

# **Monitoring athlete preparedness in professional Australian football: load, self-report measures and performance**

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## THESIS DECLARATION

This thesis contains no material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma. No parts of this thesis have been submitted towards the award of any other degree or diploma in any other tertiary institution.

No other person's work has been used without due acknowledgment in the main text of the thesis.

All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committee (where required).

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Tania Gallo

## STATEMENT OF AUTHORSHIP AND SOURCES

*Principal Supervisor:* Dr Christian Lorenzen

*Co-supervisors:* Dr Stuart Cormack & Dr Tim Gabbett

This thesis was possible with the guidance and support of my supervisory team. Dr Chris Lorenzen, Dr Stu Cormack and Dr Tim Gabbett provided intellectual input into the inception of the research questions and study designs. Interpretation of results was influenced by their critical reasoning and recurring dialogue. The proof-reading and contribution of Drs Lorenzen, Gabbett and Cormack to each of the manuscripts and other chapters was integral in the preparation of this thesis.

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## **List of Publications Contributing to Thesis**

### **ACCEPTED MANUSCRIPTS**

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2. Gallo, T., Cormack, S. J., Gabbett, T. J., & Lorenzen, C. (2015). Pre-training self-reported wellness impacts training output in Australian footballers. *Journal of Sports Sciences*. doi: 10.1080/02640414.2015.1119295 (IN PRESS).

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## CONFERENCE PRESENTATIONS

1. Gallo, T., Cormack, S., Gabbett, T., Lorenzen, C. External and internal training load in Australian Footballers. *European College of Sport Science*. Barcelona, 2013.

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## List of Abbreviations and Nomenclature

acute <sub>all</sub>	overall acute load
acute <sub>field</sub>	field-based acute load
AF	Australian football
AFL	Australian Football League
chronic <sub>all</sub>	overall chronic load
chronic <sub>field</sub>	field-based chronic load
CI	confidence interval
CL	confidence limits
CMJ	counter-movement jump
CR-10	category-ratio scale of 0–10
<i>d</i>	Cohen's effect size
DALDA	daily analysis of life demands for athletes
GPS	global positioning system
HR	heart rate
HSR	high speed running
iTRIMP	individualised TRIMP
OR	odds ratio
PCA	principal components analysis
PL	Player load <sup>TM</sup>
PL <sub>slow</sub>	Player load slow <sup>TM</sup>
POMS	profile of mood states
<i>r</i>	Pearson's correlation coefficient
RESTQ-Sport	recovery-stress questionnaire
RPE	rating of perceived exertion
s-RPE	session RPE
TE	typical error of measurement
TRIMP	training impulse

TRIMP <sub>MOD</sub>	modified TRIMP
TSB	training-stress balance
TSB <sub>all</sub>	overall TSB
TSB <sub>field</sub>	field-based TSB
VHSR	very high speed running
$\dot{V}O_{2max}$ volume	of maximal oxygen consumption
Yo-Yo IR	yo-yo intermittent recovery test
%TEM	typical error as a % coefficient of variation

## Abstract

Monitoring athlete preparedness, including quantifying training and competition load and determining fatigue/training status, is used to complement training and recovery prescription in professional sport (Kenttä & Hassmén, 2002). The overall objective of this research was to investigate contemporary athlete monitoring practices in professional Australian football (AF).

The aim of study 1 was to identify the relationship between external training load and session rating of perceived exertion (s-RPE) training load and the impact that playing experience, playing position and 2-km time-trial performance had on that relationship. Microtechnology devices provided external training load (distance, mean speed, high-speed running distance, Player load<sup>TM</sup> (PL), and Player load slow<sup>TM</sup> (PL<sub>slow</sub>)). The external training load measures had *moderate* to *very large* associations with s-RPE training load. When controlling for external training load, the 4- to 5-year players had a *small* increase in s-RPE training load compared to the 0- to 1- and 2- to 3-year players. Furthermore, ruckmen had *moderately* higher s-RPE training load than midfielders, and there was a 0.2% increase in s-RPE training load per 1 s increase in time-trial time.

