# Monitoring of Perceived Load, Fatigue and Recovery within National Football Team Contexts

**by Denny Noor**

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the degree of

**Doctor of Philosophy (Sports Medicine) from the Philosophical and Medical Faculty, Saarland University, Saarbrücken, Germany in conjunction with the Faculty of Health, University of Technology Sydney, Australia.**

under the supervision of Professor Rob Duffield
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# Certificate of Authorship and Originality of Thesis

I, Denny Noor, declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy in the Faculty of Health at the University of Technology Sydney (Australia) and in the Institute of Sport and Preventive Medicine at Saarland University (Germany).

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

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree at any other academic institution except as fully acknowledged within the text. This thesis is the result of a Collaborative Doctoral Research Degree program with Saarland University (Germany).

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# List of Publications

### Peer-reviewed journal articles

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### Conference proceedings

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# Abbreviations Symbols and Subunits

| Symbol/Abbreviations | Word/Phrase |
|---|---|
| A/C ratio | Acute:Chronic ratio |
| $AC_{2015}$ | 2015 Asian Cup |
| AFC | Asian Football Confederation |
| ANOVA | Analysis of variance |
| ASRM | Athlete self-report measures |
| $CC_{2017}$ | 2017 Confederations Cup |
| CI | Confidence intervals |
| CMJ | Countermovement jump |
| ES | Effect size |
| $F$ | F statistic |
| FIFA | Fédération Internationale de Football Association |
| GPS | Global positioning system |
| h | Hour(s) |
| i.e. | That is |
| MD | Match day |
| $n$ | Number |
| $p$ | P value |
| RPE | Rating of perceived exertion |
| $r_s$ | Spearman's rank correlation coefficient |
| s-RPE | Session Rating of Perceived Exertion |
| SD | Standard deviation |
| SIgA | Salivary immunoglobulin A |
| SJ | Squat jump |
| $U23AC_{2018}$ | 2018 Under 23 Asian Cup |
| vs. | Versus |
| $WC_{2014}$ | 2014 World Cup |
| $WC_{2018}$ | 2018 World Cup |
| y | Year/s |
| - | Minus |
| % | Percentage |
| ± | Plus-minus sign |
| < | Less than |
| = | Equals |
| > | Greater than |
| ≈ | Approximately |
| ≤ | Less than or equal to |
| ≥ | Greater than or equal to |

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# Abstract

During major international football tournaments, national team practitioners operate within a challenging context, in which physical preparation and recovery is complicated by numerous organisational, operational, and logistical factors. Despite the ubiquitousness of training load, fatigue, and recovery monitoring in football, much of the literature emanates from professional clubs; whereby, the level of competitiveness, training programmes, logistical demands and availability of equipment/facilities differ from international football tournaments. Thus, further research is warranted within applied international football settings to quantify the demands of training and match loads during international tournaments and the effects on perceived fatigue, and recovery.

Study one examined the training load profiles of international footballers as they transitioned between club, camp, and tournament contexts. Thirty-five male national team footballers (25.9 ± 3.8y) were monitored over 3 international tournaments with measures of external (session duration and count) and internal (session rating of perceived exertion [s-RPE]) training load compared across each of the three tournaments. As international footballers transitioned from their clubs to national team camp, an increase in internal training load occurred due to a large increase in the number of training sessions performed. Subsequent reductions in training volumes and increased match load characterise the camp-to-tournament transition, resulting in an overall decrease in training load. Thus, the changing dynamic of trainings and matches alters the accumulation and distribution of internal training load in international footballers. Knowledge of the players' club-based training loads becomes important to national team practitioners to help plan and manage camp and tournament training based on individual needs.

Study two investigated the effect of match load on self-reported fatigue and recovery during congested and non-congested tournament schedules. Thirty-seven male national team footballers (26.4 ± 4.1y) reported daily measures of internal training load (s-RPE) and perceived fatigue status (ratings of perceived fatigue, muscle soreness, psychological status, sleep quality, and sleep duration) during the competition phase of 3 international tournaments. Player's data was retrospectively categorised into congested or non-congested 2-match microcycles (Acute-Congestion, Non-Congestion, Single-Match, No-Match), and then comparatively assessed to determine the effect of acute match congestion on internal load and perceived fatigue/recovery profiles. During international football tournaments, variations in player's perceived fatigue status were largely responsive to the presence of match load, with transient worsening post-match in perceived fatigue, muscle soreness, and sleep ratings. Further, acute match congestion impaired player's pre-match perceived fatigue status compared to non-congested microcycles. However, within the Acute Congestion condition, no significant difference in perceptual fatigue was evident between the consecutive match days. Thus, acute match congestion does not exacerbate perceived fatigue and recovery responses within international tournaments.

Study three further examined the self-reported fatigue and recovery profiles of international footballers during congested tournament matches, while also reporting preliminary evidence of player's recovery intervention usage within a national team context. Forty male national team footballers (26.4 ± 4.1y) were monitored throughout 2 international tournaments, with outcome measures of perceived fatigue status (5-items), recovery status (1-item), and recovery intervention usage assessed according to player's match exposure (Starters, Rotations, Non-Playing, and Consecutive Starters). Repeated match exposure during a week of congested international tournament football elicits a transient worsening in perceived fatigue and recovery status, with perceptions of perceived fatigue further impaired following the second match. In response, recovery intervention use was higher for playing groups compared to non-playing, with a high prevalence of recovery methods targeting physiological recovery mechanisms, due in part to the availability and preference for these interventions. Practitioner provision of recovery modalities may also have influenced player behaviour as to the selection and frequency of recovery interventions used within the national teams.

Overall, the current thesis provides an initial and detailed description of the perceived training load, fatigue, and recovery profiles of Australian national team footballers across multiple major international tournaments. It is recommended that national team practitioners seek prior knowledge of player's club-based training loads to help plan and manage camp and tournament training according to player's individual needs. During international football tournaments, monitoring players exposure to matches and time between matches, as well as changes in perceived fatigue, recovery and intervention usage may be helpful to determine player's match readiness. However, concerns remain in relation to the validity and reliability of using multi-item and single-item self-report measures to assess athlete's training 'response', with ambiguous findings surrounding national team footballers perceived fatigue response during congested match schedules. To counter transient worsening in post-match perceived fatigue and recovery status, national team practitioners should be mindful of the influence that they have on player's recovery intervention choices, with key information such as the initial targeting of physiological recovery strategies and provision/timing of different recovery options.

# Chapter 1: Introduction

## 1.1 Introduction

Major international football (soccer) tournaments, such as the Fédération Internationale de Football Association (FIFA) World Cup and Asian Football Confederation (AFC) Asian Cup, represent highly coveted international football championships for players, coaches, and spectators. The tournaments consist of 24 or 32 national teams competing over 3-4 weeks, with a minimum of 3 and maximum of 6-7 matches played in a congested nature, depending on tournament progression. As such, the physical demand of these congested tournament matches is considerable, with regular starters required to play 2-3 matches per week separated by 72-96 hours (Silva et al., 2017). While effective player rotation may help to reduce the number of players exposed to successive matches, opportunities to do so during international tournaments are limited and inappropriate, particularly once teams progress to the knockout stages. As regular starters strive to maintain physical and technical performance throughout these tournaments, modifications in training load and prioritising recovery may be necessary to minimise residual fatigue (Halson, 2014). In contrast, ensuring that rotation and non-selected players maintain fitness (and motivation) may require adjustments in training load to stimulate acute fatigue and physical load exposure in the absence of matches (Anderson et al., 2016a; Stevens et al., 2017). Hence, understanding the training and match loads of international footballers during tournaments and its effects on fatigue and recovery is important for national team practitioners.

To better comprehend training load and fatigue responses within elite football, practitioners from both club and national teams have increasingly adopted scientific monitoring practices to quantify training load and fatigue/recovery (Akenhead & Nassis, 2016; McCall et al., 2015; Weston, 2018). However, despite the recent rise in monitoring research within elite football, much of what is known about training load, fatigue, and recovery emanates from professional club football; whereby, the level of competitiveness, training programmes, logistical demands and availability of equipment/facilities differ from national teams competing at international football tournaments (McCall et al., 2015). Thus, various gaps in the literature are present, with evidence of international footballer's training and match loads only reported during the transition between club and training camp (McCall et al., 2018a). Separately, single studies on biochemical (Hecksteden & Meyer, 2020) and immunological (Morgans et al., 2015) markers exist reporting fatigue-related outcomes of national team players. Such a lack of evidence from this environment is likely due to the logistical difficulties of national team players being based in a multitude of clubs around the world, along with varied support staff, shortened preparation periods and the infrequent nature of international tournaments; all of which complicate the process of athlete preparation and monitoring (Buchheit & Dupont, 2018; McCall et al., 2018a). Accordingly, further research is warranted within applied international football settings to quantify the training and match loads during international tournaments and effects on fatigue and recovery.

The preparation of national-team players for international football tournaments is a complex task, centring on the ability of national-team staff to find the right balance between (i) recovery – to ensure players are regenerated after their domestic club competitions, and (ii) training – to maintain fitness and readiness throughout any given tournament and return to clubs (Buchheit & Dupont, 2018). In contrast to club settings, preparation strategies for international tournaments are limited by the shortened time periods that national team staff have access to their players; typically, 3-4 weeks for discreet camps or a few days for matches – depending on when they have played their last domestic club match (Buchheit & Dupont, 2018; McCall et al., 2018a). In addition, the competitive standards and the type/amount of training these players engage in is heterogeneous, meaning players are likely to report to national team camp with varying degree of football fitness and physical preparedness (Buchheit & Dupont, 2018; Morgans et al., 2015). As such, consideration is required to manage training load so that players receive the necessary training stimuli, while simultaneously minimising symptoms of fatigue to optimally prepare them for the tournament (Morgans et al., 2015). However, in the context of transitioning from club to national teams, continuous load monitoring represents both a logistical and methodological challenge. In particular, the lack of comparability between external load monitoring devices (i.e. global positioning system [GPS] devices) limits the transferability of such information between club and national teams, and thus more simple and reliable measures of training load (i.e. training/match minutes and rate of perceived exertion [RPE]) are often required (McCall et al., 2018a)

During major international football tournaments, competitive match loads are considerable, with a high number of matches often condensed into a short period of time (Silva et al., 2017). While evidence suggests that elite footballers are able to cope with a congested match calendar for a short time period (Carling et al., 2012; Folgado et al., 2015; Lago-Peñas et al., 2011), the planning of international tournaments at the end of the regular football season may leave players fatigued and at increased risk of injury and/or underperformance during these tournaments (Ekstrand et al., 2004). Such concerns resonate with national team practitioners, who ranked accumulated fatigue, training load in clubs, and reduced recovery periods/match congestion during tournaments among the most important risk factors for non-contact injury (McCall et al., 2015). Accordingly, monitoring of fatigue status and recovery is an important element within the current practices of national team staff, with a range of measures used to determine how players are coping physically (heart rate, biochemical markers [e.g., blood, saliva], objective tests of sleep and muscle function) and mentally (athlete self-report measures [ASRM]) with the congested training and match loads (McCall et al., 2015). However, despite the prevalent use of fatigue-related monitoring tools in national teams, limited published evidence currently exists on international footballer's fatigue and recovery profiles during congested tournaments.

Within the congested match schedule of international football tournaments, the time for recovery is often limited, accentuating the need to optimise and monitor the recovery process. To aid the post-match recovery of footballers, a multitude of recovery strategies are routinely implemented in professional teams targeting various causes of fatigue (Nédélec et al., 2013). In particular, recovery strategies aimed at reducing acute inflammation from muscle damage are heavily used (Altarriba-Bartes et al., 2020). However, while the recovery practices and player habits in club football have been documented (Field et al., 2021), limited evidence currently exists regarding the use of recovery strategies during international football tournaments. This is despite the noted concerns of national team practitioners advocating the need for evidence of optimal recovery strategies within tournament contexts (McCall et al., 2015). As such, descriptions of the recovery strategies/protocol used from the ecological context of international football tournaments are warranted, particularly as the assistance from support staff and access to recovery facilities/equipment may differ to that within professional club teams.

## 1.2 Thesis aims

Given the importance of optimising player preparation for international tournaments and maintenance of their performance throughout a tournament, this thesis aims to:

1. Examine the training load profiles of international footballers as they transition from club-to-camp-to-tournament contexts during multiple international tournaments (Study 1).
2. Determine the effect of match load on self-reported fatigue and recovery profiles during congested and non-congested microcycles within international tournaments (Study 2).
3. Describe the self-reported fatigue, recovery, and usage of recovery interventions between international footballers with different match status during congested tournament schedules (Study 3).

## 1.3 Significance of thesis

The unique demands of international football challenge national team practitioners attempting to implement evidenced-based player monitoring practices to optimise team performance. The importance of player monitoring within international football contexts is relevant, highlighted by recent evidence suggesting higher injury rates occur during World Cup events when compared to domestic club settings (McCall et al., 2015). Previous research on player monitoring has primarily occurred within professional club contexts (Carling et al., 2018; Nédélec et al., 2012; Silva et al., 2018a), with limited research available attempting to quantify the magnitude of training and competition load during international tournaments and determine its effects on player fatigue and recovery. An increased understanding of player demands during international tournaments, as well as identifying the challenges and limitations of attempting to monitor players within national team contexts, will enable prospective qualifying teams to better prepare and monitor their players during international football competition. Collectively, this research will provide insight into the demands of participating in international football tournaments, with a particular focus on the effects of congested tournament match play on perceived load, fatigue, recovery, and usage of recovery interventions.

## 1.4 Limitations

Several limitations are present within the studies that comprise this thesis, including:

- The retrospective and observational nature of the studies meant that there was no control group or opportunity to expand on the fatigue and recovery measures assessed with the studies. This prevented having a greater and more detailed understanding of player's fatigue and recovery during international tournaments.
- The cohorts used within the studies were sampled from only a single national team/federation, limiting the generalisability of the findings, as many contextual factors specific to the national team likely influenced the training load periodisation and recovery provisions provided to the players.
- The use of a single measure of internal load (s-RPE) provides only part of the conceptual framework that defines the training process and presents little to no information on the physical work completed by the players. Whilst the inclusion of objective external load data would provide a more integrated assessment of the player's training and match loads; unfortunately, collection of these data types were not available across all the international tournaments sampled within this study.
- The use of subjective self-report measures provides only a single surrogate measure of footballers' fatigue and recovery response, with numerous other factors contributing to changes in these latent variables.

## 1.5 Delimitations

Several known delimitations are present in this sequence of studies, including:

- The use of top-level international footballers during highly competitive tournament environments where significant prestige ensured that competitors had significant motivation to perform.
- All training load, fatigue and recovery data were collected using a standardised athlete monitoring system implemented by Football Australia. This ensured that national team footballers were able to be consistently monitored using the same data collection protocols throughout the transition from club-to-camp-to-tournament, as well as over multiple tournaments.

# Chapter 2: Literature Review

## 2.1 Overview

The optimisation of national team footballers' performance throughout international football tournaments requires careful planning of both the preparatory and in-tournament periods (Bangsbo, 1998). However, given the logistical constraints of national teams, optimal player preparation can be a challenge, with practitioners required to find the right balance between (i) training to tactically and physically prepare for competition and (ii) recovery to allow players to regenerate from domestic leagues (Buchheit & Dupont, 2018). In response to this challenge, monitoring of training load, fatigue and recovery is currently considered an essential element of care for international footballers (McCall et al., 2015). By quantifying and understanding the interaction between these factors, national team practitioners are able to monitor the training process, from which appropriate planning of subsequent training loads and competition availability can be determined (Gabbett et al., 2017; Halson, 2014). Yet, despite the widespread use of monitoring practices within football, much of the available evidence emanates from professional club contexts where the training programmes, logistical demands and available facilities differ from national team environments (McCall et al., 2015).

Indeed, the challenge for sport science and sport medicine practitioners working in national team contexts is to implement evidenced-based player monitoring practices that are appropriate to their specific environment (Burgess, 2017). A study surveying the perceptions and practices of national team physicians at the FIFA 2014 World Cup revealed that accumulated fatigue and training load imposed on the players' (both prior and during the tournament) were perceived among the most important risk factors for non-contact injury (McCall et al., 2015). In line with these perceptions, the practitioners also reported the use of monitoring tools targeting a range of training load measures (i.e. number and/or minutes of matches played), and fatigue-recovery response (i.e. medical screening, subjective wellness, heart rate, and biochemical and objective markers of physical state) (McCall et al., 2015). However, despite the perceived importance and reported use of training load and fatigue monitoring tools within national football teams, limited evidence exists outlining the training/match demands and extent of fatigue/recovery in international players.

Contemporary reviews of training load (Jaspers et al., 2017; Miguel et al., 2021; Teixeira et al., 2021), fatigue (Nédélec et al., 2012; Silva et al., 2018a), and recovery (Altarriba-Bartes et al., 2020; Nédélec et al., 2013) in football have all centred on research emanating from club-based environments. However, there is very limited published evidence concerning international football that provides an overview of player training load, fatigue and recovery responses within national football teams. Therefore, the purpose of this chapter is to review training load, fatigue and recovery monitoring research within international football. Specifically, this chapter will explore the current training load monitoring practices in football and describe the profiles of international footballers based on the current available evidence. In addition, this chapter will review measures commonly used in football research and practice to quantify player fatigue and recovery status and detail the existing evidence surrounding international footballer's fatigue and recovery responses.

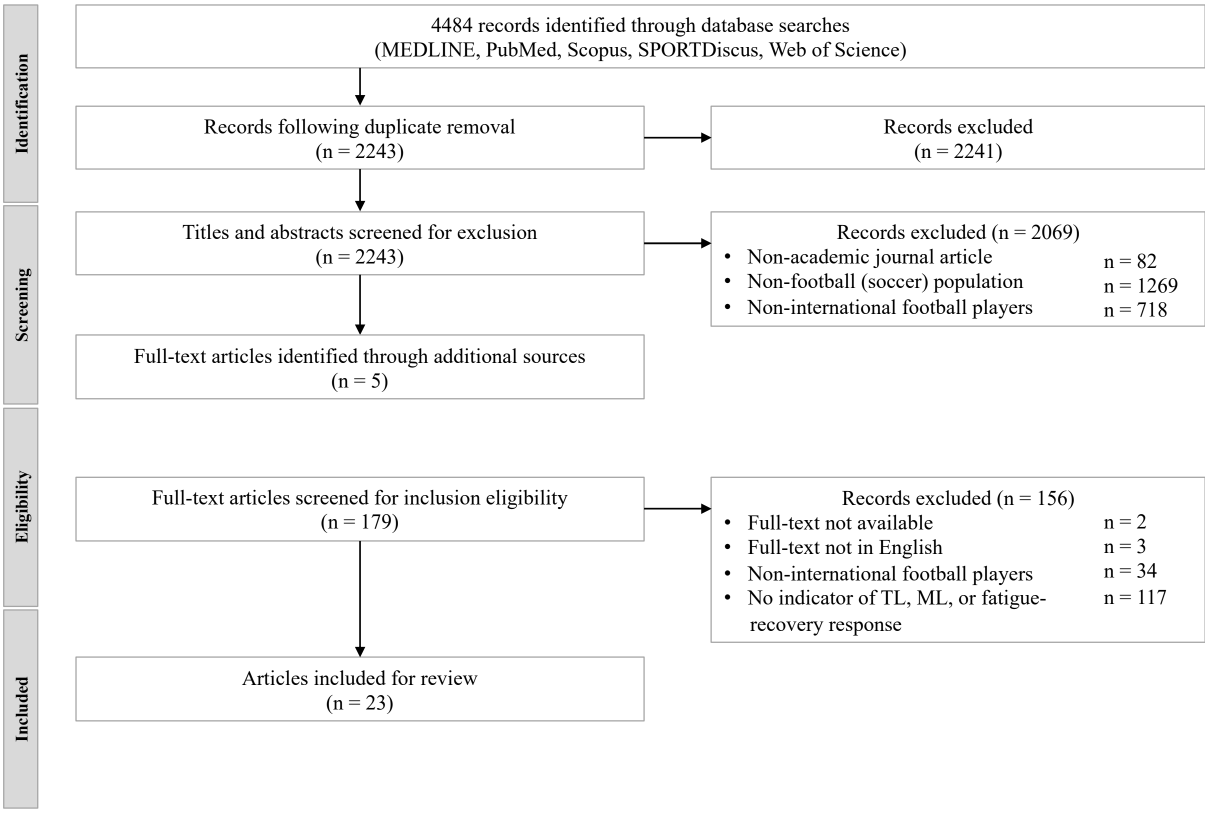
## 2.2 Literature review methods

To identify relevant articles for inclusion in this review a search of scholarly databases (MEDLINE [PubMed], Scopus, SPORTDiscus and Web of Science) was conducted using the search terms, "football", "international", "national teams", "tournament", "training load", "match load", "fatigue", and "recovery". Keywords for each of the search terms were combined and used in a Boolean search for peer-reviewed articles. In total, 4484 articles were identified after which all duplicates were removed, and titles and abstracts were screened for eligibility. Inclusion criteria for the review required articles to have examined male international footballers and reported a measure of either (i) training/match load, (ii) subjective/objective fatigue response, or (iii) recovery. Accordingly, 23 eligible articles were included relevant to international football (a schematic diagram is presented in Figure 2.1).

## 2.3 Training and match loads in international football

In order to gain an understanding of the training and match load demands of international footballers, it is important to recognise the various measures available to quantify training load in football (Halson, 2014; Miguel et al., 2021). As such, this section will briefly summarise measures commonly used in professional football to quantify training load, before describing current literature on training and match load profiles of international footballers. Final considerations will then be given to the methodological and logistical issues associated with continuous monitoring practices in national team contexts.

Figure 2.1. A schematic diagram outlining the literature review search process.



*2.3.1 Measurement of training and match load*

In recent years, the emergence of innovative technologies in sport science has provided football practitioners with more in-depth and quantifiable measures of training and match loads (Akenhead & Nassis, 2016; Cardinale & Varley, 2017). Measures of training load can be broadly categorised as either internal or external. External training load is defined as the objective measure of work that an athlete completes during training or competition (i.e. time, distance, speed, number of repetitions) (Bourdon et al., 2017; Halson, 2014). The internal training load is the associated psycho-physiological stress caused by training or competition (i.e. heart rate, blood lactate, RPE) (Bourdon et al., 2017; Halson, 2014). Given that internal and external training load are integral components of the training process (Impellizzeri et al., 2005), adopting an integrated approach to training load monitoring is widely recommend (Bourdon et al., 2017). Thus, within modern professional football teams a combination of both internal and external measures are predominantly used to monitor training load (Akenhead & Nassis, 2016; Weston, 2018). However, despite contemporary technologies producing a plethora of training load variables, there is currently no consensus as to which variables are most useful or, indeed, how to analyse the longitudinal data of a diverse squad of players within a national team context (McCall et al., 2015). A brief review of available training load monitoring options are provided as context to the logistical and methodological issues for monitoring training load in national team players.

*2.3.2 Perceived Exertion.*

The rating of perceived exertion (RPE) is one of the most common means of assessing internal load in football (Weston, 2018). The use of RPE is based on the notion that individuals have an inherent ability to gauge their physiological response to exercise (Borg, 1982). Early monitoring strategies in football were limited to reporting descriptive training and competition information such as training frequency and duration, while subjective reporting scales were used to quantify training intensity (Foster et al., 2017). In particular, the use of the RPE scale (Foster et al., 2001) multiplied by the duration of the training session or match (s-RPE) is still one of the most commonly used means of assessing internal load in applied football research and practice (Akenhead & Nassis, 2016). This is predominantly due to its ease of collection, negligible expense, and its ability to quantify loads in all forms of training (conditioning, strength, rehab, 'off-legs' etc.) and competition (Impellizzeri et al., 2004). Accordingly, s-RPE measures represent an obvious and easy method to monitor training load in national team players who are based in a diverse range of clubs in a wide range of geographical locations.

Whilst s-RPE is widely acknowledged as being a practical low-cost tool to assess training load in football, its use within national team contexts remains unreported within scientific literature. Indeed, the utility of such a simple and convenient tool would be highly advantageous for monitoring the transition of players from club to national teams (McCall et al., 2018a) Particularly given the lack of agreement between more advanced external load monitoring devices that are commonly used in club environments, limiting the transferability of the information to provide a cumulative summation of national team training load (Buchheit & Dupont, 2018). However, RPE-based training load quantification in football is not without limitations, notably the notion that a range of physiological, psychological, and environmental factors can influence an individual's perceptions of physical exertion that are unaccounted for within the single global rating of RPE (Borresen & Lambert, 2009; Brito, Hertzog, & Nassis, 2016). Further, s-RPE is a subjective measure that is often deemed to be influenced by a range of other factors and issues (i.e. win/loss, environmental conditions) (Fessi & Moalla, 2018; Haddad et al., 2014). Despite these ongoing concerns, RPE-based measures of training load remain highly practical tools that can be used reliably across multiple team contexts and training environments to quantify internal training load and represent an obvious training load monitoring tool for national teams.

### *2.3.3 Heart-rate*

Heart-rate (HR) telemetry measures allow sport science practitioners to objectively monitor the cardiovascular load and intensity of football training (Alexandre et al., 2012; Silva et al., 2018b). Whilst their use in official matches has not been sanctioned by FIFA, recent evidence surveying practitioners within high-level football clubs does indicate that the use of HR monitors to quantify load during training is very common (Akenhead & Nassis, 2016). Indeed, there are certain advantages of measuring HR variables in football, in that they are non-invasive, relatively inexpensive, time-efficient and can be applied routinely and simultaneously in a large number of players (Buchheit, 2014). Moreover, recent advancements in real-time HR monitoring can provide football coaches and practitioners with insights to alter a player's internal training stress.

However, limitations of HR monitoring in football must also be considered, with reductions in the reliability of HR variables observed during high-intensity exercises (i.e. intermittent running, Small-Sided Games, isolated directional changes etc.) (Alexandre et al., 2012), where HR may not represent mechanical loads and the linear relationship between HR and intensity disassociates (Borresen & Ian Lambert, 2009). Furthermore, whilst collection of HR measures during football training is relatively simple, a large number of indices can be computed, requiring expert analysis and somewhat time-consuming interpretation (Alexandre et al., 2012; Buchheit, 2014). Given the restrictions on match-day use there is limited information available regarding HR monitoring practices within national team contexts. A recent survey of team physicians at 2014 FIFA World Cup reported HR as the 4th most commonly used monitoring tool among the competing national teams (McCall et al., 2015), though differentiation of match or training use was not reported. Understandably a key limitation of implementing routine HR monitoring during international tournaments is that its application in matches is not sanctioned, disrupting the cumulative summation of training load, and requiring an alternative monitoring method be implemented. Hence, whilst monitoring HR during training may be of use, historical availability of measurement devices in both club and national team contexts seems varied and lacking uniformity.

*2.3.4 Player-Motion Analysis*

With the on-going development and integration of micro-technologies into applied sport settings, player movement analysis and tracking has become one of the most important components of training load monitoring in football. In particular, semi-automated multi-camera systems, local positioning systems, and Global Positioning Systems (GPS), are now utilised by professional football clubs either in isolation or in combination during both training and matches (Akenhead & Nassis, 2016; Buchheit & Simpson, 2017). Ultimately, these systems provide large amounts of data related to players overall external (locomotor) load, which is then used to make evidence-based decisions on appropriate exercise prescription to improve physical preparation and enhance team performance. Among the plethora of external load metrics available, distance covered at various speeds and the occurrence of high-speed runs, accelerations, and decelerations are the most common measures reported by practitioners (Akenhead & Nassis, 2016; Buchheit et al., 2014a). However, despite the widespread contemporary use of these devices in clubs, previous limitations on their use during official matches restricted research within national teams.

