club studies (17, 58).

As evidence for the above, total injuries were increased in MM weeks when 23 players participated in >75min of match time from a squad of 32 in a Scottish club (58). Similarly, in the current thesis (study 1) the mean percentage of players completing >75min (n=24) in both matches in MM weeks was 63.8 ± 19.6%, which also appears higher than longitudinal research reporting players completing >75mins in both matches 47.6 ± 5.6 and 50.0 ± 15.8% of occasions, respectively (33). Therefore, although speculative the limited evidence reported to date may suggest that reduced player rotation during acute periods of congestion in MM weeks appears alongside increased total injury rates (32, 58). Despite these findings, it is important to consider that individual coaching strategies will often dictate player rotation and scheduling during congested weeks.

Despite suggestions within previous research that player rotation is important during congested schedules, several factors may impede the ability for individual teams to allow for sufficient rotation (17, 33). In Australian football, smaller squad sizes (n=24) are one potential reason, though a lack of depth within a squad due to salary cap restrictions may also influence the extent coaches are willing or able to rotate their team. In the current thesis, 24 players in total competed in all MM weeks, with data excluded for any players completing SM or <75mins of match time in both games. Players completed 69 ± 7% of total available match time during MM weeks during acute congested periods in the current study. In the aforementioned European research, club and national team footballers (squad n=30-32) completed 47.6 ± 5.6 and 50.0 ± 15.8% of successive matches, respectively (33). Although speculative, this data may provide evidence for the reduced player rotation in the current thesis, which ultimately caused a greater total injury risk in MM when compared to SM weeks.

From a 36-day prolonged perspective (study 2), the current thesis reported that total injury rates were significantly increased during the congested versus non-congested period (45.3 vs. 13.4/1000h), which contrasts with findings in European football (55). Total injury rates during 3 separate prolonged periods of congestion, whereby matches were played with 3 or less days of recovery, reported total injury rates that were not significantly different than during normal match scheduling (14.4 vs. 15.6/1000h; $p>0.001$) (55). The reason for increased total injuries within study 2 are unclear, although speculative, reduced player rotation when compared to European football may still explain the results reported in the current thesis (55).

In regard to the rotation of players during congested scheduling, when 4, 5 and 6 consecutive matches are played the percentage of players completing >75mins of match time is 22.4, 13.2 and 0%, respectively across 4 seasons of professional French football (33). When compared to the rotation of players in the current 36-day period of prolonged congestion, this appears significantly higher (33). In the current thesis (study 2), players completed 9 ± 3 (87 ± 6%) out of 11 matches during a 36-day congested period with 3.4 ± 0.9 days of recovery between games. Furthermore, the congested period was significantly longer in the present case study, with 11 matches in comparison to 6 (33). Although reduced player rotation may contribute to the increased total injury rates reported within the prolonged period, when compared to the previous research, higher match exposures is more likely the cause (33, 55). The reason for increased match exposure within Australian football may also be a result of smaller squad sizes and playing depth; for example and whilst speculative, only 20 players participated in the congested period out of a 27 man squad and should be a strategy for consideration for teams participating in this tournament.

6.2.2 Match Injury in Congested Schedules

Despite reports of increased total injury rates during congested schedules, further understanding for the training or match occurrence of injuries can provide a better understating of the reason and effects of congested schedules on injury. The acute match injury rate reported in study 1 was significantly increased for MM (50.3/1000h) vs SM (44.8/1000h) weeks. Further, the injury rate was highest in season 3 (33.9/1000) alongside increased MM weeks, when compared to season 2 (28.9/1000h) and 1 (16.3/1000h), respectively. Within European football, match injury rates for 2 (97.7/1000h) and 1 (19.3/1000h) match weeks have also reported a significantly higher injury rate during 2 match weeks (58). Furthermore, muscle injury rates, as a result of match play have been reported to increase by 21% when players have <3 vs. >6 days of recovery between matches across 14 seasons in 16 different countries for 57 professional European teams (17). Hence, unlike total injury rates it seems some uniformity exists for increased match injury rates in congested schedules.

Collectively, increased match injuries rates within acute congested schedules are hypothesised to exist as a result of increased match exposure (58), which is consistent with the findings of study 1. When considering that match injury rates have previously been reported to account for 57% of all injuries in football, it is not surprising that increased exposure results in increased rates during acute congested schedules (61). However, research in French League 1 football has reported no difference ($p = 0.406$) for the incidence of match injury when <3 days (45.0 ± 54.6 per 1000h, 0.8 ± 0.9 injuries per match) versus >4 days (37.7 ± 48.4 per 1000h, injuries 0.6 ± 0.8 per match) separated matches (36). Across the 4 seasons reported, the mean squad size was 31 ± 2.5 (36), which is greater than the 24 in the present study 1 of an Australian team. Therefore, adverse effects of congested scheduling may only exist when increased match exposure corresponds with teams that have small squad sizes and reduced player availability (58). As further evidence, European-based research comparing MM versus SM weeks also reported increased match injury rates when reduced (n=23) squad sizes participated throughout 2 seasons (36, 55). Collectively, this may highlight the negative consequence that reduced squad sizes have during congested schedules, which describes the context of Australian football in Asia (17, 58).

When considering match injury rates within prolonged congested schedules, previous research presents mixed findings (36, 55). In the current thesis (study 2), match injuries were higher during the prolonged congested (64.9/1000h) versus matched-duration non-congested period (23.1/1000h); predominately resulting from non-contact soft tissue injuries (albeit with a low number of injuries to compare). Within Europe, match related injuries are increased during prolonged congested periods of 6 matches in 18 days (43.3 vs. 18.6/1000h, $p<0.001$) compared to matches played outside of these periods (55). However, match injuries were reported as unchanged for a 26-day prolonged (50.3/1000h) period of 8 matches versus matches played outside of this period (49.8/1000h) (31). Despite differing results, this research follows a similar methodology to the current thesis, with 19 players participating in total, 6 playing part of each game and 1 player completing the full duration every game (31). Consequently, it is postulated that player rotation in the previous research is higher than in the current thesis (36). When considering a higher number of matches were played in study 2, it could be hypothesised that reduced player rotation and increased match exposures provide a rationale for the increased rates reported. However, directly comparing the extent of player rotation between studies is difficult, and hence increased total match exposure is likely an important cause of increased rates, though remains to be established.