The aim of study 2 was to profile weekly wellness within the context of the competitive season of professional AF. Each morning before any physical training, players completed a 5-item customised self-report questionnaire (sleep quality, fatigue, stress, mood, and muscle soreness), with the mean of the individual indices used to determine overall wellness. Internal match load (s-RPE), match-to-match micro-cycle length, stage of the season and internal training load were included in multivariate linear models in order to determine their effect on weekly wellness profile. There was a lower weekly training load on a 6-day micro-cycle (mean  $\pm$  s = 1813  $\pm$  291 au) compared to a 7- (1898  $\pm$  327 au, *likely small*) and 8-day (1900  $\pm$  271 au, *likely small*) micro-cycle. Match load had no significant impact on weekly wellness profile, whilst there was

an interaction between micro-cycle and days-post-match. There was *likely* to be a *moderate* decrease in wellness Z-score 1 d post match for an 8-day micro-cycle compared to a 6- and 7-day cycle. There was *possibly* a *small* reduction in overall wellness Z-score in the second half of the season compared to the first half of the season. Finally, training load had no effect on wellness Z-score when controlled for days-post-match, micro-cycle and stage of the season.

The aim of study 3 was to assess the application of athlete self-report measures to prompt modifications to training dose by exploring its association with subsequent activity profiles. The impact of perceived wellness on a range of external load parameters, RPE and external load: RPE ratios, was explored during skill-based training in AF. Mixed-effect linear models revealed significant effects of wellness Z-score on PL and PL<sub>slow</sub>. A negative wellness Z-score corresponded to a *small* reduction in PL and a *moderate* reduction PL<sub>slow</sub>, compared to those without reduced wellness. A *small* reduction was also observed in the PL<sub>slow</sub>: RPE ratio models, while a *small* increase was seen in mean speed: RPE ratio.

The aim of study 4 was to corroborate the use of particular contemporary monitoring measures by examining their effect on individual match performances. The effects of internal load parameters, combined with athlete self-reported wellness, on subjective and objective measures of match performance in 20 rounds of professional AF was examined. Acute weekly internal load (s-RPE) was determined for each independent training modality. Chronic load was calculated as the rolling 4-week mean and a training-stress balance (TSB) was ascertained by dividing the acute load (1-weekly total) by the chronic load (4-week mean) expressed as a percentage. Load from every training modality was used to calculate an overall acute load, overall chronic load, and overall TSB and only outdoor skills and conditioning sessions were used to calculate a field-based acute load, a field-based chronic load and field-based TSB. Weekly wellness was quantified as the mean of the overall daily wellness scores. An iterative



linear mixed modelling approach demonstrated that load and wellness variables had minimal impact on subjective performance ratings (coaches' votes). Conversely, objective performance, measured via Champion Data© ranking points was positively associated with load, although the magnitude of this effect was greater for field-based loads compared to overall loads. Furthermore, athletes with high loads reporting low wellness, ranked better in objective performance than those reporting high wellness with high loads. Alternatively, an increase in wellness was associated with better objective performance when accompanying lower loads.

This collection of studies suggests that s-RPE has a strong relationship with measures of external load, which is moderated by playing position, experience and time-trial performance in AF and that coaches and sport scientists should give consideration to these mediators of s-RPE. It was also revealed that the weekly profile of self-reported wellness in response to matches was influenced by the match-to-match micro-cycle and stage of the season in AF. However, when factoring in these conditions, training load had minimal influence on wellness profile. As such, determination of 'red flags' in self-reported measures should be made against comparative weeks. Furthermore, pre-training self-reported wellness was shown to be associated with accelerometer-derived external load measures, suggesting an altered movement pattern during diminished training states. Understanding the changes in external load that might be produced, relative to the pre-training self-reported wellness, provides coaches with an opportunity to adjust prescription if warranted. Finally, the use of internal load and athlete self-report measures can be corroborated based on their relationship with an objective measure of performance in AF and the importance of a mixed-method approach to comprehensively assess athlete status is emphasised.