Accordingly, club contexts provided much more consistent and longitudinal monitoring of external load during trainings (Anderson et al., 2016a; Stevens et al., 2017).

While such technological advances are of evident value for practitioners and players, limitations in terms of validity and on-field usefulness of player tracking systems are still often overlooked (Buchheit & Simpson, 2017). For instance, the validity of speed and acceleration measures is dependent on the rate of change of the variables and therefore, it has been recommended that acceleration, deceleration, and directional change derived from GPS tracking should be interpreted with caution (Bourdon et al., 2017). Furthermore, GPS signal quality can be influenced by variations in time of day, location of tracking, and obstruction from infrastructure (i.e. stadium roofs may cause partial blockage) (Buchheit & Simpson, 2017). Lastly, there are large between-unit variations (up to 50%), even between units from the same brands (Buchheit et al., 2014a). Thus, it has been recommended that players should always use the same unit, and caution should be taken when comparing different players' data. Hence, data comparison between different systems used in respective club and national teams provides potential for error and misunderstanding of training and match loads.

At present, there is no clear consensus regarding how player-tracking data should be handled and reported in a football-specific context (Akenhead & Nassis, 2016). Within national teams the use of tracking technologies for the purposes of training load monitoring has been considerably unexamined, particularly in comparison to the quantity of research conducted in club-based contexts (Buchheit & Dupont, 2018). Indeed, issues concerning the comparative processing of GPS data between devices or systems, as well as, between -units, restrict the data sharing capabilities between clubs and national teams to provide a cumulative summation of training load (Buchheit, 2017; Buchheit & Dupont, 2018). Overall, the decision to use any tracking technology or any other monitoring variable should always be considered with a cost/benefit approach (i.e., cost, ease of use, portability, manpower / ability to impact on the training program) that is specific to the objectives of the monitoring system and the context in which it will be applied. In national team environments, although GPS data will be commonly used at respective club and national teams, the use of the technology is rarely uniform and may lead to erroneous training load data for national team practitioners to make informed decisions.

#### *2.3.5 International tournament preparation, periodisation, and training loads*

Contemporary international football tournaments are characterised by a high number of matches (6-7) played within a short period of time (typically 3-4 weeks) with limited recovery periods (Silva et al., 2017). Evidently, the performance level of the players not only have to be optimal at the start of the tournament during the group stages, but also throughout the entire knockout phase leading up to the final (Bangsbo, 1998). Thus, careful planning is required for both the preparation and tournament periods to strategically manage training load and recovery so that players receive the necessary training stimuli, while simultaneously preventing symptoms of fatigue to optimally prepare for the tournament (Bangsbo, 1998; Morgans et al., 2015). However, despite the anecdotal perceptions of national team practitioners operating at the FIFA 2014 World Cup alluding to the prevalent use of training load monitoring tools during these tournaments (McCall et al., 2015), only a limited number of studies (Table 2.1) have actually examined the training load of international footballers within national team contexts.

Concerning training load, research investigating the training periodisation and demands of international footballers have predominantly centred on the training camp period (Bangsbo et al., 2006; Fowler et al., 2017; Fullagar et al., 2016), as well as the time preceding arrival into training camp (Ekstrand et al., 2004; McCall, et al., 2018b). Prior to arriving to the national team, international footballers are deemed to engage in very heterogenous types and amounts of training, as well as match exposure, which likely determines their individual level of fitness/training status (Buchheit & Dupont, 2018; Morgans et al., 2015). Evidence from Ekstrand et al. (2004), demonstrates that players who participated in the 2002 FIFA World Cup played in more matches during the regular season that those who did not (46 v 33 matches). In particular, during the final 10 weeks of the season is when international footballers appear to play the most matches with their club teams relative to the first 36 weeks of the season (Ekstrand et al., 2004). Under normal circumstances, these players are able to cope with such an intensive programme because a period of rest typically follows (i.e. off-season). However, every 2-4 years this rest period is replaced by an international football tournament. As a result, Ekstrand et al. (2004) found that many of the national team players that played more than one match per week over the last 10 weeks of the regular season underperformed or incurred an injury during the 2002 World Cup. These findings indicate that the congested match calendar at the end of the domestic season may leave players fatigued, increasing the risk of injury and/or underperformance during the tournament period. This further justifies the need to monitor match and training loads during the transition from club to national team duties to optimise training prescription.

Table 2.1. Summary of results from studies reporting training load in international football players.

| Authors | Year | Origin | Study Type | Aim | Population | | | Context | | Concept (Training Load) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Level | Gender | Number | Setting | Duration | Parameter(s) | Data |
| Bansgbo *et al* | 2006 | Denmark | Case study | Description of the preparation of the Danish NT for the European Championship 2004 | Senior | Male | 1 team (*n* players not specified) | Training camp | 18 days | Duration in different HR zones (bpm) | Presented graphically |
| | | | | | | | | | | Duration in different HRmax zones (%) | |
| Ekstrand *et al* | 2004 | Sweden | Prospective cohort | Evaluate the correlation between club-based match and training exposure to injury and performance at the World Cup | Senior | Male | 65 players from 11 teams | Club-based and in-tournament | 10 months at clubs, 1 month in tournament | No. of training sessions (*n*) | 181 ± 35 |
| | | | | | | | | | | No. of matches (*n*) | 46 ± 13 |
| | | | | | | | | | | Total exposure (hours) | 293 ± 50 |
| | | | | | | | | | | Training exposure (hours) | 234 ± 42 |
| | | | | | | | | | | Match exposure (hours) | 59 ± 20 |
| Fowler *et al* | 2017 | Australia | Prospective cohort | The effects of long-haul air travel on subjective jet-lag, sleep and wellness responses in NT footballers | Senior | Male | 22 players from 1 team | Training camp | 2 weeks | Total exposure (min) | 311 (280–342) – Week prior travel<br>313 (278–348) – Week following travel |
| | | | | | | | | | | s-RPE training load (AU) | 1955 (1713–2197) – Week prior travel<br>1904 (1643–2165) – Week following travel |
| Fullagar *et al* | 2016 | Germany | Prospective cohort | Sleep, travel and recovery responses of NT footballers during and following international air travel | Senior | Male | 15 players from 1 team | Training camp and matches (international friendlies) | 10 days | Total distance (m) | 5129 ± 1110 |
| | | | | | | | | | | Mean speed (m/min) | 69 ± 2 |
| | | | | | | | | | | HSR distance (m) | 101.9 ± 47.4 |
| | | | | | | | | | | Mean HR (bpm) | 144 ± 6 |
| | | | | | | | | | | Duration >85% HRmax (min) | 18.8 ± 5.7 |
| | | | | | | | | | | s-RPE training load (AU) | 392 ± 76 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| McCall *et al* | 2017 | Australia | Prospective cohort | Load profiles between injured and non-injured NT footballers | Senior | Male | 17 players from 1 team 16 players from 1 team | Pre-camp | 4 weeks | Chronic s-RPE load (AU) | 1399 ± 508 (injured) 1861 ± 690 (non-injured) |
| | | | | | | | | | | Match s-RPE load (AU) | 1043 ± 737 (injured) 1425 ± 1128 (non-injured) |
| | | | | | | | | | | Chronic no. of sessions (*n*) | 3.9 ± 1.4 (injured) 4.9 ± 0.8 (non-injured) |
| | | | | | | | | | | No. of matches (*n*) | 2.1 ± 1.3 (injured) 2.7 ± 1.8 (non-injured) |
| | | | | | | | | Training Camp | 1 week | Acute s-RPE load (AU) | 2260 ± 510 (injured) 2149 ± 558 (non-injured) |
| | | | | | | | | | | Acute no. of sessions (*n*) | 5.3 ± 1.0 (injured) 4.6 ± 0.7 (non-injured) |
| | | | | | | | | ACWR | 1:4 weeks | ACWR s-RPE load (AU) | 1.7 ± 0.5 (injured) 1.3 ± 0.7 (non-injured) |
| | | | | | | | | | | ACWR no. of sessions (*n*) | 1.5 ± 0.5 (injured) 1.0 ± 0.1 (non-injured) |
| Wollin, *et al* | 2017 | Australia | Prospective cohort | The acute effect of competitive football match play on hamstring strength and lower limb flexibility in elite youth players | Youth | Male | 14 players from 1 team | National U21 competition | 1 week | Acute s-RPE load (AU) | 2154 ± 369 |
| | | | | | | | | | 4 weeks | Chronic s-RPE load (AU) | 7057 ± 1013 |

NT, national team; n, number; HR, heart rate; bpm, beats per minute; min, minutes; s-RPE, session rating of perceived exertion; AU, arbitrary units; m, meters; HSR, high-speed running; m/min, meters per minute; ACWR, acute-chronic workload ratio.

National team training camps function to ensure that the players are tactically, physically, and mentally prepared for tournament demands. However, complicating training camp planning is the need to appropriately balance training load and recovery within a truncated period between domestic club commitments and the tournament (Buchheit & Dupont, 2018; Morgans et al., 2015). Evidence from McCall et al. (2018a), demonstrates that players who encounter a significant increase in training load during the first week of camp potentially have a higher likelihood of injury. Specifically, players who sustained a non-contact injury during the training camp period tended to have lower pre-camp (chronic) training loads than those players who were not injured (McCall et al., 2018a). However, these authors also noted spurious associations resulting from a small and niche data set of one national team. Regardless, this finding aligns with the work published by Ekstrand et al. (2004), in that players who were exposed to high chronic club-based training loads were found to be less likely to incur a non-contact injury. As such, it has been recommended to monitor and closely align player's training loads between club and camp contexts where possible, as large spikes in load may increase the likelihood of injury (McCall et al., 2018a).

The organisation of preparation strategies for international soccer matches is limited by the transient time periods that national teams have access to their playing squads. Bangsbo (1998) previously suggested dividing the tournament preparation period into a maintenance and a rebuilding phase, whereby the first 2-weeks would constitute the maintenance phase, followed by a 5-week rebuilding phase. While contemporary national teams are not afforded such extended preparation periods, Bangsbo (2006) demonstrated how the notion of different training phases (maintenance and rebuild) were used within the 18-day tournament preparation of the Danish national for the 2004 European Championship. Furthermore, heart rate measures of training load showed that the amount of training time spent in lower heart rate zones was higher during the first 9-days of the national team training camp compared to the second 9-days (Bangsbo et al., 2006). However, the amount of training time spent in higher heart rate zones was held constant throughout the camp, indicating that a clear tapering strategy was used to help improve performance by reducing the volume of low-intensity training while maintaining a sufficient amount of high-intensity training (Bangsbo et al., 2006). This research again represents a case study of one national team during a tournament, though still highlights clear training prescription strategies used in camp based on training load monitoring tools.

An additional demand for national team players during international tournaments is the requirement to undertake long-haul international air travel to arrive at training camp or tournament. This has the potential to disrupt the training preparation of national footballers, as numerous physiological variables are disrupted (i.e. sleep-wake cycle, body temperature and hormonal circadian rhythms) when long-haul international travel is endured across multiple time-zones (Fullagar et al., 2016). However, the findings from Fowler et al. (2017) demonstrated that training exposure (minutes) and internal training load (s-RPE) were relatively similar for the week prior and following east-bound international air travel for one national team prior to a World Cup. Although some psychological effects were observed in terms of worsened perceived ratings of jet-lag, sleep, and fatigue (Fowler et al., 2017). Whilst not specific to training load monitoring, this study further highlights monitoring of player in club and during transition to national team duties is an important process given the extensive and unique contextual demands. Overall, the small amount of available literature suggests the transition from club to national team training environment results in substantial differences in the exposure to the type and volume of training stimulus. Accordingly, further detailed understanding of this change in training load between club and national team transitions is required.

### *2.3.6 Tournament match loads and the effects of congested schedules*

During international tournaments, players experience high competition demands coupled with a congested match schedule and limited time for recovery (Silva et al., 2017). Concerns regarding these competition and training demands of international footballers during congested tournaments resonate with national team practitioners, who ranked reduced recovery periods, accumulated fatigue and congested match schedules among the most important risk factors for non-contact injury (McCall et al., 2015). However, despite these concerns a lack of evidence exists within national teams examining player match loads across periods of congested tournament match-play.

Within the reviewed articles (Table 2.2) that examined match load in national team football, measures of external match load were predominantly reported (*n*=13), with only a small collection of studies reporting internal load measures (*n*=3). Common external load parameters reported in the studies included total running distance, running distance at varying velocities, peak speed, and number of sprints. While internal match load parameters of RPE and s-RPE were also reported. A high proportion of the studies (*n*=12) sampled data from multiple national teams across a single tournament, with only 4 studies found that examined a single national team.

Furthermore, only two studies investigated the influence of successive congested matches on player's tournament match load (Silva et al., 2017; Varley et al., 2018). These studies found no decline in commonly reported external match load measures, such as total distance, means speed or distances in high speed zones, during the congested tournament schedule. As such, the findings align with previous studies conducted with club teams (Carling et al., 2012; Dupont et al., 2010; Lago-Peñas et al., 2011), indicating that professional footballers are able to maintain their match-running performance even during congested match schedules.

Table 2.2. Summary of results from studies reporting match load in international football players.

| Authors | Year | Origin | Study Type | Aim | Population | | | Context | | Concept (Match Load) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Level | Gender | Number | Setting | Duration | Parameter(s) | Data (mean ± SD) |
| Chmura *et al* | 2017 | Poland | Retrospective cohort | To analyze motor activities of soccer players in seven consecutive rounds of matches of the 2014 World Cup | Senior | Male | 340 players from 32 teams | Tournament | 3-4 weeks (incl. 64 matches) | Total distance (km) | 10.1 ± 1.0 |
| | | | | | | | | | | HSR distance – 19.9-25.2 km/h (% total distance) | 8.8 ± 2.1 |
| | | | | | | | | | | No. of sprints – > 25.2 km/h (n) | 33.3 ± 10.7 |
| | | | | | | | | | | Peak running speed (km/h) | 28.0 ± 2.2 |
| Chumra *et al* | 2014 | Poland | Retrospective cohort | To examine the endurance capacity and selected technical-tactical skills of soccer players participating in the 2014 World Cup | Senior | Male | 32 teams (*n* players not specified) | Tournament | 3-4 weeks (incl. 48 matches – group matches) | Team total distance (km) | 106.8 ± 6.2 |
| | | | | | | | | | | Team LSR distance (km) | 63.1 ± 2.5 |
| | | | | | | | | | | Team MSR distance (km) | 16.6 ± 1.9 |
| | | | | | | | | | | Team HSR distance (km) | 27.2 ± 3.0 |
| Chumra *et al* | 2017 | Poland | Retrospective cohort | Effect of changes in ambient temperature and air humidity on player's physical activity profiles during the 2014 FIFA World Cup | Senior | Male | 340 players from 32 teams | Tournament | 3-4 weeks (incl. 64 matches) | Total distance (km) | |
| | | | | | | | | | | < 60% humidity | 10.5 ± 0.9 (low temp)<br>10.0 ± 1.0 (mid temp)<br>9.9 ± 0.9 (high temp) |
| | | | | | | | | | | > 60% humidity | 9.8 ± 1.1 (low temp)<br>10.2 ± 0.9 (mid temp)<br>10.2 ± 0.9 (high temp) |
| | | | | | | | | | | LSR (≤ 11 km/h) distance (km) | |
| | | | | | | | | | | < 60% humidity | 5.9 ± 0.3 (low temp)<br>5.9 ± 0.3 (mid temp)<br>6.0 ± 0.4 (high temp) |
| | | | | | | | | | | > 60% humidity | 5.7 ± 0.5 (low temp)<br>6.0 ± 0.3 (mid temp)<br>6.1 ± 0.3 (high temp) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | MSR (11-14 km/h) distance (km) | |
| | | | | | | | | | | < 60% humidity | 1.7 ± 0.3 (low temp)<br>1.6 ± 0.3 (mid temp)<br>1.5 ± 0.3 (high temp) |
| | | | | | | | | | | > 60% humidity | 1.6 ± 0.4 (low temp)<br>1.6 ± 0.4 (mid temp)<br>1.6 ± 0.3 (high temp) |
| | | | | | | | | | | HSR (> 14 km/h) distance (km) | |
| | | | | | | | | | | < 60% humidity | 3.0 ± 0.6 (low temp)<br>2.6 ± 0.6 (mid temp)<br>2.4 ± 0.6 (high temp) |
| | | | | | | | | | | > 60% humidity | 2.6 ± 0.6 (low temp)<br>2.5 ± 0.6 (mid temp)<br>2.5 ± 0.6 (high temp) |
| Clemente *et al* | 2013 | Portugal | Retrospective cohort | To analyse the distance covered and the activity profile of players competing at the 2010 FIFA World Cup | Senior | Male | 443 players from 32 teams | Tournament | 3-4 weeks (incl. 64 matches) | Total distance ($m.min^{-1}$) | 109.9 ± 8.2 |
| | | | | | | | | | | Total distance with possession ($m.min^{-1}$) | 42.3 ± 6.0 |
| | | | | | | | | | | Total distance without possession ($m.min^{-1}$) | 44.2 ± 5.9 |
| | | | | | | | | | | Low intensity activity (% time) | 82.9 ± 2.8 |
| | | | | | | | | | | Medium intensity activity (% time) | 8.2 ± 1.3 |
| | | | | | | | | | | High intensity activity (% time) | 8.9 ± 1.7 |
| da Mota *et al* | 2016 | Brazil | Retrospective cohort | The effects of high- and low-percentage ball possession teams on physical/technical indicators during 2014 FIFA World Cup | Senior | Male | 346 players | Tournament | 3-4 weeks (incl. 55 matches) | Total distance (m) | Presented graphically |
| | | | | | | | | | | LSR (≤ 11 km/h) distance (m) | |
| | | | | | | | | | | MSR (11-14 km/h) distance (m) | |
| | | | | | | | | | | HSR (> 14 km/h) distance (m) | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Total distance with possession (m) | |
| | | | | | | | | | | Total distance with-out possession (m) | |
| Duk *et al* | 2011 | Korea | Retrospective cohort | To characterise selected indices of endurance and speed of the Korea Republic team with reference to the four best teams during the World Cup of 2010 | Senior | Male | 599 players from 32 teams | Tournament | 3-4 weeks (incl. 64 matches) | Total distance (km) | 10.3 ± 0.9 (Korea)<br>10.6 ± 1.2 (Spain)<br>10.3 ± 1.1 (Netherlands)<br>10.3 ± 1.0 (Germany)<br>10.6 ± 1.2 (Uruguay) |
| | | | | | | | | | | Peak running speed (m/s) | 7.3 ± 0.5 (Korea)<br>7.1 ± 0.7 (Spain)<br>7.3 ± 0.6 (Netherlands)<br>7.2 ± 0.7 (Germany)<br>7.2 ± 0.6 (Uruguay) |
| | | | | | | | | | | Mean running speed (m/s) | 1.9 ± 0.1 (Korea)<br>1.9 ± 0.2 (Spain)<br>1.8 ± 0.2 (Netherlands)<br>1.9 ± 0.2 (Germany)<br>1.9 ± 0.2 (Uruguay) |
| Jozak *et al* | 2011 | Croatia | Retrospective cohort | To determine position-related differences in the amount, intensity and speed of movement in elite national team football players from 2010 FIFA World Cup | Senior | Male | 150 players randomly selected from 32 teams (>250 minutes played in 3 matches) | Tournament | 3-4 weeks (incl. 64 matches) | Total distance (km) | 10.0 ± 0.8 |
| | | | | | | | | | | Total distance with possession (km) | 3.9 ± 0.6 |
| | | | | | | | | | | Total distance with-out possession (km) | 4.0 ± 0.6 |
| | | | | | | | | | | Peak running speed (km/h) | 26.3 ± 2.3 |
| | | | | | | | | | | Low intensity activity (% time) | 52.3 ± 3.2 |
| | | | | | | | | | | Medium intensity activity (% time) | 5.3 ± 1.1 |
| | | | | | | | | | | High intensity activity (% time) | 5.7 ± 1.3 |
| Nassis *et al* | 2015 | Qatar | Retrospective cohort | To examine the effect of environmental heat stress on physical and technical performance indices during the 2014 FIFA World Cup | Senior | Male | 32 teams (*n* players not specified) | Tournament | 3-4 weeks (incl. 64 matches) | Total distance ($m.min^{-1}$) | Presented graphically |
| | | | | | | | | | | LSR (≤ 11 km/h) distance ($m.min^{-1}$) | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | MSR (11-14 km/h) distance (m.min$^{-1}$) | |
| | | | | | | | | | | HSR (> 14 km/h) distance (m.min$^{-1}$) | |
| | | | | | | | | | | Peak running speed (km/h) | |
| Njororai *et al* | 2012 | USA | Retrospective cohort | To examine match movement profiles of players from the USA and Ghana National teams during the 2010 FIFA World Cup | Senior | Male | 2 teams (*n* players not specified) | Tournament | 3-4 weeks (incl. 8 matches) | Team total distance (km) | USA 107.5 (vs. England)<br>107.1 (vs. Slovenia)<br>110.6 (vs. Algeria)<br>148.2 (vs. Ghana) *ET<br>Ghana 106.1 (vs. Germany)<br>101.8 (vs. Australia)<br>97.7 (vs. Serbia)<br>140.3 (vs. USA) *ET<br>131.2 (vs. Uruguay) |
| | | | | | | | | | | Total distance (km) | USA 9.8 (vs. England)<br>9.7 (vs. Slovenia)<br>10.1 (vs. Algeria)<br>13.5 (vs. Ghana) *ET<br>Ghana 9.6 (vs. Germany)<br>9.3 (vs. Australia)<br>8.9 (vs. Serbia)<br>12.8 (vs. USA) *ET<br>11.9 (vs. Uruguay) |
| Rienzi *et al* | 2000 | Uruguay | Prospective cohort | To determine the work-rate profiles of elite South American soccer players during international competition compared to English Premier League players | Senior | Male | 17 players (*n* teams not specified) | International competition | Not specified | Total distance (m) | 8638 ± 1158 (all actions)<br>2721 ± 463 (walk)<br>530 ± 171 (walk back)<br>3702 ± 1152 (jog)<br>154 ± 4103 (jog back)<br>263 ± 182 (jog side)<br>923 ± 360 (cruise)<br>345 ± 222 (sprint) |
| Schimpchen *et al* | 2016 | Germany | Retrospective cohort | To investigate the occurrence of repeated sprinting bouts in elite international football matches | Senior | Male | 30 players from 1 team | Match play (qualifiers and friendly matches) | 2 years (incl. 19 matches) | Peak running speed (km/h) | 33.7 ± 1.6 |
| | | | | | | | | | | No. sprints per match (n) | 10.8 ± 3.3 (Centre-defend)<br>17.8 ± 5.7 (Fullback)<br>18.9 ± 9.6 (Holding-mid)<br>20.8 ± 3.9 (Wide-mid) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | 14.8 ± 7.5 (Attack-mid)<br>17.4 ± 6.9 (Centre-forward) |
| | | | | | | | | | | Recovery duration between sprints (n) | |
| | | | | | | | | | | % <30 s | 12.3 ± 9.8 |
| | | | | | | | | | | % 30.1–60 s | 6.9 ± 4.3 |
| | | | | | | | | | | % 60.1–120 s | 16.0 ± 5.2 |
| | | | | | | | | | | % >120 s | 64.9 ± 13.6 |
| Silva *et al* | 2017 | Qatar | Retrospective cohort | To examine match activity of players from the four first ranked teams during the 2014 FIFA World Cup | Senior | Male | 17 players from 4 teams | Tournament | 3-4 weeks (incl. 7 matches) | Total distance ($m.min^{-1}$) | 113.4 ± 10.4 (peak game)<br>104.3 ± 11.6 (post peak)<br>102.9 ± 7.6 (average five) |
| | | | | | | | | | | LSR distance – < 11km/h ($m.min^{-1}$) | 63.1 ± 2.9 (peak game)<br>62.3 ± 4.2 (post peak)<br>61.2 ± 2.8 (average five) |
| | | | | | | | | | | MSR distance – 11-14 km/h ($m.min^{-1}$) | 19.0 ± 4.7 (peak game)<br>16.2 ± 4.8 (post peak)<br>15.6 ± 3.7 (average five) |
| | | | | | | | | | | HSR distance – > 14km/h ($m.min^{-1}$) | 31.3 ± 5.1 (peak game)<br>25.5 ± 5.8 (post peak)<br>26.1 ± 4.5 (average five) |
| | | | | | | | | | | Sprints – > 25 km/h ($n.min^{-1}$) | 0.45 ± 0.13 (peak game)<br>0.32 ± 0.08 (post peak)<br>0.35 ± 0.10 (average five) |
| Varley *et al* | 2017 | Qatar | Prospective cohort | The effects of successive matches on match-running performance during an international tournament | Senior | Male | 44 players from 13 teams | Tournament | 7 days (incl. 3 matches) | Total distance (m) | 10177 ± 730 (Match 1)<br>10266 ± 736 (Match 2)<br>9979 ± 717 (Match 3) |
| | | | | | | | | | | Walking distance – 0.19-1.99$ms^{-1}$ (m) | 3359 ± 210 (Match 1)<br>3428 ± 214 (Match 2)<br>3420 ± 214 (Match 3) |
| | | | | | | | | | | Jogging distance – 2.00-3.99$ms^{-1}$ (m) | 4055 ± 429 (Match 1)<br>4072 ± 430 (Match 2)<br>3937 ± 417 (Match 3) |
| | | | | | | | | | | HSR distance – 4.00-5.49$ms^{-1}$ (m) | 1704 ± 362 (Match 1)<br>1686 ± 359 (Match 2)<br>1602 ± 343 (Match 3) |
| | | | | | | | | | | VHSR distance – 5.50-6.99$ms^{-1}$ (m) | 719 ± 189 (Match 1)<br>717 ± 188 (Match 2)<br>675 ± 179 (Match 3) |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | Sprint distance – ≥7.00ms$^{-1}$ (m) | 261 ± 98 (Match 1)<br>292 ± 108 (Match 2)<br>265 ± 100 (Match 3) |
| Wollin *et al* | 2017 | Australia | Prospective cohort | The acute effect of competitive football match play on hamstring strength and lower limb flexibility in elite youth players | Youth | Male | 14 players from 1 team | National U21 competition | 4 days (incl. 1 match) | Match RPE (AU) | 8.3 ± 0.6 |
| | | | | | | | | | | Match s-RPE (AU) | 725.8 ± 63.58 |
| Wollin *et al* | 2018a | Australia | Prospective cohort | Effect of congested international tournament match play on adductor strength and pain in elite youth players | Youth | Male | 22 players from 1 team | International Youth (U16) Tournament | 14 days | Cumulative match s-RPE load (AU) | Presented graphically |
| Wollin *et al* | 2018b | Australia | Prospective cohort | Effect of playing two competitive football matches in three days on hamstring strength and lower limb flexibility in elite youth players | Youth | Male | 15 players from 1 team | National U21 competition | 2 × 3 days (congested periods incl. 2 matches) | Sum of match exposure over two matches (min) | 169.7 ± 16.6 |
| | | | | | | | | | | Duration played in match 1 (min) | 88.0 ± 5.3 |
| | | | | | | | | | | Duration played in match 2 (min) | 81.7 ± 14.5 |
| | | | | | | | | | | Sum of s-RPE over two matches (AU) | 1346.7 ± 253.5 |
| | | | | | | | | | | s-RPE match 1 (AU) | 703.0 ± 103.4 |
| | | | | | | | | | | s-RPE match 2 (AU) | 643.7 ± 169.7 |

Incl., including; *n*, number; min, minutes; km, kilometres; km/h, kilometres per hour; m, metres; m.min$^{-1}$, metres per minute; m/s, metres per second; m.min-1, number per minute; LSR, low speed running; MSR, medium speed running; HSR, high speed running; VHSR, very high speed running; temp, temperature; % time, percentage of time; RPE, rating of perceived exertion; s-RPE, session rating of perceived exertion; AU, arbitrary units.