A further reason for the mixed findings reported for prolonged periods may be due to overall exposure of matches throughout a season, which differs in Australian compared to European competitions (55). When focusing on teams playing congested matches over a 4-year period, teams in European competitions are exposed to 61.5 ± 3.4 matches in a single season (33). As a result of player rotation, individuals were reported to compete in 44.9 ± 7.1% of total matches, and only completed >75min of match time in 32.7 ± 5.9% of all matches (33). The team investigated in the current thesis completed 30 matches in season 1 (without ACL), 37 and 40 in season 2 and 3 (including ACL), respectively. Although the total number of matches is lower when compared to European examples, players competed in 67.2 ± 10.9%, 61.2 ± 13.1% and 59.6 ± 17.5% of total matches (>75mins) in season 1 (n=19), 2 (n=22) and 3 (n=31), respectively. Therefore, although the actual number of matches played by Australian teams is reduced in comparison to Europe, the percentage of matches that players compete is higher and may provide evidence for the increased match injury rates reported (33). Further, the mean percentage of total matches played (>75min) in season 2 and 3 are not significantly higher when compared to season 1, which had fewer total matches. Although speculative, these results may show that player rotation was not increased as a result of significantly increased match congestion. Collectively, reduced player rotation and increased match exposures appear to influence the increased match injury rates observed in the current thesis.

6.2.3 Training Injuries in Congested Schedules

To date, the majority of research investigating injury within congested schedules has focused on total and match related injuries, with few reports of training injury rates during such periods. In study 1 of the current thesis, training injury rates were highest during MM (16.9/1000h) compared to SM weeks (6.7/1000h), and in seasons with increased scheduling of matches for season 2 (14.6/1000h) and 3 (19.8/1000h). The rates reported are significantly higher than those previously reported for 2 (8.3/1000h) versus 1 (2.5/1000h) match weeks in UEFA competitions (58). The previous research within Europe highlighted that training intensities were reduced in sessions between matches to focus on recovery, thereby potentially creating an explanation for the reduced non-contact muscle injury risk (58). The effect of training load on training injuries will be explored in subsequent sections of this thesis, though load may provide some explanation for the increased rates reported. Specifically, consideration of whether reductions in training load in study 2 were sufficient to allow for recovery between matches may help explain the increased injury rates. Further, accumulative fatigue may have led to increased training injuries over long time periods (55), although only speculative, the effect of recovery and load appear important and will be further explored during the discussion.

Study 2 of the current thesis also reported an increased training injury rate during a prolonged (24.8/1000h) congested versus non-congested period (6.2/1000h).
In contrast, during 3 separate prolonged periods of fixture congestion where 6 matches were played with 3 days of recovery, training injury rates (4.6/1000h) were reported as significantly lower in comparison to non-congested matches (14.6/1000h) (55). Reduced training injuries (3.2/1000h) were also reported for UEFA football players during increased scheduling of matches as a result of world cup matches (62). Collectively, it was suggested that decreased training injuries are a result of reduced training loads during prolonged congested schedules, while players ‘controlled’ training activity in order to prepare for subsequent performances (55). However, over a prolonged period of time, whether reduced training intensities result in long-term performance decrements remains to be established. Although the effect of training load will be discussed in this thesis, the lack of physical and technical match data is a limitation and prevents a more detailed examination of injury during prolonged congested schedules.

6.2.4 Injury Summary

The current thesis reported consistent findings in regard to injury between acute and prolonged periods of congestion as demonstrated by increased total, match and training related injury rates. To date, research suggests that total injury rates remain unchanged in congested periods, as a result of increased match injuries and reduced training injury rates (36, 58). The current thesis confirmed previous observations regarding match injury rates; however, the total injury rates reported are significantly higher, which in part, is a consequence of increased training injury rates that are a novel finding in this Australian context. Further, potential increased player rotation within European football may result in players competing in reduced percentages of total matches within a season when compared to Australian teams. Reduced player rotation in Australian football may be a consequence of smaller squad sizes in a salary capped league, although the depth of the playing squad is potentially more impeding when scheduling of matches is increased. Although reduced player rotation and increased match exposure may provide a speculative rationale for the increased match injuries reported in the current thesis, reasoning for increased training injuries is less obvious and the loads players are exposed to within congested schedules should be further explored.

6.3 Training Load in Acute and Prolonged Congested Schedules

The reporting of training load volume and distribution throughout normal scheduling of matches is common (130), though few studies report training load during congested scheduling (5). Exploration of the training load distribution during congested schedules may be important given the noted observations on the resultant increased injury rates (58). Furthermore, the relationship between training load and injury within professional football (if not sport) has been the focus of significant recent research (80, 110, 184). For example, investigations suggest a load-injury relationship exists whereby injury rates increase exponentially with load (80). Despite growing conjecture over this relationship (142, 202), the interaction between the type and distribution of load and resultant injury should be considered within the congested schedule context. For example, previous research has suggested reduced training loads in prolonged congested schedules are the reason for reduced training injury rates (55). However, despite these suggestions, actual loads during prolonged times of increased schedules remain to be reported (31, 55) As such, these gaps within the literature were the rationale for reporting load distribution in acute and prolonged congested schedules in study 1 and 2, particularly given the unique demands associated with these periods for Australian teams in the ACL.

6.3.1 Training Load in Acute Congested Schedules

Study 1 of the current thesis reported acute internal and external loads for MM and SM weeks and between seasons with and without congested schedules. When examining internal sRPE load, session (125 ± 41) and weekly (436 ± 153) total loads were both significantly reduced in MM compared to SM weeks. Primarily, these reductions appear to be a result of significantly reduced number of sessions and thus total session duration in MM weeks. In comparison, research investigating the effect of 1, 2 and 3 matches/week on external load profiles of 12 EPL players reported the team completing 4 training sessions in 1 and 2 match weeks; and when 3 matches were played within a week the training volume reduced to 2 sessions (5). The number of sessions within the previous research were unchanged for 2 match weeks (5), which contrasts with study 1 whereby 3.5 ± 0.9 and 5.0 ± 0.7 sessions existed in MM and SM weeks, respectively. Although training session duration was reduced in 2-match weeks in the previous research, when adjusted to include match duration, no differences existed between weeks for total exposure (5). Similarly, despite reduction in sRPE training load in study 1, weekly total load (training + match load) was not significantly different when comparing between MM and SM weeks for internal load. Therefore, total internal load and the number of sessions completed in MM and SM weeks does not appear to provide an explanation for the increased training injury rate reported in study 1.