## Chapter 1. Introduction and Overview

In professional sport, the goal of a training program is to improve performance, which is ultimately measured by the number of competition wins. Although success in team sports is dependent on a range of factors such as, squad management, opposition, tactics, skill execution, and decision-making, the role of a conditioning coach or sports scientist is to optimally prepare athletes for competition. Intense physical training to stimulate adaptation, coupled with appropriate recovery, is essential to maximise preparedness and performance (Bompa & Haff, 2009; Meeusen et al., 2006). An insufficient training dose will fail to elicit adaptation for improved physical capacity while a training stress that is excessive (with inadequate recovery) will lead to reduced performance potential (Kreider, Fry, & O'Toole, 1998). A complex interaction of additional factors (e.g. exercise capacity, recovery potential, non-training stressors, and stress tolerance) will impact this balance and, indeed, variation between and within individuals will exist (Banister & Calvert, 1980; Lehmann, Foster, & Keul, 1993). Therefore, it is vital that an effective system is in place that assists appropriate training and recovery prescription (Hooper & Mackinnon, 1995).

Contemporary monitoring of athlete preparedness, including quantifying training and competition doses and determining fatigue/training status, is commonly implemented in elite and sub-elite sporting environments, with research into evidence-based models regularly emerging (Akenhead & Nassis, 2015; Borresen & Lambert, 2009; Coutts & Cormack, 2014; Coutts, Wallace, & Slattery, 2007; Halson, 2014; Hooper & Mackinnon, 1995; Saw, Main, & Gastin, 2015a; Twist & Highton, 2012). Specific to contemporary monitoring systems, Kenttä and Hassmén (2002) defined three important phases for consideration: (1) identifying the stimulus (2) the perception of the stimulus; and (3) the response to the stimulus. Employing such a system necessitates valid and reliable methods that quantify load to identify the stimulus,

assess an athlete's perception of the stimulus and a tool to monitor the response to that stimulus. Although considerable research into contemporary monitoring practices exists, gaps in the literature at each of these three phases of athlete monitoring remains. In particular, the measurable influence that monitoring practices have on match performance in team sport is vastly unexplored (Aughey, Elias, Esmaceli, Lazarus, & Stewart, 2015).

External exercise load (*i.e.* the physical output), and internal exercise load (*i.e.* the psychobiological response experienced by the athlete), are recognised as relevant components of dose quantification (Impellizzeri, Rampinini, & Marcora, 2005). A selection of methods for quantifying external (e.g. distance run) and internal (e.g. rating of perceived exertion) exercise loads are prominent throughout the literature (Akubat, Patel, Barrett, & Abt, 2012; Borresen & Lambert, 2008, 2009; Coutts & Sirotic, 2007). Since it is the internal training load that elicits adaptation, it has been suggested that although successful performance relies on an absolute external load being reached, internal load should be used when monitoring an athlete's response (Impellizzeri et al., 2005; B. R. Scott, Lockie, Knight, Clark, & Janse de Jonge, 2013). Perhaps the most commonly used method of internal load quantification because of its simplicity, the session-RPE (s-RPE) method has been extensively used in research since the early 2000s (Coutts, Murphy, Pine, Reaburn, & Impellizzeri, 2003; Foster et al., 2001; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004). Considered one of the features of s-RPE measure, the global, perceptual nature of the measure, makes planning and periodising training using s-RPE impractical in team sport. This is because training typically occurs as a collective and is most commonly designed using external load measures such as session duration or running doses (Impellizzeri et al., 2004; Lambert & Borresen, 2010; Manzi et al., 2010). As such, the ability to adjust the internal load an athlete will experience depends on understanding the internal load a given external load will elicit. There is accumulating research examining the relationship between external and internal parameters, with an awareness that individual factors

will moderate this relationship (Casamichana, Castellano, Calleja-Gonzalez, San Román, & Castagna, 2013; Gaudino et al., 2015; Lovell, Sirotic, Impellizzeri, & Coutts, 2013; B. R. Scott et al., 2013). However, evidence of the specific characteristics that might influence this relationship in a high-intensity, intermittent collision sport such as Australian Football (AF) is lacking. Establishing the impact that easily identifiable individual characteristics have on the relationship between external and internal training load would encourage coaches to consider these factors when prescribing and/or monitoring training loads and advance training design.