### *2.3.7 Methodological and logistical considerations*

The transition into national teams and ensuing demands of international tournaments are both major concerns for practitioners to ensure player health, availability and performance (McCall et al., 2018b). Accordingly, optimal preparation for international tournaments may be possible by monitoring player's training and match load within both club and national team contexts. However, significant challenges exist for national team practitioners in implementing training load monitoring practices that are both evidenced-based and pragmatic to their specific environment (Burgess, 2017). For instance, despite certain advantages in HR monitoring to objectively quantify internal training load, a key limitation and roadblock to implementing this measure is that FIFA has not yet sanctioned it use in official matches. Furthermore, despite the extensive external load data available from player tracking technologies, issues concerning the comparative processing of GPS data between devices or systems, restrict the data sharing capabilities between clubs and national teams to provide a cumulative summation of training load. Hence, simple and reliable methods of training load (i.e. s-RPE) that are easily transferable from club to national team contexts would be highly advantageous (McCall et al., 2018b).

## 2.4 Fatigue and recovery responses in international football

In order for practitioners to make informed decisions on training load management and recovery strategies in the days post-match, understanding the time course of player's fatigue and recovery response is of vital importance (Nédélec et al., 2012; Silva et al., 2018a). As such, this section will briefly examine the measures used in professional football to assess fatigue/recovery, before describing the fatigue and recovery profiles of international footballers from the current available literature. Final considerations will then be given to the methodological and logistical issues associated with monitoring fatigue and recovery in national team contexts.

### *2.4.1 Measurement of fatigue and recovery*

Identifying and understanding the fatigue response of football players following intensive training and competition throughout the season is necessary to avoid injury, performance decrements and overtraining (Hogarth, 2015). Whilst, some insights may be gleamed from determining the disassociation between external and internal load, they both ultimately fail to consider the complex interaction of numerous other factors that may collectively influence the athlete's response (Impellizzeri et al., 2005). Therefore, additional measures are required to evaluate the response to training/competition more directly that will enable sport scientists to make informed decisions on each player's fatigue-recovery status (Impellizzeri et al., 2005). While a plethora of proffered test methods exist to assess fatigue in football, those selected must be valid, reliable, and practically convenient in an applied setting (Thorpe et al., 2015).

### *2.4.2 Athlete Self-Report Measures*

Athlete self-report measures (ASRM) such as questionnaires including Likert or visual analogue scales were reported as the most-commonly-used measure to monitor daily changes in player's psychobiological state and wellbeing (McCall et al., 2015). Within the scientific literature, an extensive range of ASRM currently exists, including the Profile of Moods (POMS), Daily Analysis of Life Demands for Athletes (DALDA), Total Quality Recovery (TQR) scale and Recovery-Stress Questionnaire (REST-Q) (Kellmann, 2010). However, many of these psychometric inventories are often time-consuming to complete, which is important for psychometric properties, but makes daily use in football difficult with large numbers of athletes (Thorpe, Atkinson, et al., 2017). As such, in order to foster athlete compliance and improve questionnaire specificity, practitioners have incorporated customised, shortened versions of these instruments into their monitoring practices (Hooper & Mackinnon, 1995; McLean et al., 2010). The data from the questionnaires (i.e. perceived fatigue, muscle soreness, sleep, stress, and mood) are then purportedly used to evaluate how athletes are tolerating the training load, and their subsequent readiness to train or compete (Campbell et al., 2020).

However, despite the widespread use of ASRM in professional football, recent scrutiny of these measures has challenged researchers and practitioners to re-evaluate the design and use of these measures; particularly as it remains unclear how well these measures respond to training load or reflect the constructs of fatigue/recovery (Duignan et al., 2020; Jeffries et al., 2020). Previous research, aiming to determine a dose–response relationship between ASRM and markers of external and internal training load in football have demonstrated differing trends, with trivial-to-large relationships found within a variety of load metrics (Malone et al., 2018; Moalla et al., 2016; Thorpe et al., 2015). Furthermore, the reliability of ASRM were recently shown to not be reproducible within the fatigue response of academy footballers (Fitzpatrick et al., 2018), in addition to being strongly influenced by both match outcomes and match venue (Abbott et al., 2018; Fessi & Moalla, 2018). Ultimately, the efficacy of these tools is dependent upon a number of theoretical (inter-relations between the measure, social environment and outcomes) and practical factors that need to be addressed within the applied sports setting (Saw et al., 2017). Therefore, within national team football contexts, ASRM may be a useful tool to assist in the remote (i.e. whilst in clubs) and immediate (i.e. in-camp) assessment of player fatigue-recovery status. However, the appropriateness and usefulness of this data within these contexts is relatively unknown, particularly given the heightened risk of noncompliance and manipulation of responses whilst players are based within their clubs.

### *2.4.3 Blood & Salivary Markers*

Blood and saliva measures can provide detailed information on a player's health status and improve our mechanistic understanding of football-specific fatigue (Heisterberg et al., 2014). The implementation of blood and salivary analysis to investigate various biochemical, hormonal, and immunological markers of fatigue appears to be an uncommon and infrequent monitoring approach within professional football clubs (Akenhead & Nassis, 2016). Whilst many different metabolites and hormones can be measured via blood and saliva, research in football has focused on a variety of markers representative of muscle damage (creatine kinase [CK]), inflammatory response (interlukein-6 [IL-6] and C-reactive proteins [CRP]), hormonal imbalance (cortisol and testosterone) and immune function (salivary immunoglobulin A [SIgA]) (Meister et al., 2014; Meyer & Meister, 2011; Mohr et al., 2016). However, large inter- and intra-individual responses to training or match play exist, which can make interpreting monitoring results difficult (Hecksteden & Meyer, 2020; Meyer & Meister, 2011). Specifically, this variability in measured values leads to wide reference ranges, even when based on athletic populations, and thereby impedes on the diagnostic value of the parameters (Hecksteden et al., 2017). Furthermore, these measures are invasive, expensive, and practically challenging within applied football settings, even with access to laboratory equipment and analysis expertise (Carling et al., 2018). Thus, the limited utility of biochemical, hormonal, and immunological measures to monitor fatigue and recovery in football players, may partly explain why only 24% of clubs in a recent survey reported using blood markers or saliva analysis (Akenhead & Nassis, 2016).

In contrast, however, 50% of the national teams competing at the 2014 FIFA World Cup reported using blood and saliva measures as part of their monitoring strategies to identity non-contact injury risk (McCall et al., 2015). As it was not specified which biochemical, hormonal, or immunological markers were specifically monitored, or how frequent monitoring occurred (i.e. daily, weekly, monthly), it is possible that the surveyed national teams may only have conducted blood and saliva analysis as part of a single medical screening prior to the tournament (i.e. beginning of training camp). Indeed, to the author's knowledge only two studies have examined blood or salivary markers repeatedly within a national team context. Morgans et al. (2015) demonstrated that a short training camp in the lead up to an international tournament qualifier induced a significant decline in immune function (SIgA). Separately, Hecksteden et al. (2020) identified a correlation between post-match (2-day) CK values and external match load measures of total running distance and high-speed running distance. These results provide some evidence for the use of biochemical makers of damage and inflammation, though the cost, availability and access in national team context may preclude their regular use.

*2.4.4 Physical Performance Tests (Maximal & Sub-Maximal)*

Measures of submaximal and maximal performance assessment (sprints, repeated sprints, jumps, maximal voluntary contractions, and submaximal running protocols) have been used to assess fatigue and quantify the rate of recovery in the hours and days following training and competition in football (Ispirlidis et al., 2008; Nédélec et al., 2012; Nedelec et al., 2014). Whilst these types of assessment provide important information, the application of physical performance tests, which are exhaustive in nature and time consuming to implement means they are often unsuitable for use in football environments, where players are required to compete on a weekly to biweekly basis. As such, submaximal-running protocols and jump tests have been reported as being frequently used (weekly-monthly) in professional football clubs to assess player's fatigue response (Akenhead & Nassis, 2016).

Submaximal shuttle runs, in which exercise HR and HR-recovery values are monitored, represent a practically attractive option, due in part to their ease of administration, ability to simultaneously profile multiple players, and minimal encroachment on planned training activity (Rabbani et al., 2018; Schneider et al., 2018; Veugelers et al., 2016). However, the interpretation of HR values in applied environments can be challenging as ambient conditions, running surface, wind resistance, and hydration status, among other factors, can compromise the reliability of the test (Buchheit, 2014). In addition, a given change (i.e., reduced submaximal exercise HR) can be caused by either increased fatigue or increased fitness, which makes interpretation less straightforward (Buchheit, 2014; Lamberts et al., 2009). The sensitivity of the measures to football-specific load has recently been investigated in professional English Premier League (EPL) players, with both exercise HR and HR-recovery failing to fluctuate in response to within week changes in training and match load over the course of a season (Thorpe et al., 2015, 2016).

Jump protocols including squat jump (SJ) and countermovement jump (CMJ) have been adopted by football practitioners to examine the recovery of neuromuscular function following competition with significant decreases for up to 72-h are routinely reported (Ispirlidis et al., 2008; Rowell et al., 2017; Thorpe et al., 2015). Despite its adoption within high-level football clubs, CMJ height has previously been reported to have a limited relationship with acute changes of training load in football players. Among EPL players during a 17-day in-season period, Thorpe et al. (2015) reported CMJ to have a weak relationship with daily fluctuations in total high intensity running distance covered at training. Furthermore, Malone et al. (2015) found no relationship between training load variables (total distance, high intensity distance, RPE) and CMJ height among elite youth football players. This is perhaps suggestive that the use of jump height as a global indicator of neuromuscular function may lack the sensitivity to detect changes in training load. However, other neuromuscular parameters (eccentric, concentric, and total duration, time to peak force/power, flight time:contraction time ratio) derived from CMJ have been deemed suitable for neuromuscular fatigue detection (Gathercole et al., 2015), with a recent study in Australian 1st Division players providing evidence to support this notion (Rowell et al., 2017). Regardless, the different measurement technologies and tests used between clubs and within national team contexts make understanding and interpretation of such testing data difficult for national team practitioners. Currently there is limited evidence from national teams about such measures on the transition into national teams or use during international tournaments.

*2.4.5 Effect of tournament match play and match congestion on fatigue and recovery.*

Repeated exposure to matches during congested tournaments results in an accumulation of load, which in the absence of sufficient recovery may subsequently result in increased fatigue, performance decrement or injury risk (Dupont et al., 2010; Ekstrand et al., 2004). Hence, monitoring fatigue and recovery throughout international football tournaments is a common process (McCall et al., 2015). However, evidence from national football teams remains scarce (Table 2.3), with limited information concerning the effects of congested match scheduling on national-team players' post-match recovery profiles. Among the multitude of potential fatigue indicators used in professional football, only a small number of measures were found to have been examined within national team contexts, including; perceptual ratings (Fowler et al., 2017; Fullagar et al., 2016), strength tests

Table 2.3. Summary of results from studies examining measures of fatigue/recovery in international football players

| Authors | Year | Origin | Study Type | Aim | Population | | | Context | | Concept (Fatigue/Recovery) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Level | Gender | Number | Setting | Duration | Parameter |
| Fowler *et al* | 2017 | Australia | Prospective cohort | The effects of long-haul air travel on subjective jet-lag, sleep and wellness responses in NT footballers | Senior | Male | 22 players from 1 team | Training camp | 2 weeks | Perceptual recovery |
| Fullagar *et al* | 2016 | Germany | Prospective cohort | Sleep, travel and recovery responses of NT footballers during and following international air travel | Senior | Male | 15 players from 1 team | Training camp and matches (international friendlies) | 10 days | Perceptual recovery |
| Hecksteden & Meyer | 2019 | Germany | Retrospective cohort | Retrospective analysis of blood-borne fatigue markers from multiple international tournaments | Senior | Male | 68 players from 1 team | Tournament | 2 d post-match | Creatine kinase<br>Urea |
| Morgans *et al* | 2017 | Wales | Prospective cohort | Monitor resting SIgA levels in international football players during the training-camp period that precedes game day | Senior | Male | 13 players from 1 team | Training camp | 4 d pre-match | SIgA |
| Wollin, *et al* | 2017 | Australia | Prospective cohort | The acute effect of competitive football match play on hamstring strength and lower limb flexibility in elite youth players | Youth | Male | 14 players from 1 team | National U21 competition | 3 d post-match | Isometric hamstring strength<br>Ankle dorsiflexion<br>Hip extension<br>Knee extension<br>Knee flexion |
| Wollin, *et al* | 2018a | Australia | Prospective cohort | Effect of congested international tournament match play on adductor strength and pain in elite youth players | Youth | Male | 22 players from 1 team | International Youth (U16) Tournament | 2 weeks | Hip adductor strength |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Wollin, *et al* | 2018b | Australia | Prospective cohort | Effect of playing two competitive football matches in three days on hamstring strength and lower limb flexibility in elite youth players | Youth | Male | 15 players from 1 team | National U21 competition | 3 d post-match | Isometric hamstring strength<br><br>Ankle dorsiflexion<br>Hip extension<br>Knee extension<br>Knee flexion |

d, days; U, under; SIgA, salivary immunoglobulin A

(Wollin et al., 2017; Wollin et al., 2018a; Wollin et al., 2018b), blood markers (Hecksteden & Meyer, 2020), and salivary markers (Morgans et al., 2015). Furthermore, within the reviewed articles only three studies (Fowler et al., 2017; Hecksteden & Meyer, 2020; Wollin et al., 2018a) were conducted during or preceding international football tournaments, with the remaining studies conducted during either international windows or national competitions.

Physical stress as a result of football match-play has been reported to induce a range of hormonal, biochemical and immunological changes in the subsequent days post-match (Silva et al., 2018a). During a short training camp period (World Cup qualifying campaign), Morgans et al. (2015) demonstrated that SIgA declined over the days preceding international football match-play. While physiological responses from training across the short training camp may possibly have contributed towards this decline, consistent and detailed measurement of training load was not collected as a part of the study. Thus, it is unclear whether the training prescription during this short training camp was of sufficient intensity and duration to reduce SIgA or whether alternative mechanisms such as psychological and/or travel stress may be related (Morgans et al., 2015). However, unlike Morgans (2015), Hecksteden et al. (2020) was able to assess the relationship of biochemical measures of urea (U) and creatine kinase (CK) against external load metrics from tournament match-play (total running distance, high-speed running, and the number of sprints). Total running distance and high-speed running were found to be significantly correlated with CK levels 2 days after match-play with a disproportionate CK response for extra-time matches (Hecksteden & Meyer, 2020). Furthermore, group-based analyses found an overall mean and confidence interval for CK well above the clinical reference limit. The exceptional strain and tight schedule during major international tournaments seem to be a plausible explanation for the more pronounced upward shift of CK as compared to the report by Meyer et al. (2011).

Although, comparison of in-tournament values with measurements from the same players during the season would be required to verify these possible explanations (Hecksteden & Meyer, 2020). Thus, these results provide initial evidence of the responsiveness of biochemical and immunological makers of fatigue within national team contexts.

A common trend in the monitoring practices of international football teams is the daily use of ASRM to monitor the psychobiological state of players (McCall et al., 2015). Within the reviewed articles, evidence of international footballers perceived fatigue profiles have only examined their response to long-haul international travel associated with international tournaments (Fowler et al., 2017; Fullagar et al., 2016), as opposed to the training and match demands within this context. Fullagar et al. (2016) reported no significant differences in perceptual recovery between baseline and any day of the international tour, while Fowler et al. (2017) found self-reported jet-lag, sleep and perceptual ratings to be adversely affected following long-haul international travel. Possible reasons for the observed differences in perceptual response were the variance in east- vs. west-bound travel, as well as the magnitude of time-zone changes between the two studies. Evidently, it remains unclear how national team footballers perceive their fatigue and recovery throughout major international tournaments, despite previous research describing the load profiles of these players during the transition between clubs and training camp (McCall, Jones, et al., 2018). Thus, descriptions of player's fatigue and recovery profiles from ecological contexts of international tournaments are warranted, especially for the effect of congested schedules that is ever-present during such tournaments.

The activity profile of elite footballers, comprising high intensity running, sprinting, accelerations and decelerations involving a large eccentric component, may cause musculature micro-trauma (Ispirlidis et al., 2008). This cascade of physical changes including transient muscle damage could increase the risk of hamstring and groin injury, particularly at certain times when matches schedules are congested. In response to competitive football match play, Wollin et al. (2017) found a significant acute and transient effect on isometric hamstring strength in male international youth players. Hamstring strength was restored at 48h post-match, suggesting that implementation of in-season player monitoring with isometric hamstring strength testing is suitable 48h post-match. However, during congested match schedules, players exposure to frequent explosive actions that require significant eccentric muscle loading such as change of direction and acceleration/decelerations puts them at high risk of incurring a muscle injury. Indeed, the results from Wollin et al. (2018b) indicate that acute congested football match play produces a transient reduction in hamstring strength that may require >48 h to recover. Furthermore, congested tournament match schedules negatively impacts on hip adductor strength, with Wollin et al. (2018a) identifying a negative relationship between match load (sRPE) and isometric hip adductor strength. Therefore, restoration of muscle function may be considered for inclusion as an injury prevention strategy during high-risk periods such as congested football match play (Wollin, Thorborg, et al., 2018). Although, logistical issues with equipment and testing during international tournaments appears to be a major challenge as only nine (28%) teams at the FIFA 2014 World Cup reported monitoring muscle function (McCall et al., 2015).

Aside from one study of international youth footballers (Wollin, Pizzari, et al., 2018), research examining the effect of tournament match congestion on international footballers is sparse. This is despite national practitioners ranking congested match schedules 3$^{rd}$ among the most important extrinsic risk factors for injury (McCall et al., 2015). Within congested match schedules the time for recovery is reduced, accentuating the need to optimise and monitor recovery process. Previous research within club teams have shown ratings of perceived fatigue to be significantly worsened in weeks with two-competitive matches compared to one (Clemente et al., 2017; Howle et al., 2019). While, gradual decreases in match day total wellness have been observed over a prolonged period of fixture congestion (11 matches in 36 days), indicating that subjective status may be sensitive to chronic accumulations of load (Waterson, 2016). However, these reports are limited to professional club football, whereby the level of player competitiveness, logistical demands, and proportion of training and match load differ from international football tournaments. As such, it remains unclear how national team footballers perceive their recovery throughout major international tournaments and descriptions of the acute fatigue/recovery response from ecological contexts of international tournaments are warranted.

*2.4.6 Methodological and logistical considerations*

The congested nature and highly demanding competition within international tournaments are both major concerns for practitioners aiming to ensure a level of player availability and performance throughout the tournaments. Accordingly, systematic monitoring of post-match fatigue using a variety of methods and tools can be useful to evaluate player recovery and determine their readiness status for ensuing training and competition (Carling et al., 2018). However, given the realities of between tournament match-preparation (i.e. post-match recovery, travel, training, team talks and video sessions) this significantly reduces the possibility and potential impact of implementing evidenced-based fatigue monitoring practices (Carling et al., 2018). For instance, collection of biochemical and/or immunological markers requires specialist equipment and training and can be particularly invasive resulting in player reluctance to give a blood or saliva sample. Furthermore, physical performance tests may contribute to player’s training load depending on the exhaustive nature of the test also typically require some sort of equipment set-up that can be overly time-consuming. As such in order to serve as valid indicator of fatigue in national team football, prospective tools are required to be simple, quick, inexpensive and easy to administer (Thorpe, Atkinson, et al., 2017).

Hence, ASRM permit collection of subjective perceptions of fatigue and well-being during the post-match phase and are easily administered and scientifically legitimate alternatives to objective measures (Carling et al., 2018). However, recent concerns regarding the validity and reliability of both single-item and composite score ASRM question their clinical utility beyond the role of a complementary tool that is useful to facilitate communication (Duignan et al., 2020; Jeffries et al., 2020). Indeed, the existence and nature of any relationship between training load and ASRM is still up for debate, particularly considering recent evidence from Campbell et al. (2021) suggesting 'wellness' items have limited predictive capacity in relation to internal and external load measures. While, despite the popularity of ASRM, these measures have also demonstrated a limited capacity to differentiate between periodised fluctuations in training load (Campbell et al., 2020).

## 2.5 State of the literature

At present, scientific investigations and information from the elite echelons of international football are sparse and much remains unknown in this domain. Few research articles have explored the monitoring practices of national football teams; with a single survey study identifying the top five most commonly used monitoring tools by national teams to assess injury risk (McCall et al., 2015). However, beyond this survey of national team practitioners, limited research exists to describe national team players training and match demands during international soccer tournaments as well as the resultant effects on individual fatigue and recovery.

Such lack of evidence from this environment is likely due to the logistical difficulties of monitoring national team players as they transition from their clubs to national teams; along with varied support staff and the transient, infrequent nature of major international tournaments. Nonetheless, the importance of player monitoring within international football contexts can be highlighted by recent evidence suggesting higher injury rates occur during World Cup events when compared to domestic club settings (McCall et al., 2015). Therefore, primary scientific investigations are warranted within applied international football settings to quantify the demands of training and matches during international football tournaments, and determine its effects on common player monitoring variables of fatigue and recovery.

# Chapter 3: Study 1

Transitioning from club to national teams – training and match load profiles of international footballers

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## 3.1 Abstract

***Objective***: To quantify and profile the training and match loads of international footballers as they transition from club-to-camp-to-tournament contexts during multiple international tournaments. ***Design***: Retrospective single-cohort observational study. ***Methods***: External (session duration and count) and internal (session Rating of Perceived Exertion [s-RPE]) load data of all outfield players from the same national team were compared between club, pre-tournament camp and initial tournament phases of 3 recent international competitions. Further, load profiles were compared between each phase based on the acute:chronic (A/C) ratio using a 7 to 21-day ratio. ***Results***: A significant increase in the number of training sessions ($p < 0.001$, ES = 1.92; 90% CI[1.56, 2.27]) and s-RPE training load ($p < 0.001$, ES = 1.16[0.84, 1.48]) occurred from club to camp. Conversely, transitioning from camp-to-tournament a significant decrease in the number of training sessions ($p < 0.001$, ES = -3.17[-3.47, -2.86]) and s-RPE training load ($p < 0.001$, ES = -2.05[2.35, -1.75]) occurred, counterbalanced by a significant increase in the number of matches ($p < 0.001$, ES = 1.87[1.55, 2.18]) and s-RPE match load ($p < 0.001$, ES = 1.57[1.25, 1.89]). Consequently, a moderate significant increase in A/C ratio occurred during the club-to-camp transition ($p < 0.001$, ES = 1.02[0.70,1.33]), while a moderate significant decrease in the A/C ratio occurred during the camp-to-tournament transition ($p < 0.001$, ES = -0.76[-1.06, -0.46]). ***Conclusion***: International footballers showed expected increased training load when entering into pre-tournament camps, predominately via increased number of training sessions. Subsequent reductions in training volume coincide with increased match volume, though total load decreases. Such profiles provide insight into load accumulation transitioning from club to national teams in international footballers.

## 3.2 Introduction

Contemporary international football tournaments are characterised by a high number of matches condensed into a short period of time (Silva et al., 2017). Consequently, pre-tournament training camps function to ensure that the players are tactically, physically, and mentally prepared for tournament demands. However, complicating this pre-tournament planning is the need to appropriately balance training load and recovery within a truncated period between domestic club commitments and the tournament (Buchheit & Dupont, 2018; Morgans et al., 2015). Therefore, a challenge for national team staff is to manage the physical preparation of players during this transition; particularly, given the variable prior exposure to heterogeneous standards of competition and training types/volumes from a multitude of clubs in different countries (Buchheit & Dupont, 2018). Accordingly, optimal preparation for international tournaments may be possible by monitoring player's training and match load within club and national team contexts. Currently information on training and match loads in international footballers is sparse, thus profiling the distribution and accumulation of load from club- to-camp-to-tournament can provide valuable insight for national team practitioners (McCall et al., 2018a).

In recent years, the integration of load monitoring practices have been widely adopted in professional football to provide practitioners with objective evidence to guide appropriate loading strategies (Akenhead & Nassis, 2016; Bourdon et al., 2017). Primarily utilised as a systematic approach to improve performance and injury prevention (Weston, 2018), numerous studies have analysed load data to infer on fitness (Akubat et al., 2012; Fitzpatrick et al., 2018), fatigue (Thorpe et al., 2015, 2016; Thorpe, Strudwick, et al., 2017), recovery (Nédélec et al., 2012; Rowell et al., 2017) and injury risk (Bowen et al., 2017; Jaspers et al., 2018; Malone et al., 2017). However, training load monitoring research in football emanates predominantly from professional club settings and limited information exists in national team contexts. Indeed, a recently published case study was the first to demonstrate the load profiles of international footballers transitioning from club to national teams, with emphasis on injury outcomes during training camp (McCall et al., 2018a). Whilst these results provide initial insight into load 'spikes' during the transition from club to national teams, data was only analysed from one national team during a single international tournament (McCall et al., 2018a). Nevertheless, case studies of this nature are helpful in guiding sub- sequent larger studies to understand the distribution of load in international footballers transitioning into national teams.

Despite the lack of evidence describing training load profiles in international football players, the anecdotal perceptions of practitioners operating within national teams testify to the usefulness of load monitoring procedures to inform decision-making on injury risk (McCall et al., 2015). However, the paucity of evidence from this environment is likely due to the significant challenges that exist in implementing monitoring strategies within a national team environment (Burgess, 2017). For instance, continuous monitoring of international players in club and national teams is a logistical challenge given the multitude of clubs around the world, as well as the technical difficulties in exchanging load data between club and national teams (Buchheit & Dupont, 2018; McCall et al., 2018a). Furthermore, within national team camp and tournament environments additional barriers to implementing monitoring practices may also include match scheduling, travel requirements, player adherence, manager/coach buy-in, and the availability of facilitates/equipment (Burgess, 2017; McCall et al., 2018a). These difficulties in quantifying load in international footballers can also extend back to the players' clubs, whereby international breaks and tournaments may represent a 'black period' within their overall load monitoring profile, which is problematic for club and national team practitioners (Buchheit, 2017; Buchheit & Dupont, 2018).

In summary, limited research exists describing the accumulation and distribution of training and match loads of international football teams transitioning from club to national team contexts. Therefore, the aim of this study was to quantify the external (number of sessions – training and matches) and internal (s-RPE) load profiles of a single national football team as players transitioned from club, to camp, to tournament periods over multiple international tournaments.

## 3.3 Methods

Training and match load data was used from thirty-five professional male football players (25.9 ± 3.8 years) selected to compete for the Australian National Football Team at three international tournaments. All outfield players from the original 23-man tournament squad for each tournament were eligible for inclusion, with goalkeepers excluded due to variations in their training methods and match activity. Amongst the players eligible for inclusion, the majority competed in European club competitions (60%), with approximately a quarter (23.3%) playing in Australia, and the remainder in leagues located in Asia (13.3%) and North America (3.3%). The participating players consisted of seven central defenders, four wide defenders, thirteen central midfielders, five wide midfielders and six strikers. Provisional approval for the study was obtained from the National Federation involved, with individual player data previously collected as a condition of national team duty (Winter & Maughan, 2009). Data collection procedures were approved by the institutional Human Research Ethics Committee. Retrospective sharing and conditional usage of the data was undertaken in accordance with a strict data confidentiality agreement, and as such, all data were anonymised before analysis to ensure team and player confidentiality.