In the acute context of study 1, external loads were significantly reduced for all measures in MM compared to SM weeks. However, the external load from matches was not reported, which is a significant limitation of the research and makes discussion speculative, if not difficult. Interestingly, research within European football reported unchanged external load (total distance and mean speed) between 1 and 2 match weeks for all training days except the 1st training session (48h post-match) in 2 match weeks (5). Further, only when 3 matches were played within a week was total distance and mean speed in training significantly reduced compared to both 1 and 2 match weeks (5). Collectively, these results show that when considering total weekly duration, sRPE load (training + match) and external load show no differences in total workload profiles during acute congested periods (5). Despite the findings regarding total load in acute congested schedules, acute periods may represent an insufficient time period and fail to explain load, recovery and fatigue events that lead to training related injuries over time (62).

Regarding sRPE total load (match + training), the findings in study 1 are of interest, given that increased total, match and training injuries were reported in MM weeks despite unchanged total loads between weeks. Therefore, as internal loads remained similar between weeks, it is possible to speculate that increased match exposure and/or the extent and type of external load in matches is more likely the cause of increased injury rates. Interestingly, research has reported that no differences exist for external load profiles during matches before, during and after periods of congested scheduling for total distance ($p = 0.990$) and high-intensity ($p = 0.442$), moderate-intensity ($p = 0.424$), low-intensity ($p = 0.453$), light-intensity ($p = 0.059$) running (32). However, reduced training intensities during congested schedules and self-pacing strategies in matches are suggested as reasons for why players maintain physical workloads during match play (32, 58, 126). That said, the measures of external load previously investigated might not be sufficient to observe between-match differences in physical performance (8). Research on elite junior footballers also reported that measures of distance and high speed running were unchanged in congested schedules; however, high-intensity movements such as frequency of acceleration, body load impacts per minute were significantly reduced in congested compared to non-congested periods (8). It was suggested that performance of high-intensity movements is more likely to be compromised as a result of reduced recovery between matches, which may provide a reason for the results reported (8). Accordingly, the significant limitation of the current thesis is that external match loads were not reported (due to FIFA regulations at the time), therefore what effect these loads may have on injury in Australian football during congested schedules is unknown.

6.3.2 Training Load in Prolonged Congested Schedules

The current thesis is the first to present training load distribution throughout a prolonged congested period in Australian (or European) football. Similar to the acute MM congested weeks, the total number of training sessions and duration were significantly reduced during the prolonged congested period. Further, all measures of internal and external training load were reduced – albeit without match external loads reported. Interestingly, across the 36-day prolonged period, the reduced mean session training load resulted in a significantly lower mean total load for the congested (5513 ± 1866) versus the non-congested (8943 ± 1494) period. Therefore, even with the inclusion of match load in the congested period, which was more than double the non-congested period, the overall mean total load was significantly reduced. When considering previous research, which investigated the relationship between internal load and injury in professional Dutch footballers, medium 4-weekly accumulative loads of >7087 AU resulted in reduced injury risk when compared to lower total loads (110). Although these findings are not reported for congested schedules *per se*, the results do provide a reference for typical 4-weekly loads and the association with injury (110). Although only speculative, the inability to maintain higher training intensities and workloads, which are significantly lower than those previously reported over 4 weeks, may result in reduced match 'readiness' (110). However, an actual causative effect of load and injury seems unlikely and is only suggested here due to anecdotal evidence from the team investigated.

6.3.3 Acute:Chronic Workload in Congested Schedules

The current thesis is the first to report the Acute:Chronic Workload Ratio (ACWR) throughout congested periods in professional soccer. Previously, ACWR has been suggested as a method for monitoring stochastic changes in training load over longitudinal periods (102, 184). Therefore, ACWR provides a means to visualise training load distribution during prolonged periods and make comparison to loads during normal scheduling of matches (102, 184). Recent research has questioned whether monitoring loads using rolling averages via ACWR is appropriate as it fails to quantify the extent that fatigue and reductions in fitness have over time (142, 202). Despite these considerations, ACWR's are widely used within professional sport as a method of workload monitoring and its influence should be noted here (78, 102). Given that congested schedules cause a significant disruption to the 'normal' weekly microcycles within professional football, ACWR may offer further insight into the effect load has on injury during these periods and whether players are able to tolerate greater fluctuations in load (102).

In study 2, the ACWR was not different between a prolonged congested (0.96) and non-congested (0.97) period, though significant differences were observed for total (45.3 vs. 13.4), match (64.9 vs. 23.1) and training (24.8 vs. 6.2) injuries in respective periods. Despite significantly higher sRPE total match loads for the congested period, the acute and chronic workloads between periods also reported no significant differences. Therefore, the ACWR's throughout each respective period do not provide a clear rationale for significantly increased injury rates within the congested period.

Although total loads were significantly different between the congested and non-congested period in study 2, the fact that ACWR's did not change may show that internal loads that are stochastic in nature and could not be considered the primary explanation of increased total injuries. As per study 1, the type and quantity of external load that players are exposed to as a result of match exposure may have a greater influence on injury than internal load only. This is speculative, although previous research has reported that a medium (0.85 - 1.12) and high (>1.12) sRPE training load derived ACWR has a likely beneficial effect in reducing injury risk (OR: 0.39, 90% CI: 0.23–0.65; OR: 0.69, 90% CI: 0.42–1.13) for professional Dutch footballers (110). Similarly, low (<0.6) and high (>1.5) ACWR's were found to increase the likelihood of injury in professional UEFA competitions (184). When considering the effect of internal load on injury within the current thesis, the ACWR's reported appear to fall within the 'protective' medium range suggested by previous research (110, 184). Therefore, these findings may further provide reasoning for the suggestion that external load rather than internal loads, particularly in congested scheduling may have more relevance to increased injury rates.