Once training is planned, prescribed and quantified, monitoring the athlete's response to that training is an imperative component of a valuable contemporary monitoring system and the use of psychometric inventories as markers of athlete training status is well established. Professional-sport practitioners commonly incorporate customised athlete 'self-report' measures into their monitoring practices (Coutts & Reaburn, 2008; Hooper, Mackinnon, Howard, Gordon, & Bachmann, 1995; Main & Grove, 2009; Meeusen et al., 2006; Morgan, Brown, Raglin, O'Connor, & Ellickson, 1987; Saw, Main, & Gatin, 2016). Research that is focussed on the validity and sensitivity of these measures in response to exercise load is gaining support (Bahnert, Norton, & Lock, 2013; Gatin, Meyer, & Robinson, 2013; Mclean, Coutts, Kelly, McGuigan, & Cormack, 2010; Montgomery & Hopkins, 2013). A range of studies in team sport describe decreases in perceived wellness following matches and steady improvements in subsequent days (Gatin, Meyer, et al., 2013; Mclean et al., 2010; Montgomery & Hopkins, 2013; Thorpe et al., 2016). In rugby league, at 2 d post match, there was significantly better overall wellness for a 5-day micro-cycle than a 7- or 9-day cycle, suggesting that wellness profiles differ according to length of match-to-match micro-cycle. It appears that days-to-game may be an important predictor of self-reported responses with perceived wellness improving as game day approaches (Gatin, Meyer, et al., 2013). During an intensified training camp for Australian footballers overall self-reported wellness was sensitive

to subtle changes in the previous days training load (Buchheit, Racinais, et al., 2013), although training load appeared to have no contribution to perceived muscle soreness in the days following an AF match (Montgomery & Hopkins, 2013). Evidently the typical profile of wellness responses is yet to be established, and further insight into how self-report measures respond to match and training load, relative to conditions within the competitive season, is still needed.

The final phase of a successful monitoring system, is the ability to modify/adjust planned training according to an athlete's current fatigue/training state. The validity and sensitivity of self-report measures has prompted suggestion that exercise prescription can be tailored using these questionnaires (Saw, Main, & Gatin, 2015b). However, in order to assess the capacity of self-report measures to influence training load adjustments, examination of the relationship between self-report measures and subsequent exercise output is warranted. One study reported that RPE was not affected by perceived wellness during submaximal exercise in soccer players (Haddad et al., 2013). However, the submaximal aerobic exercise used in that study was vastly different from the type of skill-based training comprising of small-sided games and match-play practice, which is a large proportion of training in team sports such as AF (Gabbett, Jenkins, & Abernethy, 2009). If the impact that perceived wellness has on external load parameters and their relationship with RPE was known, coaches may be able to better understand the training response a planned session might elicit in their athletes. The current research will contribute to the existing body of knowledge by establishing if indeed pre-training self-reported wellness impacts subsequent activity profile in skills-based training.

Since the goal of a training program is to improve performance, an understanding as to how contemporary athlete monitoring relates to match performance is essential. The complex interaction between components that determine preparedness and the difficulty of quantifying

both preparedness and match performance impede such research in team sport, with few studies examining individual components of contemporary monitoring with performance (Aughey et al., 2015; Cormack, Mooney, Morgan, & McGuigan, 2012; Gastin, Fahrner, Meyer, Robinson, & Cook, 2013; Mooney, Cormack, O'Brien, Morgan, & McGuigan, 2012). Specific research on the dose-response relationship between s-RPE and performance in Australian football (AF) has only recently been explored (Aughey et al., 2015). It was found that weekly load was likely greater preceding wins compared to losses even when controlled for ladder position of the opposition (Aughey et al., 2015). However, given the multitude of factors that contribute to winning a match in AF, using win/loss as the performance outcome measure has the potential to conceal individual performance responses to training load. In a full AF season, it was shown that neuromuscular fatigue, may have a one to two match delayed impact on coaches ratings of performance (Cormack, Newton, McGuigan, & Cormie, 2008). While neuromuscular fatigue did not affect external match output variables, there was a negative effect on the relationship between Player load<sup>TM</sup> and subjective performance (coaches ratings), suggesting that a change in mechanical efficiency (increase in lateral movements) might result in altered movement patterns that produce the same global player output, but are seen negatively by coaches (Mooney et al., 2012). Research supporting or opposing the use of specific measures based on their effect on match performance in team sport is minimal (Aughey et al., 2015; Cormack et al., 2012; Filaire, Bernain, Sagnol, & Lac, 2001; Mooney et al., 2012).