The present observational study followed a retrospective single- cohort study design. Individual training and match load data was routinely collected from a single national football team competing at three Fédération Internationale de Football Association (FIFA) sanctioned international football tournaments – 2014 World Cup ($WC_{2014}$ : 13th–23rd June), 2015 Asian Cup ($AC_{2015}$ : 9th–31st January), and 2017 Confederations Cup ($CC_{2017}$: 19th–25th June). Continuous monitoring of the players began 28 days (4 weeks) prior to the commencement of each official national team training camp, whilst based with respective clubs. Data collection continued as players arrived into camp and persisted throughout the full duration of the training camps and subsequent tournaments ($WC_{2014}$, 28-days camp/11-days tournament; $AC_{2015}$, 12-days camp/23-days tournament; $CC_{2017}$, 16-days camp/7-days tournament). Retrospectively, each tournament was temporally aligned into three distinct periods defined as the club period (i.e. pre-camp), camp period (i.e. in-camp) and tournament period (i.e. in-tournament). However, in order to account for the variations in training camp and competition duration between the tournaments, data analysis of each club, camp, and tournament period were standardised to 1-week durations, as this was the maximum overlapping time period between the three tournaments. Therefore, training load profile analysis was conducted using data measured 7 days pre-training camp arrival (club period), 7 days post-camp arrival (camp period), and 7 days post-1st tournament match (tournament period).

All data was collected by remote upload via a smartphone/tablet application using the same reporting scales and recording protocol (SMARTABASE, Fusion Sport, Brisbane, Australia) while players were with their club teams and then manually entered by players during camps and tournaments. Following the completion of all training sessions and matches (≤30min), players provided a rating of perceived exertion (RPE; Modified CR-10 Borg scale) (Foster et al., 2001), relating to the perceived intensity of the session. All players had ≈1- year prior familiarity with the scale. Session load (s-RPE) was then calculated by multiplying session duration (min) by RPE (Impellizzeri et al., 2004). External loads were determined as the total exposure time (min) and number of sessions (training and matches) performed per week. In addition, external loads were also categorised according to session type, with data dichotomised as either "training load" or "match load". Global positioning system (GPS) data were not available for all tournaments and club-based GPS data was not comparable given the variety of systems used, and thus is not included here.

To evaluate players accumulated training and match load profiles, the acute:chronic ratio (A/C ratio) was calculated from s-RPE load. The A/C ratio is defined as the ratio of an athlete's short-term (acute) load to the mean of their long-term (chronic) load (Carey et al., 2017; Gabbett, 2016). The use of the A/C ratio has received significant interest in recent years, particularly in team sports including football, with varying evidence for and against its efficacy as an indicator of injury risk (Bowen et al., 2017; Fanchini et al., 2018; Malone et al., 2017). As such, the A/C ratio was calculated for each acute weekly time period (i.e. club, camp, and tournament periods) based on the mean of the preceding 3-weeks (i.e. chronic workload). Currently, there is no consensus regarding the optimal duration of both the chronic (2 vs. 3 vs. 4 weeks) and acute (1 vs. 3 vs. 7 days) time periods applied to A/C ratio, with the specific schedule likely to determine the most appropriate time periods (Carey et al., 2017).

Descriptive data for each training and match load variables are presented as means ± standard deviation (±SD). Analyses were undertaken on individual and grouped tournament data to reduce interpretation bias due to the specific case study design of investigating data from a single tournament. Repeated one-way analysis of variance (ANOVA) were performed on group tournament data to compare the match and training load profiles between the different contextual conditions (club, camp, tournament). Subsequent, Bonferroni post hoc tests were conducted to determine the between-group mean differences, with significance set at the $p \leq 0.05$ level. Effect sizes (ES) and 90% confidence intervals were calculated for both grouped and individual tournament data to determine the magnitude of differences in load profiles between the club, camp and tournament periods. The criteria used to interpret the magnitude of the ES were as follows: 0–0.2=trivial, 0.21–0.6=small, 0.6–1.2=moderate, 1.21–2=large, 2.1–4.0=very large, ≥4.1 = nearly perfect (Hopkins, 2002). To aid in the interpretation, sample means were labelled in reverse order (i.e. $mean_1$=camp, $mean_2$ = club) such that positive ES values indicate an increase and negative ES values indicate a decrease in a load variable.

## 3.4 Results

From all three tournaments, a combined total of 47 (club), 60 (camp) and 56 (tournament) player datasets were analysed from each respective time period, with player injury (*n*=4) and inconsistent reporting of load data (*n*=13) the primary reasons for player's data exclusion.

During the club-to-camp transition, a large significant increase in the number of training sessions ($p < 0.001$, ES = 1.92[1.56,2.27]) (Table 3.1) was observed,, with similar trends evident in individual tournament data; although this profile was most explicit and more pronounced during the $WC_{2014}$ (ES = 3.46[2.87, 4.05]) (Table 3.2). Furthermore, a moderate significant increase in total s-RPE load occurred during this transition period ($p < 0.001$, ES = 1.09[0.76,1.42]), resultant from a moderate significant increase in training load ($p < 0.001$, ES=1.16[0.84, 1.48]), with non-significant and small differences in match load ($p > 0.05$, ES=−0.21[−0.54, 0.13]) and mean RPE ($p > 0.05$, ES=0.26[−0.08, 0.61]). However, not all individual tournament load profiles share this trend, as a trivial decrease (ES=−0.15[−0.82, 0.52]) in training load was reported for the $CC_{2017}$; possibly due to the moderate increase (ES = 1.08[0.54, 1.62]) in match s-RPE load reported here. Regarding the A/C ratio, a moderate significant increase ($p < 0.001$, ES=1.02[0.70, 1.33]) (Figure 3.1) in relative load was evident during the club-to-camp transition; though a very large increase of the A/C ratio (ES = 2.42[1.89, 2.94]) was observed for the $WC_{2014}$.

During the camp-to-tournament transition, a very large significant decrease in the number of training sessions ($p < 0.001$, ES=−3.17[−3.47, −2.86]) was observed, with similar trends to varying extents replicated in the individual tournament data i.e. larger decrease during the $AC_{2015}$ (ES = −7.14[−7.68, −6.59]). Concomitantly, a large significant increase in the number of matches played during the tournament period was observed ($p < 0.001$, ES = 1.87[1.55, 2.18]), with the extent of this trend again larger during the $AC_{2015}$ (ES = 2.87[2.30, 3.44]). Overall, only a small non-significant decrease ($p > 0.05$, ES = −0.25[−0.56, 0.06]) in total s-RPE load was reported during this transition period, with the $CC_{2017}$ reporting an opposing trend for a moderate increase in total load (ES = 0.95[0.38, 1.52]). However, a counterbalance in how load was accumulated between the two periods was evident; with a very large significant decrease in training s-RPE load ($p < 0.001$, ES = −2.05[−2.35, −1.75]) contrasted by a large significant increase ($p < 0.001$, ES=1.57[1.25, 1.89]) in match s-RPE loads between the camp and tournament periods. In relation to the A/C ratio, a moderate significant decrease in relative load ($p < 0.001$, ES = −0.76;[1.06, −0.46]) was reported for the tournament period compared to the first week of training camp, with a slightly larger decrease of the A/C ratio (ES = −1.48[−2.01, −0.94]) observed for the $WC_{2014}$.

Table 3.1. Internal and external load (mean ± SD) during Club, Camp and Tournament periods for grouped tournament data (2014 World Cup, 2015 Asian Cup 2015, 2017 Confederations Cup).

| | Club | Camp | Tournament | Effect size | 90% CI | Effect size | 90% CI | Effect size | 90% CI |
|---|---|---|---|---|---|---|---|---|---|
| **All Tournaments** | ***n* = 47** | ***n* = 60** | ***n* = 56** | **Club vs. Camp** | | **Camp vs. Tournament** | | **Club vs. Tournament** | |
| Weekly No. Training Sessions (*n*) | 3.3 ± 1.7 # | 5.6 ± 0.6 ^ | 3.6 ± 0.6 | 1.92 ** | 1.56, 2.27 | -3.17 *** | -3.47, -2.86 | 0.27 | -0.08, 0.62 |
| Weekly Training Load (AU) | 874 ± 616 # | 1604 ± 639 ^ | 580 ± 281 | 1.16 * | 0.84, 1.48 | -2.05 *** | -2.35, -1.75 | -0.63 * | -0.98, -0.28 |
| Weekly No. Matches (*n*) | 0.4 ± 0.7 | 0.3 ± 0.4 ^ | 1.6 ± 0.9 | -0.21 | -0.55, 0.13 | 1.87 ** | 1.55, 2.18 | 1.48 ** | 1.16, 1.81 |
| Weekly Match Load (AU) | 238 ± 425 | 162 ± 316 ^ | 1047 ± 744 | -0.21 | -0.54, 0.13 | 1.57 ** | 1.25, 1.89 | 1.31 ** | 0.99, 1.62 |
| Mean RPE (1-10) | 4.7 ± 1.6 | 5.1 ± 1.0 | 4.9 ± 0.6 | 0.26 | -0.08, 0.61 | -0.24 | -0.54, 0.06 | 0.12 | -0.24, 0.47 |
| Mean Weekly Total Load (AU) | 1112 ± 866 # | 1765 ± 538 | 1627 ± 569 | 1.09 * | 0.76, 1.42 | -0.25 | -0.56, 0.06 | 0.84 * | 0.50, 1.17 |

*n*, number; AU, arbitrary units; CI, confidence intervals; LL, lower limit; UL, upper limit

#Denotes a significant difference from Camp ($p \leq 0.05$)
^Denotes a significant difference from Tournament ($p \leq 0.05$)

* Denotes a moderate effect size
** Denotes a large effect size
*** Denotes a very large effect size

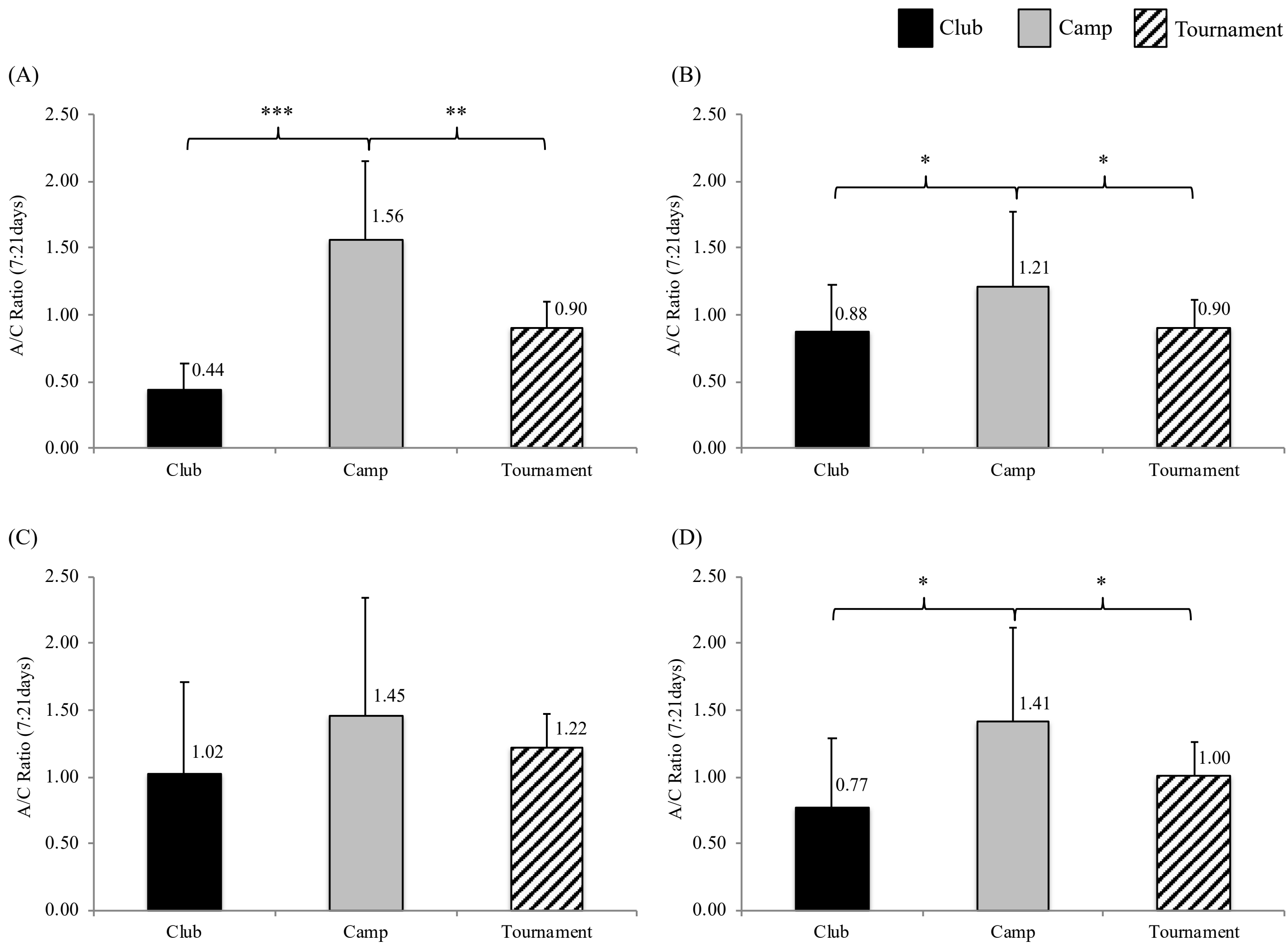
Table 3.2. Internal and external load (mean ± SD) during Club, Camp and Tournament periods for individual tournament data (2014 World Cup, 2015 Asian Cup 2015, 2017 Confederations Cup).

| | Club | Camp | Tournament | Effect size | 90% CI | Effect size | 90% CI | Effect size | 90% CI |
|---|---|---|---|---|---|---|---|---|---|
| **2014 World Cup** | ***n* = 16** | ***n* = 20** | ***n* = 19** | **Club vs. Camp** | | **Camp vs. Tournament** | | **Club vs. Tournament** | |
| Weekly No. Training Sessions (*n*) | 2.3 ± 1.1 | 5.5 ± 0.8 | 3.9 ± 0.5 | 3.46 *** | 2.87, 4.05 | -2.38 *** | -2.92, -1.85 | 2.07 *** | 1.45, 2.70 |
| Weekly Training Load (AU) | 526 ± 330 | 2135 ± 670 | 732 ± 322 | 2.94 *** | 2.41, 3.48 | -2.65 *** | -3.18, -2.11 | 0.63 * | 0.06, 1.21 |
| Weekly No. Matches (*n*) | 0.2 ± 0.4 | 0.2 ± 0.4 | 1.3 ± 0.8 | -0.10 | -0.67, 0.48 | 1.85 ** | 1.29, 2.41 | 1.70 ** | 1.15, 2.25 |
| Weekly Match Load (AU) | 114 ± 245 | 51 ± 164 | 865 ± 730 | -0.31 | -0.91, 0.29 | 1.56 ** | 0.99, 2.13 | 1.33 ** | 0.79, 1.87 |
| Mean RPE (1-10) | 4.3 ± 1.4 | 5.9 ± 0.9 | 4.7 ± 0.7 | 1.45 ** | 0.85, 2.05 | -1.52 ** | -2.06, -0.98 | 0.41 | -0.21, 1.03 |
| Mean Weekly Total Load (AU) | 640 ± 298 | 2186 ± 622 | 1597 ± 507 | 3.06 *** | 2.53, 3.59 | -1.04 * | -1.57, -0.50 | 2.25 *** | 1.70, 2.81 |
| **2015 Asian Cup** | ***n* = 16** | ***n* = 20** | ***n* = 19** | **Club vs. Camp** | | **Camp vs. Tournament** | | **Club vs. Tournament** | |
| Weekly No. Training Sessions (*n*) | 3.8 ± 2.0 | 5.9 ± 0.4 | 2.9 ± 0.5 | 1.50 ** | 0.84, 2.15 | -7.14 **** | -7.68, -6.59 | -0.66 * | -1.30, -0.02 |
| Weekly Training Load (AU) | 1034 ± 691 | 1667 ± 308 | 510 ± 247 | 1.23 ** | 0.61, 1.86 | -4.14 **** | -4.68, -3.60 | -1.05 * | -1.68, -0.42 |
| Weekly No. Matches (*n*) | 0.8 ± 0.9 | 0.0 ± 0.0 | 1.4 ± 0.7 | -1.34 ** | -2.00, 0.68 | 2.87 *** | 2.30, 3.44 | 0.70 * | 0.11, 1.29 |
| Weekly Match Load (AU) | 525 ± 556 | 0 ± 0 | 867 ± 587 | -1.42 ** | -2.08, -0.76 | 2.12 *** | 1.55, 2.69 | 0.60 | 0.02, 1.17 |
| Mean RPE (1-10) | 4.9 ± 1.7 | 5.0 ± 0.7 | 5.2 ± 0.6 | 0.08 | -0.55, 0.72 | 0.22 | -0.32, 0.76 | 0.20 | -0.43, 0.83 |
| Mean Weekly Total Load (AU) | 1559 ± 677 | 1667 ± 308 | 1377 ± 425 | 0.21 | -0.41, 0.84 | -0.78 * | -1.33, -0.24 | -0.33 | -0.93, 0.27 |
| **2017 Confederations Cup** | ***n* = 15** | ***n* = 20** | ***n* = 18** | **Club vs. Camp** | | **Camp vs. Tournament** | | **Club vs. Tournament** | |
| Weekly No. Training Sessions (*n*) | 3.7 ± 1.5 | 5.5 ± 0.6 | 4.0 ± 0.0 | 1.60 ** | 0.94, 2.26, | -3.30 *** | -3.83, -2.77 | 0.27 | -0.41, 0.94 |
| Weekly Training Load (AU) | 1075 ± 638 | 1010 ± 225 | 494 ± 207 | -0.15 | -0.82, 0.52 | -2.38 *** | -2.93, -1.83 | -1.28 ** | -1.93, -0.62 |
| Weekly No. Matches (*n*) | 0.1 ± 0.4 | 0.7 ± 0.5 | 2.1 ± 1.0 | 1.18 * | 0.63, 1.74 | 1.86 ** | 1.28, 2.43 | 2.49 *** | 1.93, 3.05 |
| Weekly Match Load (AU) | 64 ± 232 | 434 ± 406 | 1430 ± 796 | 1.08 * | 0.54, 1.62 | 1.60 ** | 1.03, 2.18 | 2.24 *** | 1.68, 2.80 |
| Mean RPE (1-10) | 5.1 ± 1.5 | 4.3 ± 0.7 | 4.7 ± 0.5 | -0.67 * | -1.33, -0.02 | 0.74 * | 0.20, 1.28 | -0.28 | -0.94, 0.38 |
| Mean Weekly Total Load (AU) | 1139 ± 635 | 1444 ± 332 | 1924 ± 647 | 0.63 * | -0.01, 1.27 | 0.95 * | 0.38, 1.52 | 1.22 ** | 0.63, 1.82 |

*n*, number; AU, arbitrary units; CI, confidence intervals; LL, lower limit; UL, upper limit

* Denotes a moderate effect size
** Denotes a large effect size
*** Denotes a very large effect size
**** Denotes a nearly perfect effect size

Figure 3.1. Comparison of the acute:chronic s-RPE load ratio (7:21days) between Club, Camp and Tournament periods for each individual tournament – (A) 2014 World Cup, (B) 2015 Asian Cup, (C) 2017 Confederations Cup and (D) grouped tournament data.




* Denotes a moderate effect size

** Denotes a large effect size

*** Denotes a very large effect size

## 3.5 Discussion

This study compared training and match load profiles of players from a single international football team as they transitioned between club, camp, and tournament periods during three major international tournaments. A large increase in the number of training sessions, resulting in higher s-RPE total load and A/C ratio was apparent when transitioning from club to camp environments. As expected, subsequent reductions in training volumes and increased match loads describe the camp-to-tournament transition. Within tournament trends replicated these patterns, though were not consistent across tournaments and likely were tailored to the specific constraints of each tournament (i.e. $AC_{2015}$ scheduled mid-domestic season). Thus, the changing dynamic of these training and match loads alters the accumulation and distribution of load profiles in international footballers, highlighting a role for effective load monitoring strategies.

The results of the present study demonstrate that during the transition between club and camp, international football players experienced a moderate increase in total s-RPE load, resulting from a large increase in training session count rather than training intensity. Such a finding is intuitive given the increased availability of the players during training camp facilitates the primary aim of maximising the player's training exposure to enhance overall team performance. Accordingly, a moderate increase in A/C ratio was also identified, and this increase in load is often perceived as a critical point of player management and highlights the need for communication between club and national team practitioners. Similar A/C ratio results were recently reported from this same cohort comparing the load profiles of injured and non-injured international football players. Players incurring an injury in camp had a greater increase in A/C ratio (1.7 ± 0.5 AU) compared to players not incurring an injury (1.3 ± 0.7 AU).4 Although, it should be noted that these results were based on group means and not all players who had a high A/C ratio (>2.0) went on to incur an injury, and some players with A/C ratios between 0.8–1.3 did incur an injury (McCall et al., 2018a). Nevertheless, consideration of the player's pre-camp workloads may still be beneficial to help national team staff profile individual player needs and prevent excessive spikes in acute load as an initial periodization strategy (Bowen et al., 2017; Malone et al., 2017).

Whilst the present findings provide further evidence to suggest that international footballers are exposed to an increase in relative load during the transition from club-to-camp, the extent and nature of this increase differed between the three included tournaments. For instance, during the $WC_{2014}$ a very large increase in the A/C ratio was evident, due to a combination of both a large increase in training intensity and very large increase in the number of training sessions. In contrast, the $AC_{2015}$ and $CC_{2017}$ only showed small-to-moderate increases in A/C ratio; driven by increases in the number of training sessions. Thus, while club-to-camp loads were more closely aligned for the $AC_{2015}$ and $CC_{2017}$ compared to $WC_{2014}$, variations in the length of the training camps for these tournaments may partly explain these differences – with the condensed scheduling of the $AC_{2015}$ and $CC_{2017}$ camps (12–16 days) constraining the relative increase in training load given the need for players to be adequately recovered in a shorter time period before the first tournament match. Indeed, despite the summary data presented in this study, contextual factors of each tournament are important to consider when interpreting the load profiles of international footballers. For example, the scheduling of the $AC_{2015}$ as a mid-season tournament meant that players arrived directly into camp from their domestic-club competitions resulting in an expected decrease in match load during this transition.

This is the first study to report training and match loads performed by elite international football players as they transition from training camp to in-tournament contexts. During this transition period a counterbalance in training and match load was evident, with large increases in match volume and s-RPE match load offset by very large decreases in training volume and s-RPE training load. This counterbalance in load accumulation intuitively represents the shift in training focus to match preparation and prioritisation of recovery for subsequent matches with the tournament periods (Bangsbo, 1998). Of note, only a small decrease in total s-RPE load existed in this transition and not all tournaments followed this trend, as $CC_{2017}$ showed a moderate increase in total s-RPE load. Again, the condensed match scheduling that occurs during this tournament likely affects load accumulation in camp. Consequently, a higher relative load was observed during the tournament period for the $CC_{2017}$, resulting in only a small decrease in the A/C ratio, while the $WC_{2014}$ and $AC_{2015}$ had large-to-moderate decreases. These load profiles highlight a novel finding of the counterbalance in training and match loads during the transition from camp-to-tournament periods, though consideration of individual player load profiles is important. In particular, how the reduction in training load may impact the preparedness of fringe players and non-starters who are not exposed to the increases in tournament match load, and thus require additional training during the tournament to maintain fitness (Anderson et al., 2016a). Furthermore, tournament load accumulation is also an important consideration for club practitioners when planning training for the start of the next domestic league season, with international match and training loads likely to influence the return dates of players, as well as the content of pre- season club programs. This issue remains a topic for future research, as data was not available in this study to examine the transition of international players returning to club teams.

Despite the novel and practical application of the findings to international football contexts, this study is not without limitations, which reflect the practicality of data collection within national football teams. Firstly, the cohort used here belongs to one national team, which limits the generalisation of the findings, as many contextual factors specific to the national team likely influenced the load periodisation of the players. Secondly, workload data within each period are presented as differences between groups. Therefore, caution should be taken when applying these findings at the individual level, particularly when interpreting the A/C ratio as this represents a relative determination of the acute load performed by a player compared to their chronic workload. In addition, there are various methods, timeframes, and parameters from which the A/C ratio can be calculated, with continued exploration of the metric within football necessary in order to determine its appropriateness and association to practical outcomes (i.e. injury). Lastly, the use of simple measures of load within this study provides only a general understanding of the load profiles of international footballers, while the inclusion of more detailed objective external load measures may provide more meaningful findings. However, the lack of comparability between types and variables of external load monitoring devices complicates the exchange of such information between clubs and national teams (Buchheit & Dupont, 2018; McCall et al., 2018a).

## 3.6 Conclusion

In summary, this study quantified the external and internal load profiles of a single national football team as players transitioned between club, camp, and tournament periods over multiple international tournaments. Distinct variations in international players' load profiles were identified between the time periods, with an increase in training volume, s-RPE load, and A/C ratio evident during the transition between club-to-camp periods. Subsequent reductions in training volume and load coincided with expected increases in match volume and load at the start of the tournament period, resulting in an overall decrease of the A/C ratio between the camp-to-tournament periods. Further research, involving data derived from multiple national teams may also enhance our understanding of players' load profiles across a broader international football context.

## 3.7 Practical implications

- Simple measures of training load (i.e. s-RPE, training and match exposure) can be applied as an easy and cost-efficient method to continuously monitor their players during the transition between club and national team environments.
- Knowledge of the players' club-based training loads may be useful to national team practitioners to help plan and manage camp and tournament training according to the players' individual load and recovery needs.
- Evaluating international players training and match loads during the transition between club and national teams is important, although future research is needed to determine which variables are most relevant within this context.

# Chapter 4: Study 2

Perceived load, fatigue, and recovery responses during congested and non-congested micro-cycles in international football tournaments.

As based on the manuscript accepted for publication in *Journal of Science and Medicine in Sport*

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## 4.1 Abstract

***Objectives***: To describe the perceived load, fatigue and recovery profiles during congested and non-congested schedules in international football tournaments. ***Design***: Retrospective single-cohort observational study ***Methods***: Internal load (session-rating of perceived exertion [s-RPE]) and perceived ratings of fatigue, muscle soreness, psychological status, sleep quality, and sleep duration were recorded daily from 37 national team footballers during the competition phase of 3 international tournaments. ANOVA and Effect Size (ES) analyses compared individualised internal load and perceived response profiles between congested and non-congested acute 2-match schedules. Conditions included Acute Congestion (≤4 days between two matches), Non-Congestion (> 4 days between two matches), Single-Match, and No-Match. ***Results***: Significantly higher s-RPE match loads ($p<0.001$) within the single- and multi-match conditions resulted in significantly worsened ($p<0.05$) subjective ratings of perceived fatigue, muscle soreness and sleep duration in the 24-48h post-match. Internal load profiles were not different between the Acute-Congestion or Non-congestion conditions ($p>0.05$); though Acute-Congestion had significantly worsened pre-match subjective ratings compared to Non-Congestion on both MD1 ($p = 0.040$; ES = 0.94) and MD2 ($p = 0.033$; ES = 0.94). However, between-match differences in Acute-Congestion showed no further impairments in perceived response between the first and second matches ($p>0.05$). ***Conclusion***: During international tournaments, internal load and perceived fatigue/recovery profiles are largely determined by their exposure (or lack thereof) to match-play. Periods of acute match congestion impaired players pre-match perceived status when compared to non-congested microcycles. However, acute match congestion does not appear to exacerbate players post-match fatigue/recovery response within the context of international football tournaments.