6.3.4 Training Load Summary

The current thesis provides novel evidence on the type and distribution of training loads throughout MM weeks and during prolonged congested periods. Study 1 within the current thesis demonstrated that internal training loads were clearly reduced in acute periods, although total load (match + training) remained unchanged between SM and MM weeks. As a result, it appears that total load does not explain the increased training injuries reported in discreet MM weeks. However, the length of time investigated may be too short for the effect of reduced load to be fully understood. As such, study 2 reported training load distribution over a prolonged period, which resulted in significantly reduced training and total loads when compared to a non-congested period. However, despite significant differences in total load, the ACWR’s between periods remained unchanged. Therefore, internal load during acute and prolonged periods of congestion may not explain increased injury rates. Increased injuries could be a result of increased external load and match exposure, although evidence of this speculation is lacking due to limitations within the current thesis. Further, load exposure is one component of player preparation, and the recovery from that load may also be a factor in any accumulating risk of injury from congested scheduling.

6.4 Recovery in Acute and Prolonged Congested Schedules

Competing in a single football match results in acute inflammatory responses and reductions in physical performance, which are apparent for ≈72-96h (153). Research investigating performance outcomes has reported 20m sprint times require between 5 and 96h to return to pre-match values (115, 153). Further, resultant post-match muscle damage, measured via biochemical markers, is present throughout the 96-120h post-match recovery period (9). In contrast, research investigating maximum voluntary contraction (MVC) and jumping ability determined that players had returned to pre-match values by 48-72h (164). However, these timelines represent recovery following single rather than consecutive matches (153). In Australian football (soccer), players may need to complete high percentages of match time in successive matches, which results from reduced squad sizes and limitations to depth of playing roster. Therefore, an understanding of recovery profiles during acute and prolonged periods of congestion is needed. To date, the reporting of recovery during congested schedules is scarce with few investigations emanating from European football and none within Asia Pacific (126, 150, 159, 171).

6.4.1 Recovery in Acute Congested Schedules

Recovery during acute congested schedules was investigated in study 3 of the current thesis, which reported the recovery profile of athletes at 48h post-match for SM and MM weeks. Measures of wellness were reduced at 48h post-match 1 in SM and MM when compared to baseline, while further reductions were present 48h post-match 2 in MM weeks, yet had retuned to baseline for SM at a comparative time point. Research investigating muscle soreness within elite European football following 1, 2 and 3 match weeks reported similar findings in comparison with study 3 (144). Using a two-group, repeated measures design, muscle soreness was reduced at 48h post-match 2 (~sevenfold) in the control group compared to an experimental ‘playing’ group (144). Further, blood markers (creatine kinase, thiobarbituric acid-reactive substances) of muscle damage peaked at 48h post for all matches, with measures collected post-match 2 exhibiting the largest differences compared to the control group (144). The previous findings are consistent with the timeline of results reported in study 3, also showing the greatest post-match reductions in perceived muscle soreness post-match 2 MM weeks. Collectively, this demonstrates a clear reduction in perceived player wellness during acute congested scheduling.

The results reported in study 3 are also consistent with those reported in professional Finnish Football during 3 vs 1 match weeks (126). Specifically, subjective measures of perceived total wellness, muscle soreness and total quality recovery were further reduced following match 2 in MM weeks within study 3. Comparatively, Lundberg et al. (126) reported decreased muscle soreness (d =1.02, CI ± 1.04) for the congested (3 match) when compared to the control group (1 match). Further, self-reported recovery measures reported a small effect (d = 0.57 ± 0.89), with a 13% decrease in congested compared to the control group (126). Despite similar findings, the methodology of the previous research differed when compared to the current thesis, mainly as the investigated recovery outcomes were collected following one week of multiple matches (126). Therefore, the results of the current thesis may be more pronounced given the repeated exposure to MM weeks. Although acute periods were investigated within the current thesis, the regularity of MM weeks is an important consideration and was not specifically investigated in study 3. However, despite limited research investigating perceived measures of recovery during congested schedules, the evidence presented to date suggests poorer recovery (perceived or otherwise) during weeks with multiple matches (126, 144).

Objective measures of recovery were also reported during acute congested schedules with hip adduction squeeze test (HAST), knee to wall (KTW), sit and reach and active knee extension (AKE). Primarily, the main finding within the current thesis were reductions in HAST scores post-match 1 for SM and MM when compared to baseline, while at 48h post-match 2 scores returned to baseline level in SM and were further reduced for MM. Comparable research using post-match measures of recovery during congested schedules is limited. However, when comparing a congested playing versus a control group, research has reported reductions in knee joint range of motion following the second match (5-7%) (144). These results are similar to study 3, whereby reduced active knee extension in MM post-match 2 compared to SM post-match 1; suggesting hamstring “tightness” may be a consequence of acute congested schedules (144). Despite some consistency between the current thesis and previous research, the discreet time periods when acute congested schedules occur may be insufficient to fully understand the negative effect that congested schedules have on recovery over longer time periods.

6.4.2 Recovery in Prolonged Congested Schedules

An accumulation of fatigue has been suggested to occur when playing matches with insufficient recovery over a prolonged time, therefore it is important to consider the timeline for recovery during prolonged and acute periods of congestion (31, 58). However, previous research has focused on investigating the physical performance of players during congested schedules with matches played outside of these periods rather than objective post-match measures of recovery. To date, only one previous study has been published investigating salivary IgA (SIgA) concentration throughout an intensive fixture of 7 games in 30 days for 21 EPL players (150). SIgA at 2 days post-match was decreased in the 3rd (p=0.001), 4th (p=0.003) and 5th (p=0.002) match within the congested period when compared to match 1, suggesting that congested schedules induce mucosal immunity changes to professional football players (150). Although tenuous to compare to our results, study 2 in the current thesis reports a comparable timeline for post-match recovery during prolonged congested periods, with total wellness reduced at 48h post-match and 24h pre-match (72h post). Interestingly, in the aforementioned research, match 3, 4 and 5 were all played as MM weeks. In contrast, match 6 and 7, which were not significantly different to match 1 and represented SM weeks within that prolonged congested period (150), further reinforcing the potential effects of congested scheduling on recovery markers.