## **OBJECTIVES**

The overall objective of this research was to investigate contemporary athlete monitoring practices in professional Australian football. Specifically, the first aim was to enhance the application of load quantification by identifying characteristics which might impact the relationship between external and internal load. A second aim was to provide insight into customised athlete self-report measures as a tool to monitor an athlete's training response, by

profiling weekly self-reported wellness relative to conditions within the competition phase of the season. A third aim was to assess the application of athlete self-report measures to prompt modifications to training load by exploring their association. The final aim was to provide evidence-based research to corroborate the use of particular contemporary monitoring measures by examining their effect on individual match performance.

## **RESEARCH QUESTIONS**

The collection of independent but related studies that comprise this thesis aimed to answer the following research questions: synopsis

- (1) a) What is the relationship between external and internal (session rating of perceived exertion) load in a high-intensity, intermittent collision sport?  
b) Do the identifiable characteristics of playing position, experience and time-trial performance impact this relationship?
- (2) a) What is the weekly profile of athlete self-reported wellness relative to internal match load, match-to-match micro-cycle, or stage of the season?  
b) Does additional training load further influence the weekly profile of self-reported wellness?
- (3) What is the association between pre-training athlete self-reported wellness and subsequent external exercise output in skill-based training?
- (4) How do parameters of contemporary monitoring practices (load and self-reported wellness) affect individual athletes' objective and/or subjective match performance?



## **Chapter 2. Literature Review**

### **2.1. Synopsis**

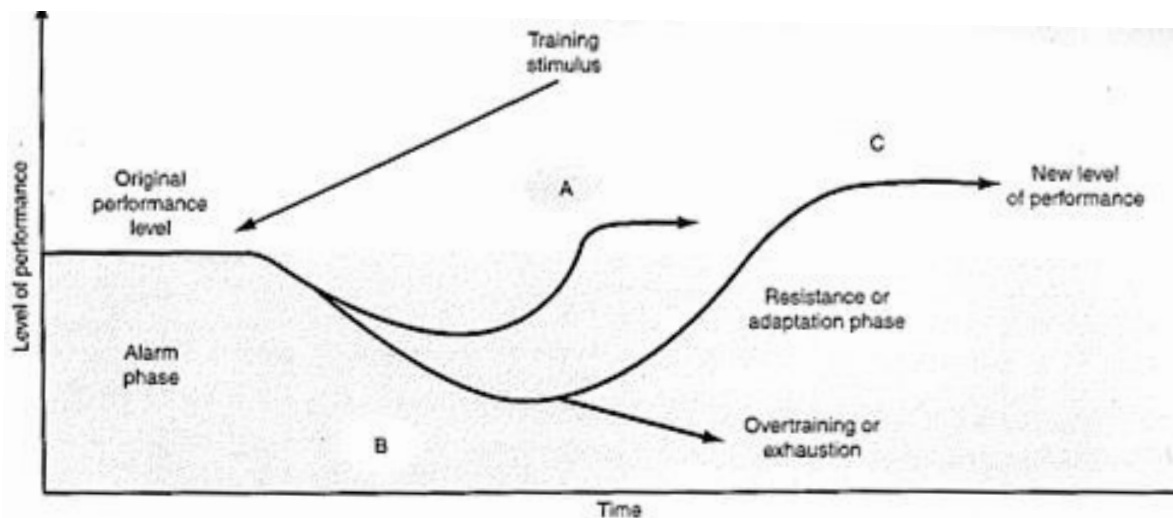
This review considers research literature relating to monitoring athlete preparedness by quantifying exercise load and determining training status. Particular attention is given to research assessing the interaction of load parameters, markers of training status and performance. Theories surrounding training to enhance physical condition are deliberated to highlight the sensitive balance between the stress and recovery required for an effective training adaptation. Protocols for reducing the likelihood of a negative consequence from training are discussed, with specific emphasis on contemporary approaches for monitoring athlete preparedness. Load quantification is then evaluated, considering the literature on both external and internal load parameters. Practices for determining fatigue and training status are reviewed including objective and subjective methods, with particular attention to athlete self-report measures. Finally, research on the direct relationship between contemporary monitoring and match performance in team sport is assessed. To provide pertinent background for the subsequent work in Australian Football (AF), there is a focus on literature specifically in team sport.