## 4.2 Introduction

Major international football tournaments consist of demanding fixtures, with teams required to play 3 matches within 7-11 days, and those in knockout phases playing up to 7 matches over 28-31 days (Silva et al., 2017). To optimise tournament performance, balancing the stress of training/competition with sufficient recovery is a major objective for support staff (Thorpe et al., 2015). Such views are articulated in a survey at the 2014 World Cup, whereby national team practitioners ranked reduced recovery periods, accumulated fatigue, and congested match schedules among the most important risk factors for non-contact injury (McCall et al., 2015). Similarly, national team practitioners also ranked monitoring tools that quantify match exposure and subjective markers of fatigue and recovery status as commonly used (McCall et al., 2015). However, whilst player monitoring practices are ubiquitous within professional football (Akenhead & Nassis, 2016; McCall et al., 2015), evidence of their usefulness emanates predominately from club-based contexts (Nédélec et al., 2012; Silva et al., 2018a), with limited research available within national team environments.

A common trend in the monitoring practices of elite football teams is the daily use of athlete self-report measures to monitor the psychobiological state or "wellness" of players (Akenhead & Nassis, 2016; McCall et al., 2015). Although the validity of such scales remains in discussion (Saw et al., 2017; Windt et al., 2019), the applicability of monitoring athlete perceived stress and fatigue in professional football has some support, with studies demonstrating their responsiveness to changes in acute training and match loads (Thorpe et al., 2015, 2016; Thorpe, Strudwick, et al., 2017). For instance, within an elite professional team, between-day changes in subjective measures of perceived fatigue, muscle soreness and sleep quality were shown to closely reflect acute fluctuations in training/match load across 'standard' in-season weeks (1-match per week) (Thorpe et al., 2016). Specifically, significant reductions in total wellness (35-40%) exist the day post-match, with subsequent improvements (17-26% increase) by 48h and a plateau thereafter due to the renewed presence of training load (Thorpe et al., 2016). However, despite the apparent responsiveness of these subjective measures to the acute presence of training/match load, the association between load and wellness in football remains equivocal, with contrasting findings depending on the load variable measured (i.e. internal or external load) and how load is calculated (i.e. previous day load, accumulation of load over multiple-days/week) (Moalla et al., 2016; Thorpe et al., 2015; Thorpe, Strudwick, et al., 2017).

While the aforementioned research examined the perceived fatigue and stress responses of professional footballers during single-match week microcycles, the competition schedules of most successful football teams includes multi-match weeks, as exists during international tournaments (Anderson et al., 2016b; Carling et al., 2016). Within congested match schedules the time for recovery is reduced, accentuating the need to optimise and monitor recovery process. However, limited research exists detailing the impact of match congestion on player recovery profiles in international competition. Recent studies within club football have shown ratings of perceived fatigue to be significantly worsened in weeks with two-competitive matches compared to one (Clemente et al., 2017; Howle et al., 2019). Gradual decreases in match day total wellness have been observed over a prolonged period of fixture congestion (11 matches in 36 days), indicating that subjective status may be sensitive to chronic accumulations of load (Waterson, 2016). Thus far, no study has examined the acute load and recovery profiles of international footballers during congested match-to-match microcycles. Accordingly, this study examined the effect of match load on self-reported fatigue and recovery profiles during congested and non-congested microcycles within international tournaments. It is hypothesised that match exposure during a congested microcycle will negatively impact perceived recovery profiles when compared to non-congested microcycles.

## 4.3 Methods

Data was collected from 37 professional male football players (26.4 ± 4.1y) selected to compete for the Australian National Football Team at three FIFA sanctioned international football tournaments: 2015 Asian Cup ($AC_{2015}$), 2017 Confederations Cup ($CC_{2017}$), and 2018 World Cup ($WC_{2018}$). All outfield players from the original 23-man squad for each tournament were eligible for inclusion, with goalkeepers excluded due to variations in their training methods and match activity. In total, participating players consisted of 8 central defenders, 6 wide defenders, 12 central midfielders, 6 wide midfielders and 5 strikers. Provisional approval for the study was obtained from the National Federation involved, with individual player data previously collected as a condition of national team duty (Winter & Maughan, 2009). Data collection procedures were approved by the institutional Human Research Ethics Committee. Retrospective sharing and conditional usage of the data was undertaken in accordance with a strict data confidentiality agreement, and all data were anonymised before analysis to ensure player confidentiality.

The present observational study followed a retrospective single-cohort study design, in which players´ internal load (training and matches) and perceived fatigue and recovery data were routinely collected from the same national team competing at three international tournaments. Data was assessed from only the competition phases of each tournament, comprising 23 days for the $AC_{2015}$ (winners), 7 days for the $CC_{2017}$ (3rd in group stages), and 12 days for the $WC_{2018}$ (4th in group stages). In total, 12 matches were played across the 3 tournaments, in which the observed national team registered 5 wins, 3 draws and 4 losses. Individual player tournament data was then categorised into congested or non-congested 2-match microcycles (i.e. consecutive matches), according to the following classification criteria: 1) Acute-Congestion – participation in 2 successive matches separated by a time interval totalling < 4 days (96h) (Lago-Peñas et al., 2011); 2) Non-Congestion – participation in 2 successive matches separated by a time interval totalling > 4 days (>96h); 3) Single-Match week – 1 match played followed by no-participation in the subsequent match; 4) No-Match week – no participation in successive matches. Match participation was defined as having played ≥ 70 minutes in a single match (Carling et al., 2016; Howle et al., 2019). For instances where microcycles overlapped (i.e. two Acute-Congestion microcycles from 3 consecutive matches) data from the middle match was included within both microcycles. Overall, a combined total of 70 match-to-match microcycles were included for analysis, consisting of 18 Acute-Congestion, 19 Non-Congestion, 10 Single-Match, and 23 No-Match microcycles.

Internal player load for all training and match sessions (including on-field, gym, recovery and rehab training sessions) were monitored throughout the assessment period using the session-rating of perceived exertion (s-RPE) method (Impellizzeri et al., 2004). Data were manually entered by the players into a tablet application (SMARTABASE, Fusion Sport, Brisbane, Australia), in which the same reporting scale (Modified CR-10 Borg scale) (Foster et al., 2001) and recording protocol were used across all international tournaments. All players had familiarity with the scale, having used such method for at least 1-year prior. Session load (s-RPE, arbitrary units, AU) was then estimated for each player by multiplying their total training or match session duration (min) by their reported RPE (Impellizzeri et al., 2004).

Player's perceived ratings were monitored daily each morning (09:00-10:00) prior to training or competition throughout the assessment period. A customised questionnaire measured player's perceived ratings to assess their fatigue and recovery responses to training and competition (Hooper & Mackinnon, 1995; McLean et al., 2010). It comprised 5 items relating to perceived fatigue, general muscle soreness, psychological status, sleep quality, and sleep duration. Each question was scored on a seven-point Likert scale ranging from 1 to 7, with point increments of 1, and scores of 1 representing "very, very good" and 7 representing "very, very poor", respectively. The five items for a given day were summated to provide a total perceived response score for each player, whereby a higher number represents a worse perceived state.

Descriptive data for internal load and perceived fatigue/recovery response variables are presented as means ± standard deviation (mean ± SD). Due to differences in the time intervals between matches (i.e. 3, 4, or 5 days), individual load and perceived response data were aligned within each 2-match microcycle according to the number of days post-match (i.e. matchday 1 [MD1], matchday 1+1 [MD1+1], matchday 1+2 [MD1+2], matchday 1+3 [MD1+3], and repeated for matchday 2 [MD2]). Subsequent analysis of the training load profile was performed using data up 2-days post-match, while player perceived ratings were analysed using data up to 3-days post-match to assess the full extent of the player responses as a proxy for recovery.

Mixed-design analysis of variances (ANOVA) determined the effect of different acute match congestion microcycles on player's load and perceived fatigue and recovery profiles, with time as the within-subjects factor and microcycle condition as the between-subjects factor. Subsequent follow-up tests were conducted using multiple one-way ANOVAs to determine where these difference/s occurred, with significance set at the $p \leq 0.05$ level. The magnitude of these differences was reported as Cohen's *d* effect sizes (ES) with [90% confidence intervals]. The criteria used to interpret the magnitude of the ES were as follows: 0.0–0.2 = trivial, 0.21–0.6 = small, 0.61–1.2 = moderate, 1.21– 2.0 = large, 2.01–4.0 = very large, >4.0 = nearly perfect (Hopkins, 2002). Additionally, Spearman's rank correlation coefficients ($r_s$) were also calculated to determine the association between internal match load and self-reported variables the day immediately post-match (MD+1). Initial correlations were performed using data from all 2-match microcycles, followed by a secondary analysis in which match loads of zero (i.e. No Match condition) were excluded. The magnitude of the correlations was classified as follows: trivial ($r_s \leq 0.1$), small ($0.1 < r_s \leq 0.3$), moderate ($0.3 < r_s \leq 0.5$), large ($0.5 < r_s \leq 0.7$), very large ($0.7 < r_s \leq 0.9$), almost perfect ($r_s > 0.9$) (Hopkins, 2002). All statistical analyses were performed using the software package SPSS (version 24.0, Chicago, IL, USA).

## 4.4 Results

Concerning internal load, both main effects of microcycle condition ($F_{[3, 66]} = 61.25$, $p<0.001$) and time ($F_{[3, 177]} = 439.77$, $p<0.001$) were significant across the 2-match microcycle periods. The interaction between microcycle condition and time was also significant ($F_{[8, 177]} = 197.01$, $p<0.001$); with post-hoc comparison tests revealing significantly higher ($p<0.001$; Figure 4.1a) match loads for Acute-Congestion (ES = 12.69[12.07,13.31]), Non-Congestion (ES = 12.91[12.32, 13.50]), and Single-Match (ES = 12.36[11.29,13.44]) on MD1, and for Acute-Congestion (ES = 9.98[9.47,10.48]; ES = 12.22[11.60,12.84]) and Non-Congestion (ES = 12.07[11.58,12.55]; ES = 14.69[14.09,15.28]) on MD2. Post-matchday, the No-Match condition reported significantly ($p<0.001$) higher training loads on MD1+1 compared to all other conditions ($ES_{range}$ = 3.02–3.11); while on MD2+1, training loads were significantly higher ($p<0.001$) for Single-Match (ES = -3.30[-4.29, -2.32]; ES = -3.14[-4.12, -2.16]) and No-Match (ES = -3.39[-3.87, -2.92];

ES = -3.30[-3.79, -2.82]) conditions compared to Acute-Congestion and Non-Congestion. On MD1+2, Non-Congestion reported significantly higher loads compared to Acute-Congestion (*p* = 0.063; ES = -0.86[-1.41, -0.30]) and Single-Match (*p* = 0.009; ES = 1.04[0.54,1.53]), while the No-Match group also had significantly higher (*p* = 0.011) training loads compared to Single-Match (ES = -0.87[-1.31, -0.44]). Lastly on MD2+2, Acute Congestion reported significantly higher (*p* = 0.015) training loads compared to Non-Congestion (ES = 1.16[0.57,1.75]).

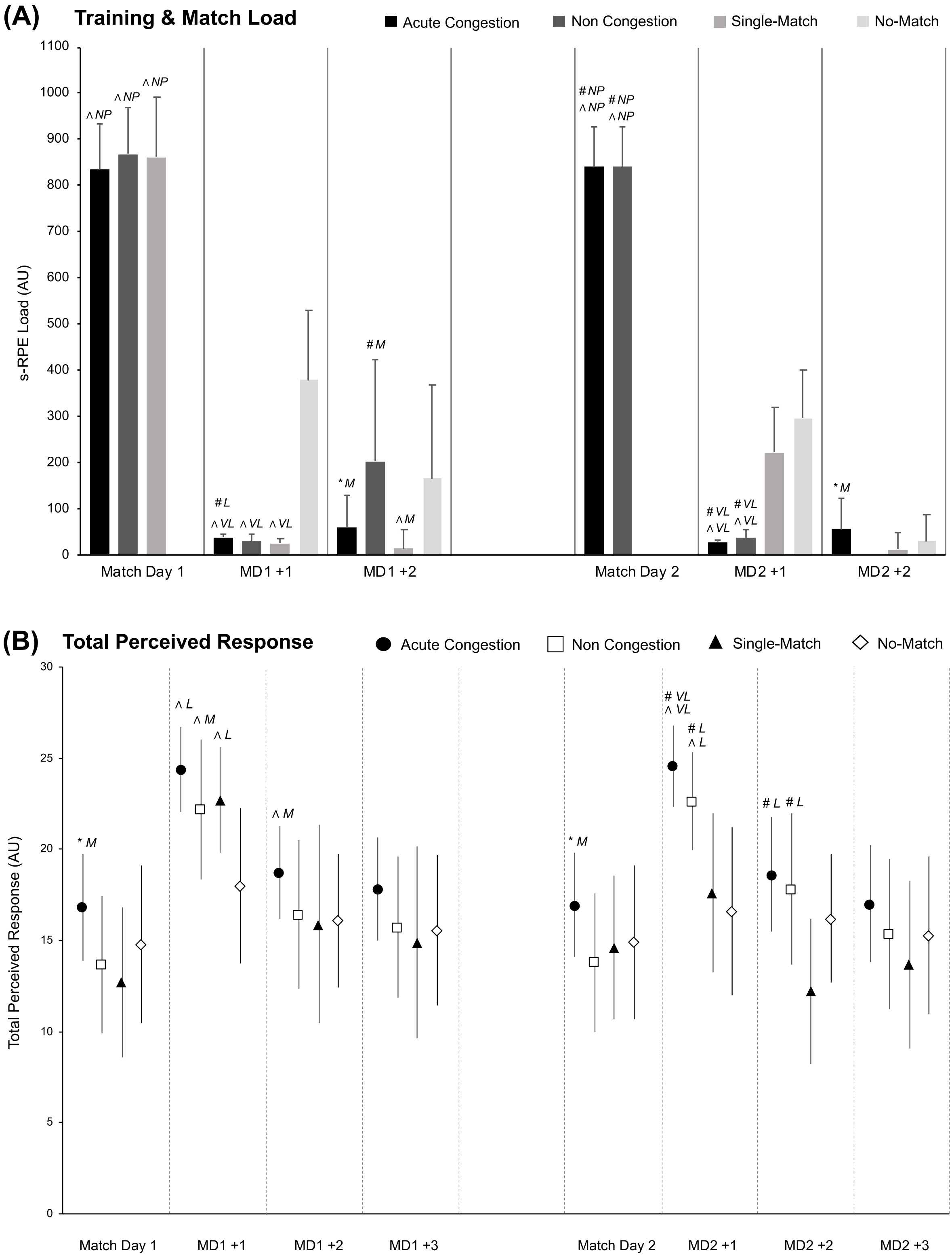


Figure 4.1. Internal (s-RPE) training/match load (Figure A) and total perceived response profiles (Figure B) for Acute Congestion, Non-Congestion, Single-Match, and No-Match microcycles.

Note: Higher perceived response scores represent a worsened status.
*Denotes a significant difference from NC, #Denotes a significant difference from SM, ^Denotes a significant difference from NM; $p \leq 0.05$. Effect size abbreviations: *S* = small, *M* = Moderate, *L* = large, *VL* = very large, *NP* = nearly perfect

Concerning total perceived responses, both main effects of microcycle condition ($F_{[3, 66]}$ = 5.42, $p$ = 0.002) and time ($F_{[4, 254]}$ = 57.56, $p$<0.001) were significant across the 2-match microcycle periods. The interaction between microcycle condition and time was also significant ($F_{[12, 254]}$ = 4.77, $p$<0.001); with post-hoc comparison tests revealing significantly higher (worsened) total perceived responses for Acute-Congestion compared to Non-Congestion on MD1 ($p$=0.040; ES = 0.94[0.37,1.50]) and MD2 ($p$ = 0.048; ES = 0.94[0.39,1.49]) (Figure 4.1b). Post-matchday, total response values were significantly higher for Acute-Congestion ($p$<0.001; ES = 1.81[1.31,2.31]), Non-Congestion ($p$ = 0.009; ES = 1.04[0.52,1.56]), and Single-Match ($p$ = 0.005; ES = 1.21[0.65,1.77]) on MD1+1; while on MD2+1, total response values were significantly higher for Acute-Congestion and Non-Congestion compared to both Single-Match ($p$ = 0.003; ES = 2.20[1.36,3.05]; $p$ = 0.026; ES = 1.51[0.70,2.32]) and No-Match ($p$<0.001; ES = 2.10[1.61,2.59]; $p$<0.001; ES = 1.56[1.06,205]) conditions. Thereafter, total perceived response ratings remained significantly ($p$ = 0.048) higher for Acute-Congestion (ES = 0.81[0.31, 1.32]) compared to No-Match on MD1+2, while no significant differences ($p$>0.05) were evident on MD1+3. Lastly, on MD2+2, total perceived response remained significantly higher for Acute-Congestion ($p$ = 0.005; ES = 1.86[1.08,2.65]) and Non-Congestion ($p$ = 0.017; ES = 1.37[0.67,2.08]) compared to Single-Match, while no significant differences ($p$>0.05) between microcycle conditions were evident on MD2+3.

In relation to the perceived response sub-scales, significant interaction effects for perceived fatigue, muscle soreness, sleep duration and sleep quality were evident ($p$<0.05; Table 4.1), whereby Acute-Congestion and Non-Congestion showed significantly higher post-match ratings of perceived fatigue ($p$≤0.032; $ES_{range}$ = 0.98–2.78) and muscle soreness ($p$≤0.024; $ES_{range}$ = 1.00–3.33) up to 48h post-match. These significantly higher fatigue ratings remained elevated up to 72h post-match, although higher muscle soreness ratings were only evident at 72h post-MD2. In addition, Acute-Congestion reported significantly higher sleep duration and sleep quality on both MD1+1 and MD2+1 compared to No-Match.

Significant positive correlations ($p<0.001$; Figure 4.2) existed between s-RPE match load and the following post-match items: total perceived response ($r_s=0.571$), fatigue ($r_s=0.673$), muscle soreness ($r_s=0.675$), sleep quality ($r_s=0.364$), and sleep duration ($r_s=0.303$). However, when data points with zero match load were excluded (i.e. No-Match microcycles) and the correlation analysis repeated, only a small negative correlation ($r_s=-0.255$; $p<0.05$) was found between s-RPE match load and sleep duration (i.e. higher load and reduced sleep duration), while no significant correlations were identified for the other post-match perceived response items ($p>0.05$).

Table 4.1. Sub-scale perceived response profiles for Acute-Congestion, Non-Congestion, Single-Match, and No-Match microcycles.

| | MD1 | MD1 +1 | MD1 +2 | MD1 +3 | MD2 | MD2 +1 | MD2 +2 | MD2 +3 |
|---|---|---|---|---|---|---|---|---|
| **Fatigue** | | | | | | | | |
| Acute-Congestion | 3.4 ± 0.8 | 5.2 ± 0.5 ^L | 4.1 ± 0.8 ^M | 3.7 ± 0.8 ^M | 3.6 ± 0.6 *M #L ^M | 5.2 ± 0.4 #VL ^VL | 4.3 ± 0.6 #VL ^L | 3.7 ± 0.8 ^M |
| Non-Congestion | 2.6 ± 1.2 | 4.9 ± 1.0 ^L | 3.7 ± 1.1 | 3.2 ± 1.2 | 2.7 ± 1.1 | 4.9 ± 0.9 #L ^L | 4.0 ± 1.0 #L ^M | 3.3 ± 1.1 |
| Single-Match | 2.3 ± 1.3 | 4.4 ± 1.4 | 3.2 ± 1.6 | 2.8 ± 1.4 | 2.2 ± 1.1 | 2.6 ± 1.5 | 1.9 ± 1.3 | 2.3 ± 1.4 |
| No-Match | 2.7 ± 1.3 | 3.1 ± 1.3 | 3.0 ± 1.3 | 2.8 ± 1.3 | 2.7 ± 1.2 | 2.8 ± 1.3 | 2.9 ± 1.3 | 2.7 ± 1.3 |
| **Muscle Soreness** | | | | | | | | |
| Acute-Congestion | 3.6 ± 0.8 | 5.0 ± 0.7 ^L | 4.2 ± 0.5 ^M | 3.7 ± 0.8 | 3.6 ± 0.7 #L ^M | 5.1 ± 0.4 #VL ^VL | 4.4 ± 0.7 #VL ^L | 3.7 ± 0.8 #L ^M |
| Non-Congestion | 2.7 ± 1.2 | 4.8 ± 0.8 ^L | 3.9 ± 1.1 | 3.4 ± 1.1 | 2.9 ± 1.1 | 4.9 ± 0.8 #VL ^VL | 4.2 ± 1.0 #L ^M | 3.4 ± 1.2 |
| Single-Match | 2.7 ± 1.2 | 4.8 ± 0.8 ^L | 4.2 ± 1.1 | 3.3 ± 1.2 | 2.6 ± 0.8 | 2.7 ± 1.1 | 2.4 ± 1.1 | 2.5 ± 1.0 |
| No-Match | 3.0 ± 1.3 | 3.3 ± 1.2 | 3.2 ± 1.2 | 3.0 ± 1.1 | 2.8 ± 1.1 | 2.7 ± 1.3 | 3.2 ± 1.0 | 2.8 ± 1.1 |
| **Psychological Status** | | | | | | | | |
| Acute-Congestion | 2.7 ± 1.0 | 3.1 ± 1.0 | 2.9 ± 1.0 | 2.7 ± 0.9 | 2.7 ± 0.9 | 3.2 ± 1.0 | 3.0 ± 0.9 | 2.6 ± 1.0 |
| Non-Congestion | 2.3 ± 0.8 | 2.5 ± 1.0 | 2.3 ± 0.7 | 2.3 ± 0.8 | 2.3 ± 0.7 | 2.6 ± 1.1 | 2.5 ± 0.9 | 2.3 ± 0.8 |
| Single-Match | 2.1 ± 1.0 | 2.8 ± 1.0 | 2.4 ± 1.1 | 2.2 ± 0.9 | 2.5 ± 1.2 | 2.7 ± 0.9 | 2.4 ± 0.9 | 2.3 ± 0.9 |
| No-Match | 2.5 ± 1.2 | 3.0 ± 1.1 | 1.9 ± 1.2 | 2.9 ± 1.2 | 2.7 ± 1.2 | 3.0 ± 1.3 | 3.2 ± 1.2 | 2.8 ± 1.1 |
| **Sleep Quality** | | | | | | | | |
| Acute-Congestion | 3.2 ± 0.8 | 4.9 ± 0.9 ^L | 3.4 ± 1.0 | 3.4 ± 0.9 | 3.2 ± 0.9 | 4.9 ± 1.3 ^L | 3.1 ± 1.3 | 3.2 ± 0.9 |
| Non-Congestion | 2.8 ± 0.9 | 4.4 ± 1.2 | 2.9 ± 1.4 | 2.9 ± 1.2 | 2.7 ± 1.0 | 4.4 ± 1.0 ^M | 3.2 ± 1.6 | 2.7 ± 1.2 |
| Single-Match | 2.7 ± 0.9 | 4.5 ± 0.9 | 2.8 ± 1.6 | 3.0 ± 1.3 | 3.3 ± 1.1 | 4.2 ± 1.0 | 2.6 ± 0.9 | 2.8 ± 1.2 |
| No-Match | 3.0 ± 1.1 | 3.7 ± 1.1 | 3.3 ± 0.8 | 3.2 ± 0.9 | 3.2 ± 1.0 | 3.3 ± 1.0 | 3.4 ± 0.8 | 3.2 ± 1.0 |
| **Sleep Duration** | | | | | | | | |
| Acute-Congestion | 3.9 ± 0.9 #M | 6.2 ± 0.6 ^M | 4.1 ± 1.0 | 4.4 ± 0.9 ^M | 3.8 ± 0.9 | 6.1 ± 0.8 ^L | 3.8 ± 1.4 | 3.8 ± 1.0 |
| Non-Congestion | 3.2 ± 1.0 | 5.5 ± 1.3 | 3.5 ± 1.2 | 3.9 ± 1.4 | 3.2 ± 1.0 | 5.8 ± 0.8 ^M | 3.9 ± 1.6 | 3.6 ± 1.4 |
| Single-Match | 2.9 ± 0.9 | 6.2 ± 0.4 ^M | 3.3 ± 1.6 | 3.6 ± 1.4 | 4.0 ± 1.2 | 5.4 ± 1.0 | 2.9 ± 1.2 | 3.8 ± 1.2 |
| No-Match | 3.6 ± 0.8 | 5.0 ± 1.4 | 3.7 ± 0.8 | 3.7 ± 0.8 | 3.6 ± 0.8 | 4.7 ± 1.2 | 3.6 ± 1.0 | 3.8 ± 1.1 |

MD1, Match Day 1; MD2, Match Day 2

*Denotes a significant difference from NC, #Denotes a significant difference from SM, ^Denotes a significant difference from NM; $p \leq 0.05$.

Effect size abbreviations: S = small, M = Moderate, L = large, VL = very large

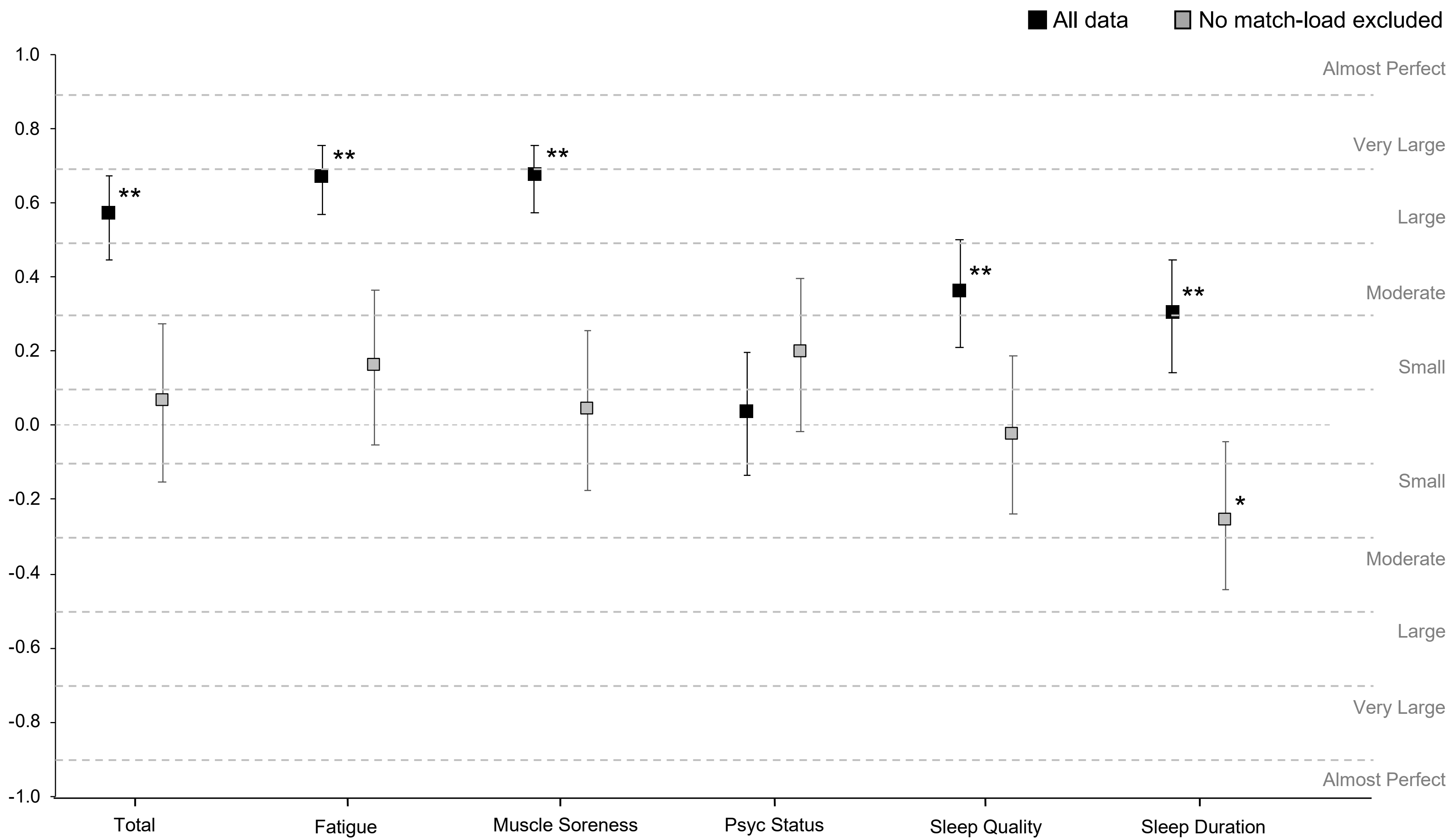


Figure 4.2. Correlation coefficients ($r_s$) between s-RPE match load and post-match MD-1 perceived response items, plotted as means ± 95% CI for all data (black squares) and no-match load data excluded (grey squares).
*correlation is significant ($p$<0.05)
**correlation is significant ($p$<0.001)

## 4.5 Discussion

This study examined the perceived load, fatigue, and recovery profiles of international footballers during congested and non-congested tournament schedules. Variations in training load and player perceived status profiles were largely determined by exposure to match-play, in turn influencing acute post-match responses. As expected, high internal match loads preceded reduced next-day training loads in single and multi-match conditions. The resultant post-match responses showed worsened ratings of fatigue, muscle soreness, and sleep quality/duration within these 2-match microcycles. Furthermore, pre-match ratings for Acute-Congestion were significantly worse compared to Non-Congestion on both match days. However, within the Acute Congestion conditions no significant differences in perceived status were evident between respective match days. Within the context of international football tournaments, acute match congestion (i.e. 2 matches within 4 days) does not appear to exacerbate post-match perceptual fatigue and recovery responses.