6.4.3 Travel Demands in Congested Schedules

In Australian football, congested schedules are primarily a result of competing in the ACL, of which a consequence is extensive transmeridian travel, and is suggested to negatively influence player preparedness (76). Although not a focus of research in the current thesis, the travel demands were high throughout the 36-day congested period (study 2), with 4 international flights (Japan and Korea) of ~ 10 h duration and 6 domestic flights >2.5h. Despite a significant duration, the distance of international flights to Japan and Korea were 7819km and 8324km, respectively and crossed 1 time zone. While domestic travel ranged from 800 (Melbourne) - 4000 (Perth) km and crossed 1 -2 time zones. Despite limited evidence of travel demands for other competitions, travel remains a major concern for congested schedules in the ACL and may influence recovery from matches (75).

Previously, research in Australian football suggests that matches played with domestic travel do not have a negative effect on subjective wellness when compared to matches played at home during normal scheduling (75). However, the away matches investigated required short (<3-4h) travel times (75). In contrast, research investigating the effect of international west and east bound travel reported significant reductions to subjective and physical performance following travel from Sydney to Qatar (76). Specifically, measures of sleep as well as subjective jet lag, fatigue and motivation were all reduced for up to 4 days post-travel when compared to baseline (76). Further, markers of physical performance, including; CMJ, 20 and 5m sprint time and YoYo level 1 intermittent recovery test measures were also reduced for 4 days following travel when compared to baseline (76). Interestingly, eastbound travel reported the most significant reductions for subjective and physical measures when compared to baseline and westbound (76). Given that international travel occurred 4 times during the 36-day period, it could be assumed that players in the current thesis may also have experienced reduced recovery following matches, which was prolonged as a result of significant east/west bound travel (76). As further evidence and more relevant to the current examples, data during and following a 9h journey to Japan for a pre-season match was reported from the same Australian club used in this thesis (74). Whilst limited effects of travel were evident on wellness or sleep, the study was outbound only (i.e. not post-match) and high individual variability in responses were evident. Accordingly, travel may still affect recovery either by the act of travel (seated, cramped conditions, hypoxia) or as a physical barrier preventing post-match access to medical or rehabilitation services (74). Regardless of these considerations, the lack of physical match performance measures (GPS) is a limitation that prevents the current research from investigating if reduced player capacity exists and is influenced by travel in either acute or prolonged periods.

6.4.4 Recovery Summary

Collectively, the findings presented to date suggest that post-match recovery measures are responsive to acute periods of congestion where matches are played with short recovery (<4 days) between matches. Consistent results are reported for measures of subjective and objective measures of recovery within acute periods of congestion, however during prolonged periods the influence of multiple matches on recovery is less clear. During prolonged congested periods the time between matches varies, which may result in individual players having sufficient time to recover before ensuing matches. Furthermore, as discussed earlier, player rotation during times of prolonged congestion are also high, meaning that the actual negative response of fatigue is minimised during these periods for some players. Lastly, whether post-match recovery responses during congested schedules are more pronounced when international travel exists remains to be seen. Although speculative, increased travel demands may impede recovery for longer durations post-match, though these demands were not investigated specifically in the current thesis.

6.5 Limitations

The current thesis investigated the impact of acute and prolonged congested periods on injury, training load distribution and recovery in professional football. While the studies presented contribute to existing research, several limitations are present which should be acknowledged. A significant limitation of the research is that data was collected from 1 professional club, meaning that the findings may not be relevant to other teams. However, large epidemiological studies, which have recently been published on congested schedules, also have significant limitations associated with the standardisation of data (17, 89). Either way, recognition of one club during their ACL experiences does not constitute an overall representation of Australian clubs in the ACL. However, the iconic experience of this particular club's success in the ACL also presents novel data that otherwise does not exist.

A further limitation within study 1 and 2 existed due to restrictions on collection of GPS data from matches. At the time of data collection within the thesis, the Football Internationale de Federation Association (FIFA) had a ban on GPS technology within matches. As a result, the external load distribution reported within study 1 and 2 for SM, MM weeks, between seasons with and without congested scheduling and for prolonged congested vs. non-congested periods is limited to data collected in training.

Further, a comparison between the external load measures collected within study 1 and 2 and relevant research was difficult without reporting match load (31, 58).

Chapter 7

Conclusions

7.1 Thesis Aims

This thesis describes the effect of acute and prolonged congested scheduling has on injury, training load distribution and recovery in professional Australian football competing in the Asian Champions League (ACL). Specifically, the aim of study 1 was to examine internal and external training and match loads during SM, MM weeks and between seasons with and without fixture congestion. Further, the injury incidence rates (/1000h) were also reported as total, match and training injuries in congested fixtures. Study 2 examined training load distribution, wellness (as recovery) and injury rates for a 36-day congested period versus a matched non-congested period. Lastly, study 3 investigated recovery profiles of subjective and objective markers in SM versus MM weeks. Collectively, the studies within the current thesis add to the growing body of research investigating the demands of congested scheduling within professional football, and further intertwine concepts of training load, recovery and injury in these contexts. Accordingly, the novel addition of training and match loads and recovery data in the current thesis help to improve knowledge on the demands associated with congested schedules and help provide further insight for Australian teams competing in the ACL.

7.2 Main Conclusions

Study 1 - Injury incidence and workloads during congested schedules in football

- Increased total, match and training injury rates existed in acute congested periods during acute MM weeks.
- Total, match and training injuries were increased in seasons with greater volume of fixture congestion.

- Internal and external training loads were lower during MM weeks in comparison to SM.
- Match loads are higher as a result of increased exposure in MM when compared to SM weeks.
- No differences exist in sRPE total load between MM and SM, despite significant reduction in sRPE training load in MM weeks.
- Total injury rates are increased in seasons with greater match scheduling despite reduced sRPE total and training load.

Study 2 - Prolonged periods of fixture congestion in Australian soccer; effects on training load distribution, recovery and injury.