Despite an abundance of club-based data, limited match load and recovery data exists from national team contexts. In the present study, exposure (or lack thereof) to tournament match-play largely determined the change in load profiles between match congestion microcycles. Likely at the instigation of coaching staff, players exposed to >70min playing time resulted in lower training loads over the ensuing days compared to non-playing condition. Although intuitive, this finding reflects a common post-match squad load management strategy, whereby recovery is emphasised for starters/substitutes and maintenance of physical loading for non-players (Anderson et al., 2016a; Stevens et al., 2017). Regardless of the existence or absence of match congestion, similar internal load profiles existed between matches, which concurs with findings from club-based contexts (Howle et al., 2019). In further support, external locomotion-based variables have also reported to be not significantly different during congested schedules in both professional (Carling et al., 2015; Lago-Peñas et al., 2011) and international football (Silva et al., 2017). Thus, while the absence of external load measures is a potential limitation (collection of such data was not available across all tournaments), the similarities in internal load responses between the conditions suggest an appropriate reference point from which to compare the post-match perceptual recovery profiles.

Differences in perceived fatigue and recovery profiles between the match congestion conditions closely reflected exposure to tournament match-play, hence questioning whether exposure or load are of importance. For instance, similar impairments in total perceived response values were observed up to 48h post-match in both single and multiple matches. Previous research reporting perceptual wellness responses within 'standard' 1 match microcycles (Thorpe et al., 2015, 2016), as well as, both single and multi-match weeks (Howle et al., 2019), reported comparable post-match recovery time courses. However, unlike the present study, multi-match congestion was shown to further exacerbate perceived fatigue ratings following the 2nd match (Howle et al., 2019). The contradictions between these findings may in part be due to the contextual differences of club football, as the previous study included a club team with excessive post-match travel demands. Further, factors like club training programmes with higher post-match training loads, or limited/reduced access to recovery facilities must also be considered in domestic Australian clubs (Thorpe et al., 2016; Waterson, 2016). Nevertheless, within the current study exposure to acute tournament match congestion does not appear to exacerbate international footballer's post-match fatigue and recovery responses. Although the generalisability of this finding is unknown and future research in other national teams over longer tournament periods are warranted.

Closer examination of the between-group comparison of the multi-match conditions alludes to significant variations in player perceptual ratings between Acute-Congestion and Non-Congestion microcycles despite similar load profiles. Specifically, moderate effect sizes existed for worse recovery of perceived fatigue, muscle soreness and sleep duration in Acute-Congestion. Previously, research within club-based contexts identified these parameters as the most responsive to match load during multi-match weeks, citing the repeated matches, logistical demands, and limited opportunity for recovery as justification for the observed responses (Clemente et al., 2017; Howle et al., 2019). However, exposure to match load may not be the only determinant of perceived fatigue and recovery responses, as other match-related factors including match outcome and players' individual performance can influence post-match perceived fatigue, stress and sleep (Fessi & Moalla, 2018). Although, the authors acknowledge these factors were not controlled for within this analysis, their contribution may only be evident up to 24h post-match (Fessi & Moalla, 2018). Notwithstanding, day-to-day variances within the No-Match condition were also evident within this study. Most notably total perceived response values were worsened on MD1+1, due largely to higher (poorer) ratings in sleep duration, with some late-night fixtures and possible air travel likely compromising player's sleep patterns (Fullagar et al., 2015).

The association between match-day load and the subsequent post-match perceived response had moderate-to-large positive correlations for all items, except psychological status. These findings align with research by Moalla and colleagues (2016) who reported similar correlations ($r$ = 0.23–0.48) between daily internal training load (s-RPE) and subjective ratings in professional footballers during pre- and in-season periods. Notably, perceived ratings of fatigue and muscle soreness were the most strongly associated with match loads, likely due to the high physical demands of football match-play resulting in residual post-match fatigue and tiredness (Silva et al., 2018a). In contrast, sleep quality and sleep duration were less sensitive to match loads, which may be a reflection of their responsiveness to contextual match factors (i.e. reduced recovery time and travel demands) rather than the match load itself. However, removing the no-match condition showed no significant correlations between any perceived response items and s-RPE match load. Thus, player perceptual responses may be responsive to the presence of match load, but is likely not sensitive to the variations/fluctuations evident within congested microcycles. Indeed, recent concerns have been raised relating to the validity and reliability of using single-item and composite scores to measure athlete's training 'response", with these measures unlikely to be influenced by only training and match load (Duignan et al., 2020; Jeffries et al., 2020).

## 4.6 Conclusion

Variations in perceived load, fatigue, and recovery profiles between congested and non-congested microcycles were largely determined by exposure to tournament match-play. While a consistent trend of worsened subjective ratings for Acute-Congestion was observed compared to the other congestion conditions, similarities in the magnitude of player responses on MD1 and MD2 suggest that acute match congestion does not exacerbate perceived fatigue and recovery responses within the context of international football tournaments.

## 4.7 Practical implications

- During international football tournaments, periods of acute-match congestion are followed by impaired states of pre-match subjective status compared to non-congested microcycles.

- The sensitivity of players perceived total response to training and match load appears to be less evident within congested microcycles.
- Future research should aim to determine the sensitivity, if not validity, of the subjective metrics in relation to external load or another response measure during congested schedules.

# Chapter 5: Study 3

Self-reported post-match recovery and recovery intervention use during congested international football tournament matches.

As based on the manuscript for journal submission in *International Journal of Sports Physiology and Performance*.

Noor D., McCall A., Jones M., Duncan C., Ehrmann F., Meyer T., Duffield R. Self-reported post-match recovery and recovery intervention use during congested international football tournament matches, *International Journal of Sports Physiology and Performance*, Article under review.

## 5.1 Abstract

***Purpose***: To report perceived fatigue and recovery of national team footballers during congested international tournament matches and describe their use of recovery interventions. ***Methods***: Forty male national team footballers were monitored throughout 2 tournaments. Outcome measures of perceived fatigue (5-items), recovery (1-item), and type/frequency of recovery interventions used were collected daily via customised questionnaires. Data were collated and analysed based on a 2-match microcycle, with outcome measures from each matchday (MD1, MD2) and the ensuing 2-days post-match (MD+1, MD+2). Comparisons between Starters (≥70 min), Rotation (<70 min), Non-Playing (0 min), and Consecutive Starters (≥70 min in consecutive matches) were analysed using two-way mixed ANOVAs and Effect Sizes (ES) with 90% confidence intervals. ***Results***: A transient worsening in total fatigue ($p$<0.034,$ES_{range}$=1.03–1.31) and recovery status ($p$<0.015,$ES_{range}$=1.27–1.35) were observed 24h post-MD1 for Starters and Consecutive Starters compared to Non-Playing. Similar impairments in total fatigue and recovery were evident 24h post-MD2 ($p$<0.004,$ES_{range}$=1.45–1.94); however, exacerbated perceptions of fatigue ($p$<0.049,$ES_{range}$=1.02–1.22) persisted until 48h post-MD2. The frequency of recovery intervention usage was significantly higher post-match for Starters ($p$<0.010,$ES_{range}$=1.19–1.69) and Consecutive Starters ($p$<0.030,$ES_{range}$=1.29–2.84) than Non-Playing, with the highest rate of usage occurring at MD+2. The most prevalent interventions used were massage (24%), sleep/nap (22%) and active recovery (13%). ***Conclusion***: Match exposure during international football tournaments elicits a transient reduction in perceived fatigue and recovery, which is prolonged after congested matches. In response, recovery intervention use is higher for playing groups, with recovery methods targeting physiological recovery mechanisms.

## 5.2 Introduction

During international tournaments, national-team footballers compete within a concentrated fixture schedule where time for recovery is often limited (Silva et al., 2017). Repeated exposure to matches during congested tournaments results in an accumulation of load, and the absence of sufficient recovery may subsequently result in increased fatigue, performance decrement or injury risk (Dupont et al., 2010; Ekstrand et al., 2004). Hence, monitoring recovery and optimising recovery strategies throughout international football tournaments is a common process (McCall et al., 2015). However, evidence from national football teams remains scarce, with limited information concerning the effects of congested match scheduling on national-team players' post-match recovery profiles. Furthermore, despite the routine implementation of post-match recovery strategies in professional football clubs (Nédélec et al., 2013), descriptions of national-team players' use of recovery interventions (i.e. type and frequency) remains anecdotal. Understanding the type and volume of recovery interventions used may prove valuable for national team practitioners, particularly given the contextual variances (i.e. training programmes, logistical demands and facilities) between club and international football.

Post-match recovery is regarded as a multifaceted restorative process relative to time and characterised by a return to pre-match status of specific performance, physiological and/or perceptual states (Kellmann et al., 2018). In professional football, appropriate recovery between successive matches (without any specific recovery strategies implemented) is suggested to require ≈72-96 h, depending on the physiological/psychological recovery mechanism of interest i.e. neuromuscular or damage (Nédélec et al., 2012; Silva et al., 2018a). However, during congested competition fixtures, the high exposure to match load coupled with the condensed time between matches may be inadequate to allow full recovery

(Nédélec et al., 2012). As evidence, when matches were separated by 3-days during a congested match week, professional male club footballers demonstrated pronounced reductions in repeated sprint performance, as well as elevated soreness and indicators of muscle damage (Mohr et al., 2016). Furthermore, following acute weekly periods of match congestion, professional male club players exhibited a prolonged return to baseline in biochemical, perceptual, and isometric strength measures when compared to single-match weeks (Howle et al., 2019; Lundberg & Weckström, 2017). However, these reports are limited to professional club football, whereby the level of player competitiveness, logistical demands, and proportion of training and match load differ from international football tournaments (McCall et al., 2015; Noor et al., 2019). Whilst club-based footballers have the season-long assistance of support staff, training and recovery facilities, many national teams may not be afforded such possibilities in the condensed nature of international matches in foreign environments. As such, it remains unclear how male national team footballers perceive their recovery throughout major international tournaments and descriptions of the recovery timeline from ecological contexts of international tournaments are warranted.

To reduce the magnitude of fatigue and aid post-match recovery, numerous recovery strategies are routinely implemented in professional football teams (Nédélec et al., 2013). These interventions primarily target reducing soreness and acute inflammation from muscle damage and improving neuromuscular performance. For instance, a survey of practitioners within professional French football teams reported a high prevalence of cold-water immersion/contrast water therapy (88% of respondents), active recovery (81%) and massage (78%); while broader strategies such as nutrition (97%), hydration (97%) and sleep (95%) were perceived as highly effective (Nédélec et al., 2013). Whilst such surveys of practitioner and player habits are popular in clubs, quantification of recovery interventions in international football is limited. This is despite the noted concerns of national team practitioners advocating the need for evidence of optimal recovery strategies within tournament contexts (McCall et al., 2015). Given the sparsity of research that exists in national team contexts, the objective of this study was to 1) describe the self-reported fatigue and recovery profiles and 2) usage of recovery interventions by senior male national team footballers during congested international tournaments.

## 5.3 Methods

Data was collected from 40 professional male football players (23.0 ± 3.7 years) selected to compete for the Australian National Football Team at two FIFA sanctioned international football tournaments: 2017 Confederations Cup ($CC_{2017}$) and 2018 U23 Asian Cup ($U23AC_{2018}$). All outfield players from the original 23-man squads for each tournament were eligible for inclusion, with goalkeepers excluded due to variations in their training methods and match activity. In total, participating players consisted of 8 central defenders, 6 wide defenders, 11 central midfielders, 9 wide midfielders and 6 strikers. Provisional approval for the study was obtained from the National Federation involved, with individual player data previously collected as a condition of national team duty (Winter & Maughan, 2009). Data collection procedures were approved by the University Human Research Ethics Committee. Retrospective sharing and conditional usage of the data was undertaken in accordance with a strict data confidentiality agreement, and all data were anonymised before analysis to ensure player confidentiality.

The present observational study analysed a single-cohort study design, in which player's perceived fatigue/recovery data and self-reported usage of recovery interventions were collected from a men's Senior and U23's national teams competing at two separate tournaments. Both cohorts were predominantly independent of each other, with the exception of two players who were selected in both international tournaments. Data from the competition phases of each tournament were assessed, both of which comprised 3 group-stage matches played over a duration of 7-days with identical match scheduling (matches on day 1, 4 and 7). Each matchday and the ensuing 2 days post-match (i.e. matchday 1 [MD1], matchday 1+1 [MD1+1], matchday 1+2 [MD1+2]) were grouped and then analysed independently as separate continuum of days due to changes in player classification. However, the absence of data collected after the final match (matchday 3) resulted in only data collated from the first two matches being analysed. In order to account for the effect of match load on perceived fatigue and recovery, players were categorised each matchday based on their match exposure using the following classification criteria: Starters – participation in a match from its commencement to at least 70 min duration; Rotations – participation in a match as either a starter or substitute for < 70 min duration; Non-Playing – non-participation in a match. Additionally, a subset group of Starters were also included within the analysis, classified as Consecutive Starters – participation of >70 min in two consecutive matches. Overall, a combined total of 100 data series were included for analysis, consisting of 34 Starters, 17 Rotations, 29 Non-Playing, and 20 Consecutive Starters.

Daily measurement of player's perceived fatigue and recovery ratings were monitored throughout the assessment period using a customised questionnaire completed each morning (09:00 – 10:00) prior to the commencement of training or competition. The questionnaire was based on previous athlete self-report measures used to assess subjective responses to exercise and comprised 5-items relating to 'fatigue' (perceived fatigue, general muscle soreness, psychological status, sleep quality, and sleep duration) (Gastin et al., 2013; Hooper & Mackinnon, 1995; McLean et al., 2010) and 1-item relating to recovery status (Laurent et al., 2011). Each of the fatigue items were scored on a seven-point Likert scale ranging from 1–7, with point increments of 1, and scores of 1 and 7 representing “very, very good” and “very, very poor”, respectively. Summation of the 5 fatigue items for each given day were calculated to provide a ‘total fatigue’ score for each player, whereby a higher number represented a worse perceived state. Contrastingly, the recovery status item was scored on an eleven-point Likert scale, with point increments of 1, and numerical and verbal anchors ranging from 0, “very poorly recovered” to 10, “very well recovered”.

As a part of the same monitoring system outlined above, players were asked if they had used any recovery intervention/s within the last 24h prior to the commencement of ensuing training/matches. Players reported the type of recovery method/s used in the online-based questionnaire, which gave them a selection of all the recovery interventions available for use. These options included Ice Bath (>5mins); Hot & Cold Contrast Bath; Massage/Manual Therapy; Foam Rolling/Stretching; Compression Garments; Recovery Pumps; Active Recovery (>15mins); Sleep/Nap (>30mins, additional to evening sleep); Meditation; Other (required to specify). Players reported the use of multiple interventions each day, which was then summated and added to the total number of interventions used for that day based on the playing categories outlined earlier. Access to the recovery interventions was based on player choice, though recommendations were likely from staff as part of daily servicing.

Descriptive data for perceived fatigue, recovery and frequency of recovery interventions used are presented as means ± standard deviation (mean ± SD). Respective two-way mixed analyses of variances (ANOVA) were performed independently for each matchday continuum to determine the effect of match exposure (4 levels: Starter, Rotations, Non-Playing and Consecutive Starters) on the aforementioned outcome variables measured over time (3 levels: MD, MD+1, MD+2). Significance was set at $p \leq 0.05$ level. If a significant effect was found, follow-up ANOVAs with Bonferroni post-hoc tests were performed to determine where the difference/s occurred ($p \leq 0.05$). Effect sizes (ES) and 90% confidence intervals were calculated to determine the magnitude of difference between the respective 48h post-match profiles. 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) (Batterham & Hopkins, 2006). Furthermore, descriptive statistics relating to the type of recovery interventions used were also presented as a daily count (*n*) and percentage contribution (%) calculated as a proportion of the total number of recovery interventions used for a given day.

## 5.4 Results

Differences in the profiles of perceived fatigue and recovery between match exposure groups are shown in Figure 5.1 and 5.2. Following matchday 1, no significant interaction effect ($F_{[5,73]} = 2.26$, $p = 0.060$) was evident for perceived total fatigue. However, a significant main effect ($F_{[2,73]} = 53.77$, $p < 0.001$) of time was present; with post-hoc comparison testing revealing significantly higher (worsened) total fatigue for Starters ($p = 0.029$, ES = 1.03[0.44,1.63]) and Consecutive Starters ($p = 0.034$, ES = 1.31[0.56, 2.06]) compared to Non-Playing players at MD1+1. Contrastingly, for the matchday 2 continuum a significant interaction effect existed ($F_{[5,62]} = 26.86$, $p < 0.001$), with significant main effects of match exposure ($F_{[3,46]} = 3.42$, $p = 0.025$) and time ($F_{[2,92]} = 55.86$, $p < 0.001$). Post-hoc comparison testing revealed significantly higher total fatigue for Starters ($p = 0.043$, ES = 1.02[0.40,1.64]) and Consecutive Starters ($p = 0.049$, ES = 1.22[0.50,1.94]) compared to Non-Playing players at MD2+1. Furthermore, total fatigue remained significantly higher for Starters ($p = 0.043$, ES = 1.02[0.40,1.64]) and Consecutive Starters ($p = 0.049$, ES = 1.22[0.50,1.94]) compared to Non-Playing players at MD2+2, which was largely the resultant of the perceived fatigue sub-scale ($p_{range}$ = 0.016–0.034, $ES_{range}$ = 1.09–1.32) remaining significantly elevated within both groups.

Concerning perceived recovery, a significant interaction effect ($F_{[5,64]} = 2.42$, $p = 0.048$) and main effect of time ($F_{[2,64]} = 32.57$, $p < 0.001$) were evident across the matchday 1 continuum. Post-hoc comparison testing revealed significantly lower (poorer) recovery ratings for Starters ($p = 0.009$, ES = -1.27[-1.90,-0.65]), Rotations ($p = 0.033$, *ES* = -1.22[-1.92,-0.52]) and Consecutive Starters ($p = 0.015$, ES = -1.35[-2.05,-0.66]) compared to Non-Playing players at MD1+1. For the matchday 2 continuum, a significant interaction effect existed ($F_{[5,62]} = 6.97$, $p < 0.001$), with significant main effects of match exposure ($F_{[3,41]} = 3.30$, $p = 0.030$) and time ($F_{[2,62]} = 31.95$, $p < 0.001$). Post-hoc comparison testing revealed significantly lower recovery ratings for Starters ($p = 0.003$, ES = -1.55[-2.20,-0.89]) and Consecutive Starters ($p < 0.001$, ES = 1.94[1.24,2.64]) compared to Non-Playing players at MD2+1. While in contrast, Rotation players had significantly higher ratings of recovery ($p = 0.014$, ES = 1.69[0.85,2.54]) compared to Consecutive Starters at MD2+1.

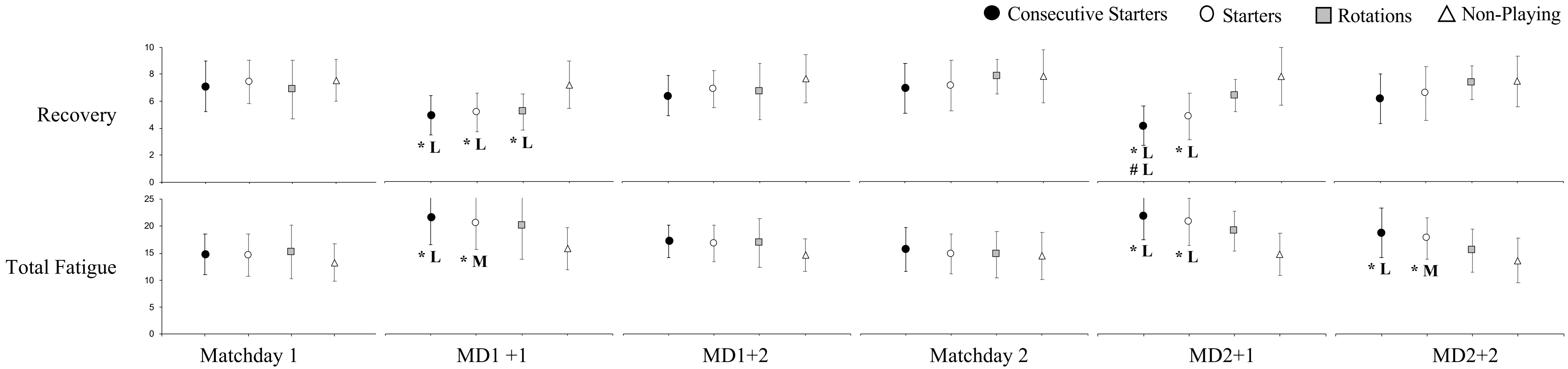


Figure 5.1. Total perceived fatigue and recovery profiles of Starters, Rotations, Non-Playing, and Consecutive Starters post-Matchday 1 and 2. Perceived response and recovery data were combined from $CC_{2017}$ and $U23AC_{2018}$ tournaments.

*Denotes a significant difference from Non-Playing, #Denotes a significant difference from Rotations, ^Denotes a significant difference from Starters; $p \leq 0.05$. Effect size abbreviations: S = small, M = Moderate, L = large, VL = very large.

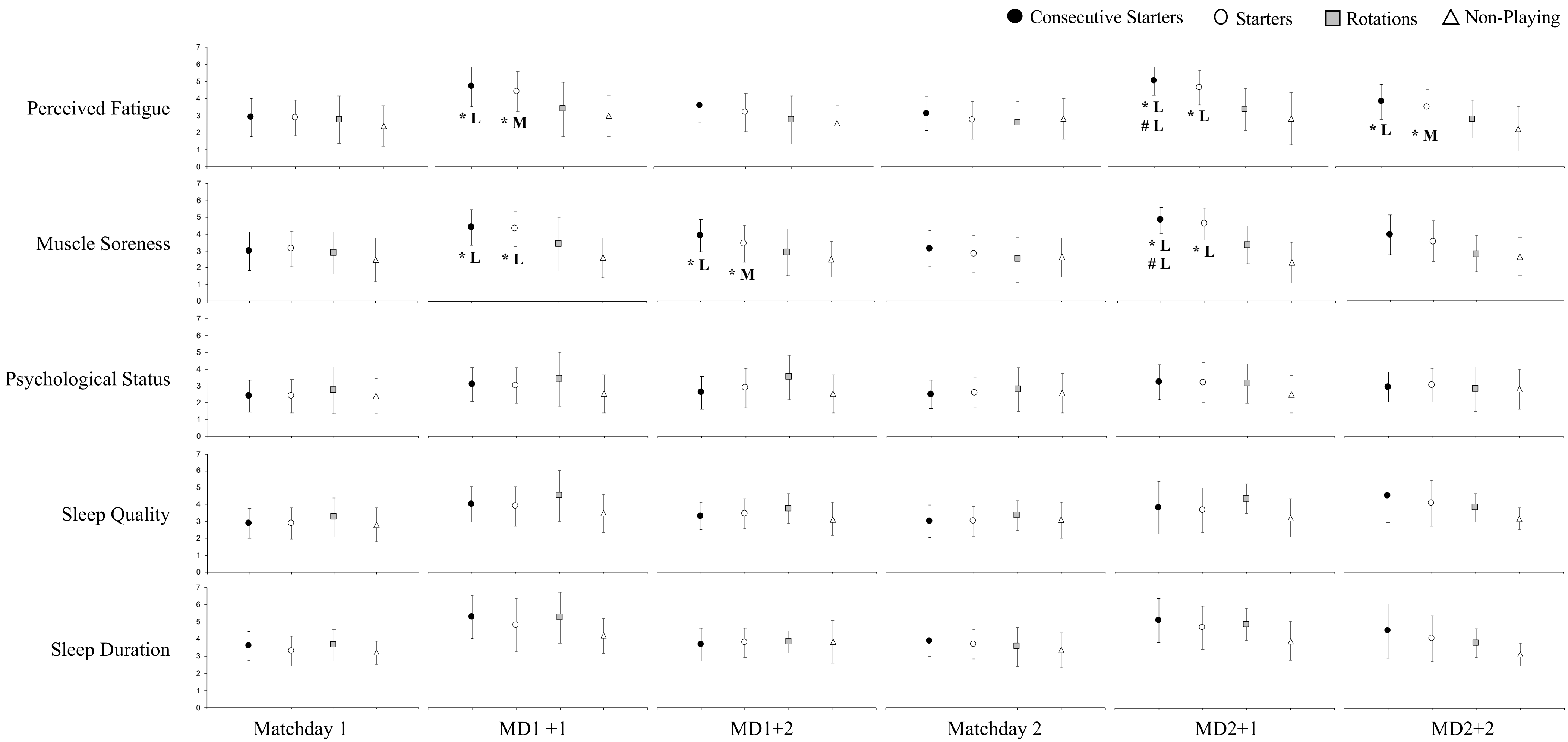


Figure 5.2. Perceived fatigue sub-scales of Starters, Rotations, Non-Playing, and Consecutive Starters post-Matchday 1 and 2. Perceived response and recovery data were combined from $CC_{2017}$ and $U23AC_{2018}$ tournaments.

*Denotes a significant difference from Non-Playing, #Denotes a significant difference from Rotations, ^Denotes a significant difference from Starters; $p \leq 0.05$. Effect size abbreviations: S = small, M = Moderate, L = large, VL = very large

Descriptive statistics of all player's self-reported recovery intervention usage are presented in Figure 5.3. The dominant recovery interventions used at MD1+1 and MD2+1 were massage/manual therapy (29% and 33%), compression garments (24% and 25%), and ice baths (18% and 16%). Thereafter, the most prevalent recovery interventions used at MD1+2 and MD2+2 were sleep/nap (25% and 27%), massage/manual therapy (21% and 24%), and active recovery (14% and 15%), accounting for approximately 60% and 66% of the total daily usage, respectively. The most commonly used recovery methods across the whole tournament week were massage/manual therapy (24%), closely followed by sleep/nap (22%) and then active recovery (13%).

Concerning the frequency of recovery interventions usage, observable decreases in the total sum of interventions used were evident at MD1+1 ($n$=63) and MD2+1 ($n$=67), followed by increases at MD1+2 ($n$=125) and MD2+2 (n=108). Comparison of intervention usage between match exposure groups (Figure 5.4) found no significant interaction effect ($F_{[6,92]}$ = 1.22, $p$ = 0.304) for the matchday 1 continuum; despite significant main effects of match exposure ($F_{[3,46]}$ = 3.75, $p$ = 0.017) and time ($F_{[2,92]}$ = 26.48, $p$ < 0.001). Similarly, for the matchday 2 continuum, both main effects of match exposure ($F_{[3,46]}$ = 7.84, $p$ < 0.001) and time ($F_{[3,46]}$ = 7.84, $p$ < 0.001) were significant. Post-hoc comparison testing found Starters ($p$ = 0.010, ES = 1.19[0.59,1.79]) and Consecutive Starters ($p$ = 0.006, ES = 1.58[0.86,2.29]) to have used significantly more recovery interventions compared to Non-Playing players at MD1+1. While Starters, Consecutive Starters and Rotation ($p$ = 0.038, ES = 1.76[0.78,2.74]) players used significantly more recovery interventions compared to Non-Playing players at MD2+1. Subsequent increases in the number of recovery methods used by all groups resulted in Consecutive Starters maintaining a significantly higher ($p$ = 0.030, ES = 1.24[0.54,1.95]) frequency of intervention usage compared to Non-Playing players at MD1+2.

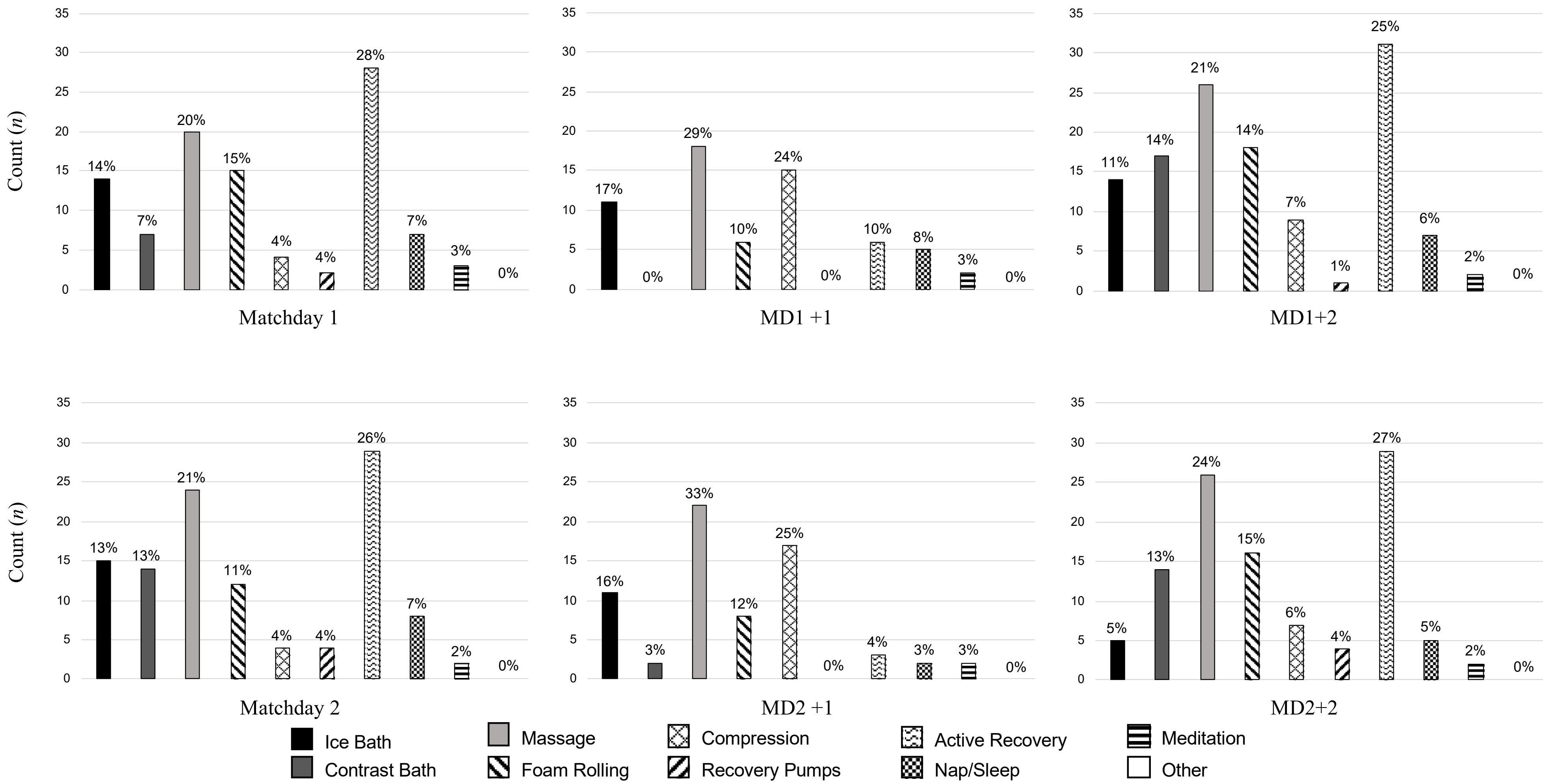


Figure 5.3. Types of recovery interventions used per day presented as a daily count (*n*) and percentage (*%*) calculated as a proportion of the total number of recovery interventions used for a given day. Intervention usage data was combined from $CC_{2017}$ and $U23AC_{2018}$ tournaments.

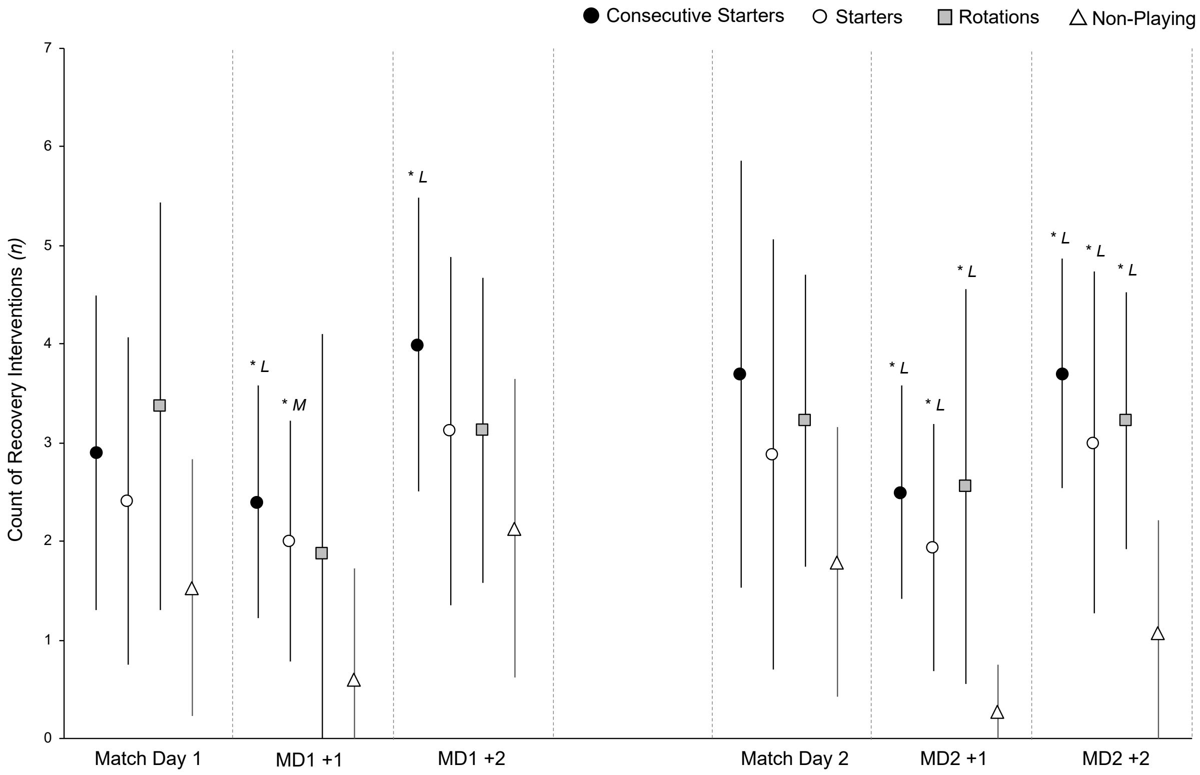


Figure 5.4. Average number of self-reported recovery interventions used by Starters, Rotations, Non-Playing, and Consecutive Starters post-Matchday 1 and 2. Intervention usage data was combined from $CC_{2017}$ and $U23AC_{2018}$ tournaments.

*Denotes a significant difference from Non-Playing, #Denotes a significant difference from Rotations, ^Denotes a significant difference from Starters; $p \leq 0.05$.
Effect size abbreviations: S = small, M = Moderate, L = large, VL = very large, NP = nearly perfect.

While at MD2+2, usage of recovery interventions remained significantly higher for Starters ($p$ = 0.005, ES = 1.29[0.70,1.88]), Rotations ($p$ = 0.005, ES = 1.79[1.01,2.56]), and Consecutive Starters ($p$ < 0.001, ES = 2.29[1.57,3.01]) compared to Non-Playing.

## 5.5 Discussion

This study is the first to examine the effect of acute match congestion on perceived fatigue, recovery and recovery intervention use during international football tournaments. The results indicate that exposure to match-play during congested international football produces a transient reduction in ratings of perceived fatigue and recovery. Furthermore, Starters and Consecutive Starters showed exacerbated perceived fatigue responses following the 2$^{nd}$ matchday within the congested tournament schedule. The corresponding frequency of recovery interventions used was higher for playing groups compared to non-playing. Specifically, interventions targeting peripheral physiological recovery (i.e. muscle massage/manual therapy, ice baths, and compression garments) were predominant immediately post-match, while a combination of central and peripheral mechanisms (i.e. sleep/napping, massage, and active recovery) were preferred during the 24-48h thereafter.

Self-report measures of athlete's perceived fatigue and recovery are routinely implemented in professional football (Akenhead & Nassis, 2016) and have previously been used to assess player readiness and responsiveness to training/match load (Thorpe et al., 2015, 2016). In the present study, exposure to match-play elicited a worsened total fatigue and recovery response compared to non-playing players at MD+1 following both matches, along with a prolonged impairment at MD+2 (Figure 5.1). Previous research has demonstrated increased perceived fatigue and reduced recovery at 48h post-match within both congested and non-congested match weeks (Howle et al., 2019; Thorpe et al., 2016). However, these impairments were assessed in reference to either pre-season baseline measurements or between-day changes from the previous day, with no consideration for how variance in match exposure may impact player's subjective responses. Notably, repeated match exposure is concerning for practitioners in national team contexts (McCall et al., 2015); and the current study found Starters and Consecutive Starters to have exacerbated ratings of total fatigue at MD2+2 within a congested tournament week. This aligns with previous findings in Australian club footballers that reported subjective total wellness and recovery to be further reduced 48h after the second matchday within a multi-match week (Howle et al., 2019). Additionally, greater muscle soreness and lower perceived recovery have also been reported within Finnish club footballers 72h after a congested match-week cycle (3 matches in 7 days) compared to a single match-week cycle (Lundberg & Weckström, 2017), further highlighting the effects of congested schedules.

Underlying the elevations of total fatigue within Starters and Consecutive Starters, perceived fatigue and muscle soreness were the primary perceptual scales contributing to the change in total fatigue (Figure 5.2). This is consistent with previous research in professional club teams that found perceived fatigue and muscle soreness to be responsive to match load, as well as sleep quality, which was not identified within this study (Howle et al., 2019; Thorpe et al., 2016). Perceived muscle soreness in particular has been shown to be impaired up to 72h post-match, alongside changes in both performance and biochemical measures, suggesting mechanisms of peripheral fatigue are considerable following football competition (Howle et al., 2019; Lundberg & Weckström, 2017). Although, no physiological or performance measures were collected within the current study, evidence of elevated muscle damage (i.e. creatine kinase) 48h post-match has been found within national-team footballers competing at international tournaments when compared to club footballers during the regular football season (Hecksteden & Meyer, 2020; Meyer & Meister, 2011). These findings affirm the increased perceived fatigue and soreness resulting from scheduling during major international tournaments.

During periods of competitive fixture congestion, augmenting the recovery process is of critical importance to team practitioners by means of appropriately selecting and implementing recovery strategies (Nédélec et al., 2013). Within the context of congested international tournament matches, player's match exposure influenced the number of post-match recovery interventions used; as higher usage was reported by Starters, Rotations, and Consecutive Starters (Figure 5.4). This finding appears intuitive given that the need for recovery is related to the extent of the load imposed on the various physiological and neuromuscular systems (Nédélec et al., 2012). However, temporal alignment of perceived fatigue and recovery against the frequency of recovery interventions used shows a decline in intervention usage to its lowest rate at MD1+1 and MD2+1; despite player's perceived fatigue and recovery states being most severely worsened. Such a finding seems contradictory, as the need to recover is arguably most critical during this time period, yet less recovery interventions were utilised by the players. This may be due to variances in contextual factors and travel logistics limiting the aggregated use of recovery strategies immediately post-match. For instance, during the $CC_{2017}$ the team travelled immediately post-match, whereas during the $U23AC_{2018}$ all matches were played at the same venue, thus altering access and time for recovery. Furthermore, differences in training/recovery periodisation between the groups also likely contributed to the spike in recovery interventions used by Starters and Consecutive Starters between at MD1+2 and MD1+2; as starters were assigned a rest day following both matches, thus affording them time and preference of recovery modalities.

In addition to the potential accumulative effect of implementing multiple recovery strategies, the selection and timing of recovery methods is also of importance. Previous research revealed that cold water immersion/contrast water therapy (88%), active recovery (81%) and massage (78%) to be the most commonly implemented recovery strategies by practitioners within professional French club teams (*n*=32) (Nédélec et al., 2013). The results of the present study are largely consistent with these findings, with massage, sleep/nap and active recovery the top three most commonly used recovery interventions across the tournament week. Furthermore, cold water baths and contrast baths were also frequently used, which when combined (as in the aforementioned study) would place them among the top three most commonly used recovery strategies. Evidently recovery interventions targeting physiological recovery mechanisms are prevalent within both club and national-team football. In particular, immediate post-match recovery strategies focussed on reducing acute inflammation (i.e. muscle massage/manual therapy, ice baths, and compression garments) accounted for 70-80% of interventions used by these national team players. However, over the subsequent 24h, a more integrative approach to recovery was observed, with an increased percentage (25-27%) of players utilising sleeping/nap as a recovery strategy; possibly due to the starters not having on-pitch duties and more time to choose preferred recovery methods. Finally, the influence of support staff should be recognised, whereby post-match information related to maximising use of available facilities and recovery interventions. However, in the ensuing days when players were left to their own preferred interventions (or that were made available), the change in frequency and type of intervention also reflected this personal preference and availability. This may also point to the role of practitioners for their support and provision of recovery options throughout a tournament period.

Despite the novel findings in this population, there are some limitations to this study that must be acknowledged. Firstly, data was sampled from only two acute congested tournament weeks, resulting in a potential coupling effect between the Consecutive Starters and Starters groups. Secondly, of the two cohorts used both were representative teams of the same national football association, limiting the generalisability of the findings to other teams in different contexts. Lastly, despite their widespread use, concerns remain over the validity and reliability of using single-item self-report measures to assess athletes' responses to training and competition (Duignan et al., 2020; Jeffries et al., 2020). As such, researchers and practitioners should consider the measurement properties of single-item self-report measures and aim to establish their relationship with more clinically meaningful outcomes (Duignan et al., 2020).

## 5.6 Conclusion

This study is the first to examine the effect of match congestion on perceived fatigue, recovery, and recovery intervention use during international football tournaments. Match exposure was shown to produce a transient reduction in players' perceived fatigue and recovery response, although perceptions of fatigue remained exacerbated at 2 days post matchday 2. Correspondingly, the frequency of recovery interventions used was higher post-match for playing groups compared to non-playing, with a high prevalence of recovery methods targeting physiological recovery mechanisms, due in part to the availability and preference for these particular recovery interventions based on contextual factors.

## 5.7 Practical implications

- Repeated match exposure during a week of congested match fixtures, impairs players perceived fatigue and recovery status such that the frequency of their recovery interventions increases compared to non-playing players.
- Monitoring players exposure to matches, as well as their day-to-day changes in perceived fatigue, recovery and intervention usage may be helpful to assess player readiness.
- Practitioner provision of recovery modalities may also influence player behaviour as to the selection and frequency of recovery intervention used in national teams.

# Chapter 6: Discussion

## 6.1 Summary of findings

The physical preparation and maintenance of national team footballers during international tournaments is a challenging task, in which the scheduling and tournament formats result in shortened preparation periods, fixture congestion, high logistical demands and limited availability of facilities/equipment (Buchheit & Dupont, 2018). Monitoring of training loads, fatigue and recovery can be used to assist national team practitioners to strategically manage international footballers as they transition from their club teams to training camp and throughout the tournament itself (McCall et al., 2015; McCall et al., 2018a). Thus, the series of investigations within this thesis aimed to examine the effects of international tournament football on perceived training load, fatigue, recovery status, and recovery intervention usage. All data collection was conducted within teams from the same national football federation, in which measures of training and match load, self-reported fatigue and recovery status, and recovery intervention usage were routinely collected during several international football tournaments. Specifically, the aims of this thesis were to: (1) examine the training load profiles of international footballers as they transition from club to national-team contexts; (2) determine the effect of tournament match congestion on perceived fatigue and recovery; (3) describe the self-reported usage of recovery interventions in response to tournament match congestion. The following chapter will aim to thematically collate the findings from each chapter to develop conclusions from each of the studies based on the aforementioned objectives of the current thesis.

### 6.1.1 Study 1 – Training Load profiles of footballers transitioning from club to national-team contexts.

Study 1 aimed to quantify and profile the training and match loads of international footballers as they transitioned from club-to-camp-to-tournament contexts during multiple international tournaments. The study found that as these international footballers transitioned from their club to national-team camps, increases in s-RPE load and A/C ratio were evident, driven predominantly by increases in training volume (i.e. number of training sessions). Subsequently, during the transition from camp-to-tournament contexts a counterbalance in training and match load was evident, with large increases in match volume and s-RPE match load offset by very large decreases in training volume and s-RPE training load. As a result, an overall decrease in the A/C ratio between the camp-to-tournament periods existed. Within individual tournaments these trends were consistent, though between tournaments the extent of these changes differed due to contextual factors (i.e. condensed training camp and/or match congestion) of the tournaments constraining the distribution and accumulation of training load.

6.1.2 Study 2 – Effect of tournament match congestion on perceived fatigue and recovery.
Study 2 aimed to examine the effect of match load on player's perceived fatigue and recovery during congested and non-congested schedules in international football tournaments. The study found that player's internal load and perceived fatigue and recovery profiles were largely determined by their exposure to tournament match-play, with high internal match loads preceding a worsening in perceived response variables (fatigue, muscle soreness, sleep quality/duration), as well as reductions in the subsequent days training load. Regardless of the existence or absence of match congestion, similar internal match load profiles existed between match conditions, reflecting a common post-match squad load management strategy; whereby recovery is emphasised for starters/substitutes and maintenance of physical loading for non-players. Despite the similarities in load profiles, periods of acute match congestion were shown to impair players pre-match perceived status when compared to non-congested microcycles. Although, within the acute match congestion condition perceived ratings of

fatigue and recovery remained similar on MD1 and MD2 suggesting that acute match congestion (i.e. 2 matches within 4 days) does not exacerbate perceived fatigue and recovery responses within the context of international football tournaments.

#### 6.1.3 Study 3 – Perceived recovery and usage of recovery interventions in response to tournament match congestion.

Study 3 aimed to further examine the effect of acute match congestion on perceived fatigue and recovery, as well as recovery intervention usage during international football tournaments. The study found that match exposure during international football tournaments elicits a transient worsening in perceived total fatigue and recovery, which is prolonged after congested matches (2 matches within less than 3 days). Elevated ratings of perceived fatigue and muscle soreness were shown to be the primary perceptual scales contributing towards the change in total fatigue (wellness). In response, recovery intervention use was higher for playing groups compared to non-playing, with a high prevalence of recovery methods targeting physiological recovery mechanisms, due in part to the availability and preference for these particular recovery interventions. Usage of recovery interventions by Starters and Consecutive increased between 24-48h post-match, as starters were assigned a rest day on MD+1 affording them time and preference in recovery modalities.

## 6.2 Internal load in international football tournaments

The preparation of national-team players for international football tournaments is a complex task, centring on the ability of national-team staff to balance recovery and training needs throughout the entire tournament (McCall et al., 2015; McCall et al., 2018a). In the lead up to international tournaments, players typically report for national-team duty in the weeks prior to the first match, often with varying fitness levels depending on their recent match schedule, injury history and training programs at their respective clubs (McCall et al., 2018a; Morgans et al., 2015). Upon arrival to training camp, coaches and performance staff generally first seek to understand players' individual level of fitness and match readiness, which is assessable through physical screening and fitness testing, as well as training load monitoring over the weeks preceding the international fixture (Buchheit & Dupont, 2018; McCall et al., 2015). However, in the context of transitioning from club to national teams, continuous player monitoring presents several challenges, not least the fact that players within a single national team often play in more than 10 different clubs and leagues (Buchheit, 2017; Buchheit & Dupont, 2018; McCall et al., 2018a). Thus, national team practitioners require simple and reliable measures of training load to ensure that players can seamlessly transition into a national team environment in which they are continuously monitored (McCall et al., 2015; McCall et al., 2018a).

Previous research on training loads during the transition between club and national teams is sparse and highlights the lack of evidence to guide practitioners. Study one (Chapter 3) reports that during the transition between club and camp, international football players experienced moderate increases in internal training load, resulting from a large increase in training session count rather than training intensity. This finding concurs with previous research reported by McCall et al. (2018a) who found that relative increases in training load came from an increase in the number of sessions performed during the first week of training camp, rather than an increase in the duration or perceived intensity (RPE) of the actual training sessions. Such a finding appears logical given that in-season match commitments reduce players' availability to train, while in-camp there is an increased availability to complete a greater number of sessions. Evidently, a moderate increase in A/C ratio was also identified within study one, with this increase in relative training load reported as important for injury management (Bowen et al., 2017, 2020; Gabbett, 2016), though this has since been discredited (Impellizzeri, Tenan, et al., 2020; Impellizzeri et al., 2021). Similarly, McCall et al. (2018a) reported players who encountered a greater relative increase in training load during the first week of camp had a higher likelihood of injury. However, it was acknowledged that the A/C ratio did not conclusively define injured and non-injured players during the training camp and was reported to result in spurious associations with injury (Fanchini et al., 2018; McCall et al., 2018b). This also fits with recent evidence challenging the predictive ability of the A/C ratio and demonstrating statistical artefacts inherent within the models (Impellizzeri, Tenan, et al., 2020; Impellizzeri et al., 2021; Suarez-Arrones et al., 2020).

Beyond monitoring load to optimise the tournament preparation of international footballers, limited evidence exists as to how national team practitioners implement training load monitoring strategies to maintain and manage players' performance throughout the tournaments. Study one (Chapter 3) is the first study to report training and match loads performed by elite international football players as they transition from training camp to in-tournament contexts. The training load profiles from these periods demonstrate a counterbalance in training and match loads, in which large increases in match volume and internal s-RPE load during the tournament were offset by very large decreases in training volume and s-RPE training load. This counterbalance in load accumulation intuitively represents the shift in training focus to match preparation and prioritisation of recovery for subsequent matches during the tournament (Bangsbo, 1998). Further, different training load profiles were observed between playing and non-playing groups in study two (Chapter 4), with players who did not participate in matches exposed to higher training loads the day after the matches, presumably to help maintain their fitness and match readiness. As not all players (i.e. non-starters) are exposed to increases in tournament match load, individual training load needs form a key consideration for national team practitioners aiming to maintain squad physical fitness (Bangsbo, 1998; McCall et al., 2015).

During major international football tournaments, match loads are considerable with a high number of matches often condensed into a short period of time (Silva et al., 2017). Study two (Chapter 4) demonstrates that match exposure largely determines the change in training load profiles between different congestion conditions, rather than match congestion itself. For instance, regardless of the presence or absence of match congestion, similar match load profiles existed between playing conditions (i.e. Acute-Congestion, Non-Congestion, and Single-Match), with only non-playing conditions (No-Match) showing obvious reductions. This finding concurs with research from a professional Australian football (soccer) club, in which internal match loads were comparable between players exposed to single or multi-match weeks (Howle et al., 2019). Furthermore, when players were exposed to >70min match play this resulted in significant reductions in training load over the ensuing days post-match when compared to non-playing players. These variances in training load profiles likely occurred at the instigation of coaching and performance staff and reflects a common post-match squad load management strategy, whereby recovery is emphasised for starters/substitutes and maintenance of physical loading for non-players (Anderson et al., 2016a; Stevens et al., 2017).

Optimising and monitoring individual player training loads within an international tournament context remains a key challenge for national team practitioners (McCall et al., 2015). Thus, despite the summary data presented in this thesis, contextual factors of each tournament are important to consider when interpreting the training load profiles of international footballers. For instance, before the $WC_{2014}$ an extensive training camp was performed leading to a very large increase in the A/C ratio, driven by a combination of both a large increase in training intensity and very large increase in the number of training sessions. As highlighted earlier, such increases in relative training load were associated with, but not causative of non-contact injury (McCall et al., 2018a). In contrast to the $WC_{2014}$, the first week of training camp for the $AC_{2015}$ and $CC_{2017}$ were more closely aligned to the players' pre-camp loads. Although this may have been an intentional periodisation strategy from the national-team staff to prevent excessive spikes in acute training load at the start of the training camps. The condensed length of the $AC_{2015}$ and $CC_{2017}$ training camps (12-16 days) also constrained any relative increase in training load, given the need for players to be adequately recovered in a shorter time period before the first tournament match. Furthermore, the scheduling of the $AC_{2015}$ as a mid-season tournament meant that players arrived directly into camp from their domestic-club competitions, resulting in a decrease in match load during this transition, which was not observed during the other two tournaments. Hence, it is recognised the individual variances of respective camps and tournament scheduling will also play a role in the training load management and periodisation of national team footballers.

In summary, distinct variations in international players' training and match load profiles were identified as they transition between club, camp, and tournament contexts. Increases in training volume and internal load were evident during the transition from club to camp, with excessive spikes in relative load a key point of concern for national team practitioners (McCall et al., 2018a). A subsequent counterbalance in training and match load accumulation occurred during the transition from camp to tournament, resulting in an overall decrease in relative load. For national team staff this intuitively represents the shift in training periodisation from tournament preparation to post-match recovery and load management during the tournaments. Furthermore, match congestion during tournaments did not alter the load profiles between playing conditions, which is in line with research from club-based contexts (Howle et al., 2019). The studies from this thesis demonstrate how the changing dynamic of training and match loads alters the accumulation and distribution and accumulation of training exposure for international footballers as they transition from club to camp to tournament contexts. Consideration of these alterations in training load as well as individualised player profiles (i.e. starters, fringe, non-playing), highlight the usefulness of effective monitoring strategies for national team practitioners.