- Total load (match + training) during the prolonged congested period was reduced when compared to the non-congested period.
- sRPE ACWR's do not differ between congested and non-congested periods, despite reduced internal and external training loads during the congested period.
- Perceived wellness was reduced at 48h post and 24h pre (72h post) match in prolonged congested vs. non-congested period.
- Increased total, match and training injury rates were present during prolonged congested periods.
- Injury severity and non-contact injuries were increased during prolonged congested periods.

Study 3 - Recovery profiles following single and multiple matches per week in professional football.

- Perceived wellness and total quality recovery were reduced at 48h post MM match 2, when compared to SM match and Baseline.
- Measures of wellness returned to Baseline at 72h post-match 1 in SM playing group indicating a 72 recovery period during SM weeks.
- The hip adduction squeeze test measures at 48h post MM match 2 were reduced when compared to non-playing SM match 2 and MM match 1.

7.3 Practical Applications

Some of the practical applications that may be developed from the findings in this thesis include:

- Injury rates during periods of fixture congestion are evident primarily as a result of increased match exposure; however, the current thesis and previous research has reported an increase to training injuries during acute MM weeks. Therefore, care should be taken to ensure appropriate training loads are prescribed during MM weeks with an emphasis on recovery.
- Athlete monitoring could use subjective (fatigue, sleep, soreness) and objective (hip adduction squeeze) measures in the identification and management of players with reduced function (due to fatigue) and possibly health during congested match schedules.
- Increased international travel during congested schedules may further impede recovery when reduced times between matches already exist. Extended recovery profiles (~72h) may exist as a result of travel when compared to

normal match scheduling, this should be considered when administering player loads following travel in congested schedules.

7.4 Future Research

Recommendations for future research related to the findings from the current thesis should look to examine:

- Investigate External match loads via GPS/accelerometery along with post-match recovery profiles in acute and prolonged congested schedules.
- Simulated laboratory studies that investigate more invasive markers of recovery to increase the understanding of underlying mechanism of fatigue post-match in congested scheduling.
- The influence of travel on recovery during acute and prolonged congested schedules.
- Single league multi-team studies investigating injury, load distribution and post-match recovery in multiple teams and competitions.
- An investigation of the effect that rotational strategies employed by individual teams has on injury and/or recovery profiles during acute and prolonged congested schedules.

Chapter 8

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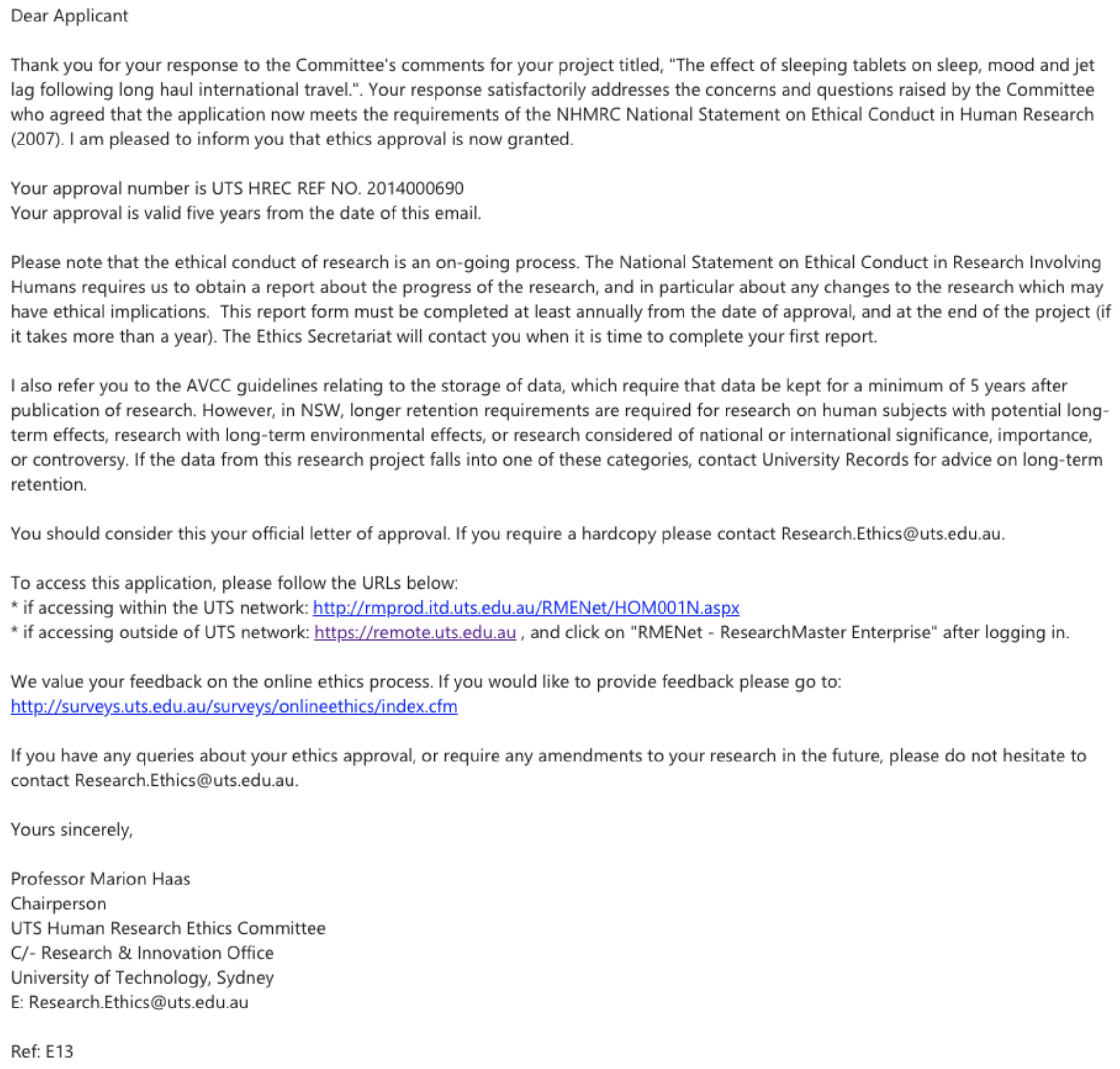
Appendices

Appendix A - Ethics Approval



Dear Applicant

Thank you for your response to the Committee's comments for your project titled, "The effect of sleeping tablets on sleep, mood and jet lag following long haul international travel.". Your response satisfactorily addresses the concerns and questions raised by the Committee who agreed that the application now meets the requirements of the NHMRC National Statement on Ethical Conduct in Human Research (2007). I am pleased to inform you that ethics approval is now granted.