## 6.3 Perceived fatigue in international football tournaments

International football tournaments are characterised by a demanding and concentrated fixture schedule, in which a minimum of 3 and maximum of 6-7 matches are played over a 3-4 week period (Silva et al., 2017). Occurring habitually every 2-4 years, these tournaments are often held directly after the regular football season, effectively replacing international footballers' off-season with a continuation or increase in training load. While, previous research suggests that elite footballers are able to cope with a congested match calendar for a short period of time (Carling et al., 2012; Folgado et al., 2015; Lago-Peñas et al., 2011), the scheduling of international tournaments at the end of the regular football season may exacerbate player fatigue and increase the risk of injury and/or underperformance during the tournament (Ekstrand et al., 2004). Such concerns resonate with national team practitioners, who ranked accumulated fatigue (throughout the season), training and match loads in clubs, and reduced recovery periods/match congestion among the most important risk factors for non-contact injury (McCall et al., 2015). Evidently, management of fatigue during international tournaments is important in mediating any negative responses to training/matches (particularly during congested schedules) and ensuring that players are prepared for subsequent matches.

Participation in football match-play leads to transient and residual fatigue, in which players may experience perceptual, biochemical, metabolic, and physical disturbances over the subsequent hours and days (Carling et al., 2018; Marqués-Jiménez et al., 2017; Silva et al., 2018a). Accordingly, monitoring of fatigue status is an important process within the current practices of national teams, with a range of subjective and objective measures used to determine how players are coping physically and mentally (Akenhead & Nassis, 2016; McCall et al., 2015). However, while an extensive body of research exists in relation to residual post-match fatigue in football (Nédélec et al., 2012; Silva et al., 2018a), much of the research tends to investigate the time-course of fatigue responses after a single match within professional club settings (Rowell et al., 2017; Thorpe et al., 2015, 2016). As such, repeated measures gathered within national team contexts are scarce, as are studies examining multiple consecutive matches played over a short timeframe (Howle et al., 2019; Lundberg & Weckström, 2017; Mohr et al., 2016). Consequently, a description of the extent and time-course of post-match fatigue during congested international tournaments is warranted.

The anecdotal perceptions of national team practitioners report the prevalent use of fatigue monitoring tools during international tournaments (McCall et al., 2015), despite limited published evidence from within national team contexts. Study two and three (Chapters 4 and 5) demonstrated that match exposure (of >70 minutes) during international tournaments elicits a transient worsening in ratings of perceived total fatigue, which is prolonged following the second matchday within a two-match microcycle. Previous research from professional football clubs reported comparable post-match perceived fatigue time courses during both single (Thorpe et al., 2015, 2016) and multi-match weeks (Howle et al., 2019). However, between study two and three a difference in the magnitude of post-match perceived fatigue after the 2nd matchday was observed, with study two demonstrating a prolonged (but not elevated) return to pre-match values, while study three exhibited an exacerbation (elevation) in perceived fatigue for both Starters and Consecutive Starters. The contradiction between these findings may be due to the difference in match congestion between the studies with Starters and Consecutive Starters having 72 h recovery between matches in study three, while the Acute-Congestion group in study two had closer to 96 h recovery. Previous research within a professional Australian football club supports the findings within study three, with exacerbated ratings of perceived fatigue reported after the 2nd matchday within multi-match weeks, although the recovery time between matches were more similar to that within study two (i.e. between 72 and 96 h) (Howle et al., 2019). In addition, contextual differences between national- and club-football should be considered as factors such as the excessive post-match travel demands, possible differences in training loads post-matchday and/or limited/reduced access to recovery facilities may have influenced the reported findings. Thus, the generalisability of the findings within study two and three is unknown and future research in other national teams over longer tournament periods are warranted.

Underlying the elevations in perceived total fatigue, subjective ratings of fatigue and muscle soreness were the primary perceptual scales contributing to the change in total fatigue within both study two and three (Chapters 4 and 5). This is consistent with previous research in professional club teams that found perceived fatigue and muscle soreness to be responsive to match load (Howle et al., 2019; Thorpe et al., 2016). Furthermore, perceived muscle soreness has been shown to be impaired up to 72h post-match alongside changes in both performance and biochemical measures, suggesting mechanisms of peripheral fatigue are considerable following football competition (Lundberg & Weckström, 2017; Mohr et al., 2016). Inconsistent responses of perceived sleep ratings (quality and duration) to match load across study two and three likely reflect the influence of other match-related factors on sleep ratings, such as match outcome, individual performance, late-night fixtures and possible air travel (Fessi & Moalla, 2018; Fullagar et al., 2016). Nonetheless, day-to-day variances in self-reported sleep duration were evident within the No-Match group in study two, while sleep duration and sleep quality immediately post-match were considerably worse across all groups due in part to late-night fixtures and possible air travel compromising player's sleep patterns.

Despite the apparent responsiveness of ASRM to the acute presence of training/match load, the association between load and 'wellness' in football and other team sports remains equivocal (Campbell et al., 2020, 2021), with contrasting findings depending on the type of load variable measured (i.e. internal or external load) and the method used for calculating load (i.e. previous day load or accumulated load over multiple-days/week) (Moalla et al., 2016; Thorpe et al., 2015; Thorpe, Strudwick, et al., 2017). Within study two, the association between internal match load and the subsequent day perceptual ratings had moderate-to-large positive correlations ($r$ = 0.30–0.68; $p$ < 0.01) for all items, except psychological status. While other studies have typically found negative associations between training load and wellness (Clemente et al., 2017; Thorpe et al., 2015; Thorpe, Strudwick, et al., 2017). This may be due to a methodological difference in the composition of the perceptual rating scales, rather than the actual direction of the relationship, with study two demonstrating that as internal match load increases player's perceptual ratings become worse. These findings align with research by Moalla et al. (2016) who reported similar correlations ($r$ = 0.23–0.48; $p$ < 0.01) between the mean daily internal training load (s-RPE) and subjective ratings of fatigue, muscle soreness, stress, and sleep quality in professional footballers across a period of 16 weeks including both the pre- and in-season. Although, the influence of accumulated training load on perceived fatigue ratings was not examined within this thesis, the lower associations within the study of Moalla et al. (2016) compared to study two follows a similar trend to that found by Thorpe et al. (2015; Thorpe, Strudwick, et al., 2017); whereby the training load of the preceding day was shown to have higher correlations to player's perceived fatigue ratings than the total load accumulated over multiple (2-4) days. Therefore, the use of ASRM to monitor changes in fatigue status of elite footballers is likely most effective when implemented and assessed on a daily basis.

However, recent concerns have been raised relating to the validity and reliability of using single-item and composite scores to measure athlete's training response/status, with these measures unlikely to be influenced by only training and match load (Duignan et al., 2020; Jeffries et al., 2020). For instance, measures of perceived fatigue and muscle soreness were the most strongly associated with internal match load, likely due to the high physical demands of football match-play causing residual post-match fatigue and tiredness (Silva et al., 2018a). While in contrast, sleep quality and sleep duration were less associated to match load, which may be a reflection of their responsiveness to other contextual match factors (i.e. reduced recovery time, increased psychological stress and travel demands) rather than the match load itself. As such, this suggests that ASRM may be more reflective of a complex state of "readiness" than a linear training "response" (Duignan et al., 2020). Perhaps indicative of this notion, the results of the secondary correlation analysis in study two found no significant correlation between any of the perpetual response items and internal match load when the No-Match condition (i.e. players with zero match load) were removed. This indicates that player perceptual responses may be responsive to the presence of match load, but are not likely sensitive enough to smaller variations in load within a homogenous group of players exposed to ≥ 70 minutes of match-play.

In summary, match exposure within both congested and non-congested tournament microcycles was shown to elicit a transient reduction in international footballers perceived fatigue responses. Specifically, measures of perceived fatigue and muscle soreness were found to be the primary perceptual scales contributing to the worsening of total fatigue post-match, and this aligns with previous research in professional club teams (Howle et al., 2019; Thorpe et al., 2016). Furthermore, acute match congestion was found to prolong international footballer's worsened ratings of perceived fatigue following the second matchday within a congested microcycle. While it is unclear as to whether acute match congestion causes an exacerbation in player's perceived fatigue, with the duration between matches likely determining the magnitude of player's impaired subjective ratings.

## 6.4 Perceived recovery and intervention usage in international football tournaments

During international tournaments, national team footballers compete within a concentrated fixture schedule where time for recovery is often limited (Silva et al., 2017). Repeated exposure to matches within such contexts result in an accumulation of training/match load (Chapter 3), which in the absence of sufficient recovery may subsequently result in increased fatigue (Chapter 4), performance decrement or even potential injury risk (Dupont et al., 2010; Ekstrand et al., 2004; Howle et al., 2019). While, effective player rotation may help to reduce the number of players exposed to successive matches, the ability/capacity to a maintain a core group of players throughout these tournaments has been found to positively influence the team's final tournament ranking (Silva et al., 2017). Hence, monitoring recovery and optimising recovery strategies throughout international football tournaments is an important and common process to help ensure that players are adequately recovered before each match (McCall et al., 2015).

Post-match recovery is regarded as a multifaceted restorative process relative to time and characterised by a return to pre-match status of specific performance, physiological and/or perceptual states (Kellmann et al., 2018). In professional football, appropriate recovery between successive matches is suggested to require ≈72-96 h, depending on the physiological/psychological recovery mechanism of interest (Nédélec et al., 2012; Silva et al., 2018a). However, during congested competition fixtures, the high exposure to match load coupled with the condensed time between matches may be inadequate to allow for full recovery (Nédélec et al., 2012). As such, understanding and then augmenting the recovery process is of critical importance to national-team practitioners by means of appropriately selecting and timing effective recovery strategies, as well as, monitoring player's individual recovery response (Field et al., 2021; Nédélec et al., 2013).

The rate of post-exercise recovery is related to the extent of the load imposed on the various physiological and neuromuscular systems by the training and/or match (Minett & Duffield, 2014; Nédélec et al., 2012). Study three (Chapter 5) demonstrated that match exposure during a week of congested international tournament matches produces a transient reduction in ratings of perceived recovery, which return close to pre-match values by ≈48 h post-match. Previous research, using a similar perceptual recovery scale (total quality recovery [TQR]) supports this finding with recovery scores at 48 h post-match relatively unchanged (compared to a pre-season baseline) in professional Australian footballers participating in either single or multi-match weeks (Howle et al., 2019). However, unlike the results in study three, Howle et al. (2019) found a significant decrease in players perceived recovery after the second matchday within the multi-match week group; inferring that players may only start to perceive suppressed recovery when multiple matches have occurred. The contradictions between these findings may in part be due to the contextual differences between club and national-team football, as the previous study included a club team with excessive post-match travel demands. Furthermore, factors like club training programmes with higher post-match training loads or limited/reduced access to recovery facilities must also be considered in domestic Australian clubs (Thorpe et al., 2016; Waterson, 2016). Nevertheless, match exposure during international football tournaments was found to elicit only transient changes in post-match perceived recovery, regardless of whether players participated in single or multiple matches per week.

To maximise the performance capacity of an athlete, an optimal balance between training and recovery is needed to prevent maladaptation to accumulated physiological and psychological stresses induced by training and matches (Meeusen et al., 2013; Soligard et al., 2016). While a significant research focus has been placed on determining and managing player's training load, it is notable that less attention has been given to post-match recovery strategies (Nédélec et al., 2013; Querido et al., 2021). As such, within the context of congested international tournament football, study three demonstrated that player's match exposure influenced the number of post-match recovery interventions used, with higher usage reported by Starters, Rotations, and Consecutive Starters. This finding appears intuitive given that the need for recovery is related to the extent of the load (i.e. high match load) imposed on the various physiological and neuromuscular systems (Nédélec et al., 2012).

While it may be hypothesised that match exposure increases the frequency of post-match recovery interventions usage, study three found that the rate of usage declined at MD+1 within all conditions but most significantly within the Non-Playing group. This may be due to differences in training/recovery periodisation between the groups, as well as contextual factors and travel logistics limiting the aggregated use of recovery strategies immediately post-match (Altarriba-Bartes et al., 2021). For instance, during the $CC_{2017}$ the team travelled immediately post-match, whereas during the $U23AC_{2018}$ all matches were played at the same venue. Furthermore, differences in training/recovery periodisation between the groups also likely contributed to the spike in recovery interventions used by Starters and Consecutive Starters between 24-48h post-match, as starters were assigned a rest day on MD+1 affording them time and preference of recovery modalities (Anderson et al., 2016a). Hence, the nature and use of recovery interventions may be more explained by the variability and scheduling factors than the explicit effectiveness of any interventions.

At present, there is not an agreed holistic approach for post-match recovery monitoring or information regarding habitual recovery monitoring practices in football (Harper et al. 2019). Previous research revealed that cold water immersion/contrast water therapy (88%), active recovery (81%) and massage (78%) to be the most commonly implemented recovery strategies by practitioners within professional French club teams (n=32) (Nédélec et al., 2013). Yet, while club-based footballers have the season-long assistance of support staff and access to recovery facilities/equipment, many national teams may not be afforded such possibilities given various logistical and operational challenges. Despite this, the results of study three are largely consistent with the findings of Nédélec et al. (2013), with massage, sleep/nap and active recovery the top three most commonly used recovery interventions across the tournament week. Furthermore, cold water baths and contrast baths were also heavily used, which when combined would place them among the top three most commonly used recovery strategies. Evidently, recovery strategies aimed at reducing acute inflammation from muscle damage and enhancing its rate of removal are particularly prevalent within both club and national-team football contexts.

The findings within study three also align with the objectives most frequently identified for recovery strategy use in club football teams which were alleviating muscle damage and fatigue," "minimizing injury risk," and "performance optimization" (Field et al., 2021). In particular, immediate post-match recovery strategies focused on reducing acute inflammation (i.e. muscle massage/manual therapy, ice baths, and compression garments) accounted for 70-80% of interventions used by these national team players. However, over the subsequent 24h, a more integrative approach to recovery was observed, with an increased percentage (25-27%) of players utilising sleeping/nap as a recovery strategy; possibly due to the starters not having on-pitch duties and more time to choose preferred recovery methods. The influence of support staff on the provision of recovery strategies should be recognised, whereby post-match information related to maximising use of available facilities and recovery interventions would likely influence many players behaviour and choices about recovery (Crowther et al., 2017; Venter, 2014). Although, it is also important to consider that practitioners may endeavour to execute recovery protocols based on robust scientific evidence, player-related barriers (player compliance and education) may prevent their implementation (Field et al., 2021). This may also explain the change in frequency and type of interventions used over the ensuing days post-match as players were left to their own preferred interventions or time was made available to them to choose based on their personal preferences and availability.

In summary, match exposure during a week of congested international tournament football elicited transient changes in post-match perceived recovery, regardless of whether players participated in single or multiple matches per week. Consequently, the frequency of recovery interventions used was higher post-match for playing groups compared to non-playing, with a higher prevalence of recovery methods targeting physiological recovery mechanisms. This was likely due to the availability and preference for these particular recovery interventions based on the scheduling and logistical contexts. Practitioner provision of recovery modalities may also have influenced player behaviour as to the selection and frequency of recovery intervention used within the national teams. Such considerations should guide resource and practitioner availability to assist with post-match recovery during international tournaments.

## 6.5 Limitations

While the current thesis examined the perceived load, fatigue and recovery profiles of international footballers during major international tournaments, there are several limitations that need to be considered. Firstly, the cohorts used within the studies were sampled from a single national federation, resulting in a similar pool of players selected across tournaments, except for $U23AC_{2018}$ due to age restrictions. As such, the data and findings from these studies are reflective of the paradigms and practices of the national team examined, as well as the inherent fitness and training status of the players. Consequently, generalisation to other national teams or populations may not be appropriate.

Secondly, the outcome measures (e.g., internal load, perceived fatigue/recovery, and self-reported recovery intervention usage) within each of the studies were predominantly analysed and presented as mean differences between groups/conditions. Therefore, caution should be taken if applying these findings at the individual level (McCall et al., 2015).

Thirdly, training and match load quantification throughout the studies centred on measurement of internal load (s-RPE) in the absence of more objective external load metrics. While s-RPE is a widely applied method in professional football (Akenhead & Nassis, 2016; Impellizzeri et al., 2004), it is characterised as a global measure of internal load, indiscriminate to the contribution of physiological, biomechanical, and psychological factors (Brito et al., 2016; Nassis et al., 2017). Thus, an advantage of having greater or additional information on external load is that this provides a clear understanding of the physical work done by the players, which may allow for more precise prescription/planning of training. Furthermore, the uncoupling between internal and external load may be used to identify how a player is coping with the demands of training and match schedule (Halson, 2014; Impellizzeri et al., 2019).

Lastly, the use of subjective measures of fatigue and recovery provides a limited understanding of international footballer's response to tournament training and matches, with the addition of more diverse measures (i.e. performance, strength, neuromuscular and/or biochemical parameters) likely to provide a more holistic understanding of players' fatigue. Furthermore, concerns remain over the validity and reliability of using single-item self-report measures to assess athletes' responses to training and competition (Duignan et al., 2020; Jeffries et al., 2020). As such, researchers and practitioners should consider the measurement properties of single-item self-report measures and aim to establish their relationship with more clinically meaningful outcomes (Duignan et al., 2020).

# Chapter 7: Conclusions and Practical Applications

## 7.1 Thesis aims

Previous research has reported the training load and fatigue/recovery responses of professional footballers in club environments, with very few studies conducted within national-team contexts. However, despite the limited published evidence, the anecdotal perceptions of practitioners operating within national teams report the prevalent use of fatigue-related monitoring tools during international tournaments (McCall et al., 2015). Thus, it is important to describe the training and match load demands of international footballers during tournaments, and how variations in match congestion may influence players' match load and their subsequent fatigue and recovery response.

This thesis provides an initial and detailed description of international footballers' training load, fatigue and recovery profiles during international football tournaments. Specifically, Chapter 3 (study one) examined the training load profiles of international footballers as they transitioned from club-to-camp-to-tournament contexts, with previous evidence only available on the transition from clubs to training camp (McCall et al., 2018a). Subsequently, Chapter 4 (study two) and Chapter 5 (study three) determined the effect of match load on international footballers' self-reported fatigue and recovery profiles during congested and non-congested tournament microcycles. Findings from Chapter 4 (study two) and 5 (study three) fill a gap in the literature, with previous evidence of footballers perceived fatigue and recovery response to standard (Rowell et al., 2017; Thorpe et al., 2015, 2016) and congested (Howle et al., 2019; Lundberg & Weckström, 2017) match schedules only available within club-based contexts. Additionally, Chapter 5 (study three) provided the first description of international footballers' self-reported usage of recovery interventions during major international tournaments, with variances in usage examined based on match status. By examining the internal load and perceived fatigue and recovery profiles of international footballers over multiple international tournaments, a detailed case study of player monitoring practices was presented. Hence, these findings may enable prospective qualifying teams to better prepare and monitor their players to ensure that they can cope with the demands associated with international football tournaments.

## 7.2 Key findings

The key findings from this thesis are:

- During the transition between club and camp, international footballers experienced an increase in internal load and A/C ratio, resulting from a large increase in training session count rather than training intensity.
- During the transition between camp and in-tournament, a counterbalance in training and match load was evident, with large increases in match volume and internal match load offset by very large decreases in training volume and training load.
- During international tournaments, exposure (or lack thereof) to match play largely determined the variation in match load profiles between match congestion conditions, with players exposed to >70min playing time reporting lower training loads over the ensuing days post-match compared to non-playing conditions.
- The association between match-day load and the subsequent post-match perceived fatigue response had moderate-to-large positive correlations for all perceptual items, except psychological status. However, when data from non-playing conditions are excluded (i.e. only players exposed to match load were analysed) then no significant correlations were found between any of the perceived fatigue items and match load.
- Exposure to >70mins match-play elicited a worsened perceived fatigue and recovery response compared to non-playing players 24h post-match, with a prolonged impairment of perceptual fatigue items also observed 48h post-match. Specifically,

the primary perceptual scales contributing to the worsening in perceived total fatigue were perceived fatigue, muscle soreness and to a lesser extent sleep duration.

- Repeated exposure to match play during acute match congestion (<96h between matches) elicited a consistent trend of worsened perceived total fatigue compared to non-congested conditions. However, mixed findings were found as to whether acute congestion exacerbated player's perceived fatigue response on the second matchday within a congested week, with differences in the duration between matches (i.e. 72 or 96h) contributing to this uncertainty.
- During congested international tournament weeks, players exposed to match load (Consecutive Starters, Starters, and Rotations) reported significantly higher post-match recovery intervention usage than non-playing players, with the most significant spike in usage between 24-48h post-match.
- The most used recovery interventions across the tournament weeks were massage/manual therapy (24%), sleep/nap (22%), and active recovery (13%). Within the first 24h post-match, the most used recovery interventions were massage/manual therapy (29-33%), compression garments (24-25%), and ice baths (16-18%).

## 7.3 Practical applications

From the findings in the present thesis, several practical implications are derived for player monitoring practices in national-team contexts. While these findings are discussed from the perspective of informing national-team practitioners, the implications may also be of interest to club practitioners wishing to understand the demands of international football on their players. Indeed, given the challenges associated with monitoring players transitioning from club to national teams (and conversely), establishing a collaborative and transparent approach between staff would likely improve overall player monitoring, which in turn can only have a positive impact on each team's performance (Buchheit & Dupont, 2018).

- Prior knowledge of the players' club-based training loads may be useful to national team practitioners to help plan and manage camp and tournament training according to the players' individual load and recovery needs. Simple measures of load (i.e. s-RPE, training and match exposure) can be applied as an easy and cost-efficient method to continuously monitor their players during the transition between club and national team environments.
- Evaluating international footballers training and match loads during the transition between club and national teams. However, caution is advised to practitioners intending to utilise the A/C ratio to provide training recommendations aimed at modifying load to reduce injury risk (Impellizzeri et al., 2020). This advice is predicated on recent conceptual and methodological (Lolli et al., 2019) criticisms that suggest the A/C ratio is an inaccurate metric that can lead to inappropriate training recommendations because its causal relation to injury has not yet been established (Impellizzeri et al., 2021; Impellizzeri, McCall, et al., 2020; Impellizzeri, Tenan, et al., 2020). Alternatively, practitioners should rely on traditional training principles such as progressive overload to appropriately align players' club and camp training loads, whilst also adjusting individual load based on the players' responses.
- During international football tournaments, national team practitioners should monitor players exposure to matches, as well as their day-to-day changes in perceived fatigue and recovery status to help determine their match readiness and preparedness. Measurement of internal training and match loads (i.e. s-RPE load) is also suggested, despite Study 2 and 3 showing similar load profiles between playing groups regardless of the existence or absence of match congestion.

- Practitioner provisions of recovery modalities within the first 24h post-match should look to target physiological recovery mechanisms, such as reduced inflammation, before taking a more holistic approach to recovery. Furthermore, national-team practitioners should be mindful of the influence that they have on their players' recovery intervention choices, with key information emphasised such as maximising the use of available interventions within the 24-48h post-match.

## 7.4 Future research

While the current thesis provides novel findings within the context of national-team football, further and more comprehensive studies are required to increase the understanding and practical applications in this area. Thus, recommendations for future research related to the findings from the current thesis should look to examine:

- The external load profiles of international footballers as they transition from club to national teams, as well as during international tournaments. The inclusion of objective external load measures would likely provide a broader and more detailed understanding of international footballers' training and match loads. However, this process would likely require a collaborative exchange of GPS data between national team staff and numerous professional clubs, which may be complicated by the lack of comparability between data providers/devices and the types of external load metrics measured (Buchheit & Dupont, 2018).
- The validity of monitoring athlete self-report measures in relation to both internal and external load metrics, as well as clinically meaningful outcomes (i.e. injury/illness). Despite the widespread use of athlete self-report measures in elite football, concerns remain over the validity of using multi-item and single-item self-report measures to assess athlete's response to training and competition (Duignan et al., 2020; Jeffries et

al., 2020). Specifically, it has been recommended that researchers and practitioners examine the responsiveness of athlete self-report measures to known training stressors (i.e. matches or difficult training sessions) to support the validity of evaluating within-athlete changes (Windt et al., 2019).

- A multi-variable approach to fatigue and recovery monitoring in international footballers, given that the mechanisms that drive these phenomena are multifaceted and often differ in relation to their time-course changes (Lundberg & Weckström, 2017; Mohr et al., 2016).
- The efficacy of recovery interventions during congested tournament schedules. While Study 3 demonstrated that international footballers utilise many and often multiple combinations of recovery interventions, there is limited scientific about the effectiveness of these modalities. To determine the efficacy of recovery interventions within a national team context, an experimental approach similar to Bahnert (2012) could be used, in which the associations between the recovery modalities chosen by international footballers and their subsequent physical and/or perceptual recovery is assessed.

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# Appendices

# Appendix 1: Human Research Ethics Approval

Dear Applicant

Thank you for your response to the Committee's comments for your project titled, "Load, Recovery and Injury in Professional Football players". 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. 2014000355 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, 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
T: (02) 9514 9772
F: (02) 9514 1244
E: Research.Ethics@uts.edu.au
I: http://www.research.uts.edu.au/policies/restricted/ethics.html
P: PO Box 123, BROADWAY NSW 2007

## Appendix 2: Letter of Intent for a Data Confidentiality Agreement

Football Federation Australia
Dr Mark Jones
Football Federation Australia
Level 22, 1 Oxford St, Darlinghurst NSW 2010

Date
14.09.2017

**Letter of Intent for a Data Confidentiality Agreement**

Dear Dr Mark Jones,

I am writing to inform you of my acknowledgment that as part of the proposed research project "Monitoring of Fatigue and Recovery in National Football Teams", data provided by FFA Medical and Sports Science staff containing personal information of Australian national team football players will be treated with strict confidentiality and anonymity.

I acknowledge that the data will be used as part of a research project to inform FFA, to be used in my PhD and eventually published provided player anonymity is ensured. Associate Professor Rob Duffield will directly oversee the research project as one of my University supervisors as well as, his position as Research & Development Coordinator within the FFA.

I understand that I will have access to confidential information on players selected to represent the Australian National Football Team at the 2014 FIFA World Cup, 2015 AFC Asian Cup, and 2017 FIFA Confederations Cup. As a member of the research group, I undertake

i. to take all possible steps to preserve strict confidentiality regarding any information to which I have access through my work.

ii. never to pass any information obtained as part of the research to anyone outside the research group, unless I have been directed to do so by Dr Mark Jones (Head of FFA Medical), with appropriate explanations for doing so.

iii. to keep all names, contact details and personal information of research participants secure.

I understand that any breach of the above will result in disciplinary action and FFA revoking the right for me to use this data.

I look forward to our successful collaboration.

Kind regards,

Production Note:
Signature removed prior to publication.

Mr Denny Noor

PhD Candidate
Saarland University & University of Technology Sydney
Address: [redacted]
Mobile: +49 [redacted]
Email: [redacted]@uni-saarland.de

# Appendix 3: Letter of Approval for a Data Confidentiality Agreement

FOOTBALL
FEDERATION
AUSTRALIA

14 November 2017

University of Technology Sydney
Broadway Campus, Sydney

To Whom It May Concern,

As Head of Medical for Football Federation Australia, this document serves as an approval letter for Denny Noor to conduct research using National Team training load, fatigue and recovery data obtained by Football Federation Australia. Approval is granted on the condition that participant and club anonymity is maintained and reasonable measures are taken to keep confidentiality of medical information.

If you have any queries please feel free to contact me at Mark.Jones@ffa.com.au

Yours Sincerely,

Production Note:
Signature removed
prior to publication.

Dr Mark Jones

**Head of Medical Services**

**Football Federation Australia**