Your approval number is UTS HREC REF NO. 2014000690
Your approval is valid five years from the date of this email.

Please note that the ethical conduct of research is an on-going process. The National Statement on Ethical Conduct in Research Involving Humans requires us to obtain a report about the progress of the research, and in particular about any changes to the research which may have ethical implications. This report form must be completed at least annually from the date of approval, and at the end of the project (if it takes more than a year). The Ethics Secretariat will contact you when it is time to complete your first report.

I also refer you to the AVCC guidelines relating to the storage of data, which require that data be kept for a minimum of 5 years after publication of research. However, in NSW, longer retention requirements are required for research on human subjects with potential long-term effects, research with long-term environmental effects, or research considered of national or international significance, importance, or controversy. If the data from this research project falls into one of these categories, contact University Records for advice on long-term retention.

You should consider this your official letter of approval. If you require a hardcopy please contact Research.Ethics@uts.edu.au.

To access this application, please follow the URLs below:
* if accessing within the UTS network: http://rmprod.itd.uts.edu.au/RMENet/HOM001N.aspx
* if accessing outside of UTS network: https://remote.uts.edu.au , and click on "RMENet - ResearchMaster Enterprise" after logging in.

We value your feedback on the online ethics process. If you would like to provide feedback please go to:
http://surveys.uts.edu.au/surveys/onlineethics/index.cfm

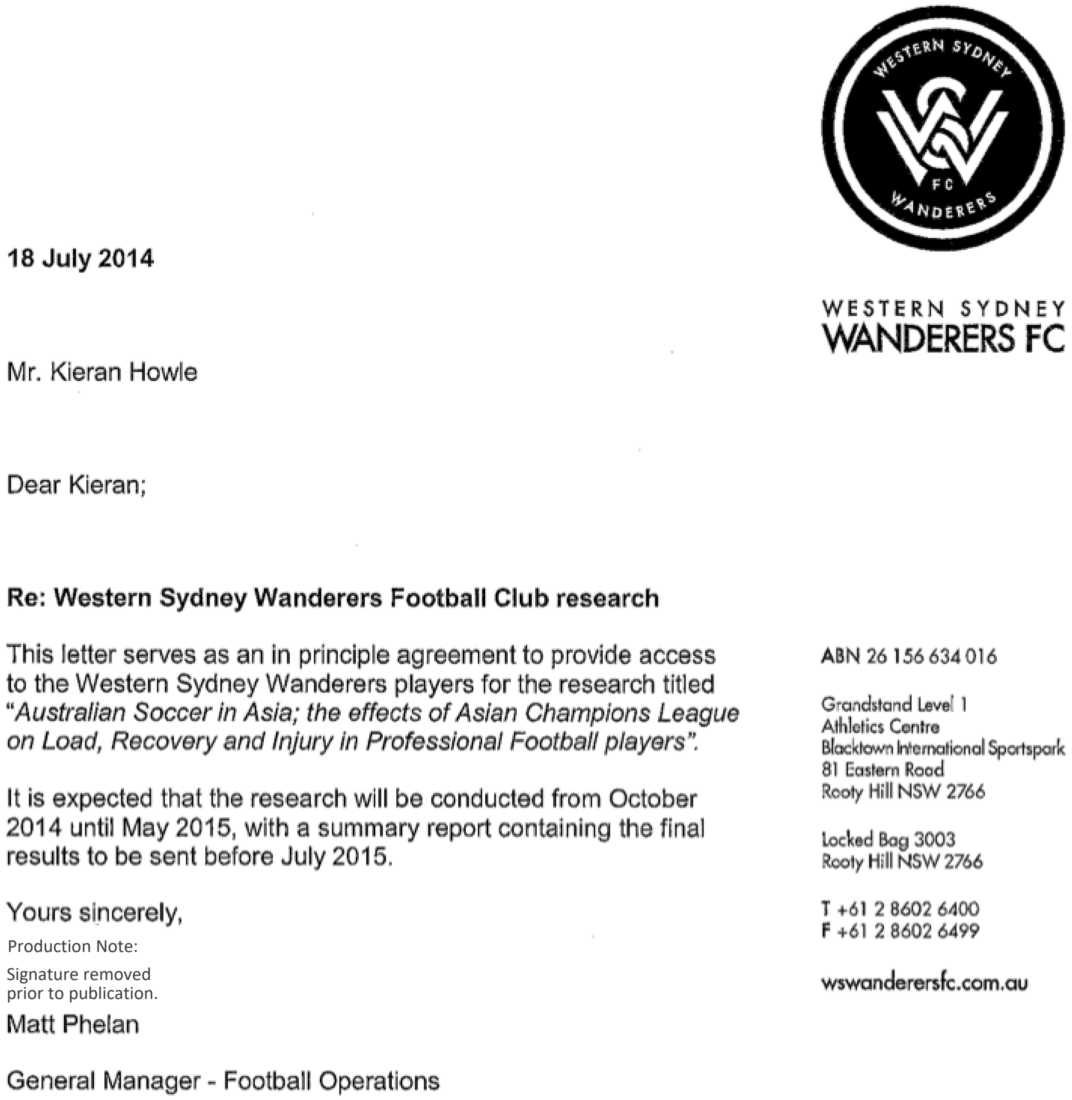
If you have any queries about your ethics approval, or require any amendments to your research in the future, please do not hesitate to contact Research.Ethics@uts.edu.au.

Yours sincerely,

Professor Marion Haas
Chairperson
UTS Human Research Ethics Committee
C/- Research & Innovation Office
University of Technology, Sydney
E: Research.Ethics@uts.edu.au

Ref: E13

Appendix B Letter of Support



WESTERN SYDNEY
WANDERERS FC

18 July 2014

Mr. Kieran Howle

Dear Kieran;

Re: Western Sydney Wanderers Football Club research

This letter serves as an in principle agreement to provide access to the Western Sydney Wanderers players for the research titled "*Australian Soccer in Asia; the effects of Asian Champions League on Load, Recovery and Injury in Professional Football players*".

It is expected that the research will be conducted from October 2014 until May 2015, with a summary report containing the final results to be sent before July 2015.

Yours sincerely,

Production Note:

Signature removed
prior to publication.

Matt Phelan

General Manager - Football Operations

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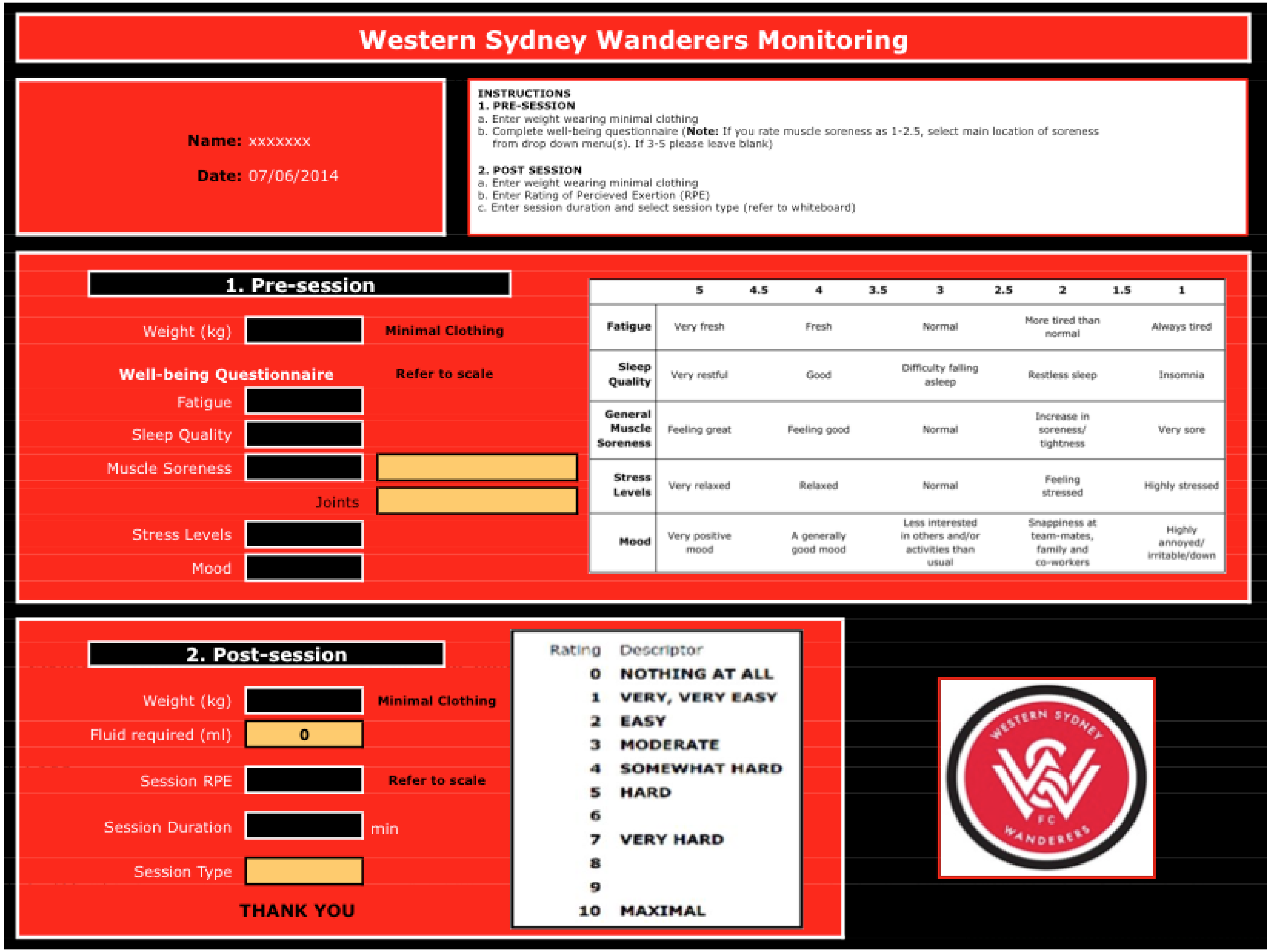
Appendix C - Example of subjective wellness and sRPE data collection form.



Western Sydney Wanderers Monitoring

Name: xxxxxxx

Date: 07/06/2014

INSTRUCTIONS
1. PRE-SESSION
a. Enter weight wearing minimal clothing
b. Complete well-being questionnaire (**Note:** If you rate muscle soreness as 1-2.5, select main location of soreness from drop down menu(s). If 3-5 please leave blank)

2. POST SESSION
a. Enter weight wearing minimal clothing
b. Enter Rating of Percieved Exertion (RPE)
c. Enter session duration and select session type (refer to whiteboard)

1. Pre-session

Weight (kg) ☐ **Minimal Clothing**

Well-being Questionnaire **Refer to scale**
Fatigue ☐
Sleep Quality ☐
Muscle Soreness ☐ ☐
Joints ☐
Stress Levels ☐
Mood ☐

	5	4.5	4	3.5	3	2.5	2	1.5	1
Fatigue	Very fresh		Fresh		Normal		More tired than normal		Always tired
Sleep Quality	Very restful		Good		Difficulty falling asleep		Restless sleep		Insomnia
General Muscle Soreness	Feeling great		Feeling good		Normal		Increase in soreness/ tightness		Very sore
Stress Levels	Very relaxed		Relaxed		Normal		Feeling stressed		Highly stressed
Mood	Very positive mood		A generally good mood		Less interested in others and/or activities than usual		Snappiness at team-mates, family and co-workers		Highly annoyed/ irritable/down

2. Post-session

Weight (kg) ☐ **Minimal Clothing**
Fluid required (ml) 0
Session RPE ☐ **Refer to scale**
Session Duration ☐ min
Session Type ☐

THANK YOU

Rating	Descriptor
0	NOTHING AT ALL
1	VERY, VERY EASY
2	EASY
3	MODERATE
4	SOMEWHAT HARD
5	HARD
6	
7	VERY HARD
8	
9	
10	MAXIMAL