### **2.2. Training for Optimal Physical Condition**

#### **Theories of training**

Physical capacity can be improved by means of the biological adaptation feature common amongst living species' (Bompa, 1983). Stress, defined as a destabilisation from the norm in a biological system, stimulates adaptive responses to restore homeostasis beyond recovery until overcompensation (also referred to as super-compensation) is attained (Selye, 1956; Viru, 1984). Selye (1956) described this as the general adaptation syndrome, where a stressor results in a sequence of responses (Figure 2-1). The initial response is a negative 'alarm stage' where

the physiological state is diminished (fatigue). With adequate recovery, there is a positive resistance response where regeneration occurs, resulting in a super-compensation effect (fitness) (Bompa, 1983; Budgett, 1990; Matveyev, 1981; Morton, 1997). However, if the stress is greater than the organisms' adaptive capabilities, exhaustion occurs. The response phase is considered to be proportionate to the magnitude of the stimulus, and with sufficient regeneration, leads to an improved condition.



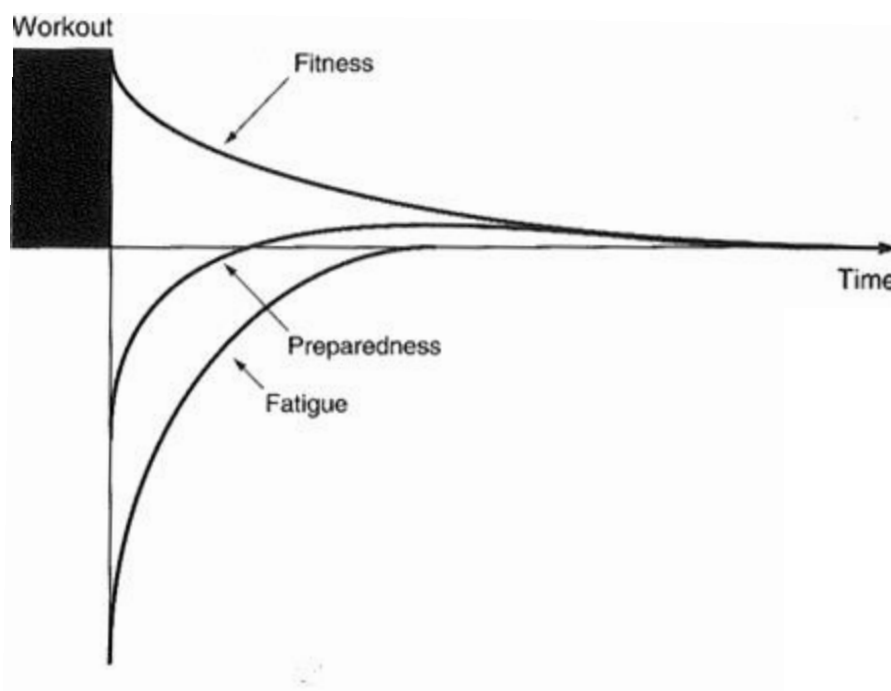
**Figure 2-1** Selye's General Adaptation Syndrome (G.A.S.) Theory.

A= typical training; B= overtraining; C= overreaching or super-compensation

From Bompa, T. O., & Haff, G. G. (2009). *Periodization: theory and methodology of training* (5 ed.). IL: Human Kinetics.

An expansion upon this theory is the Fitness-Fatigue Model (Figure 2-2). Banister and colleagues (1975) proposed that performance could be determined from the interaction of fitness and fatigue. They contended that an exercise stimulus induces two responses, indicated by a positive (fitness) and negative (fatigue) function. However, these responses differ in magnitude and duration; fitness having a smaller magnitude but longer duration (Zatsiorsky & Kraemer, 1995). Provided enough time is given for the negative effect of fatigue to subside between exercise bouts, the cumulative fitness effects of long term training will lead to improved physical capacity (Bompa & Haff, 1999). It has also been proposed that there are

fitness and fatigue effects on more than one system of the body (Chiu & Barnes, 2003). Specific stimuli will have different fatigue responses (e.g. musculoskeletal, metabolic, and immunological) and it is the summation of the after-effects of fitness and fatigue on all of these systems that ultimately represents preparedness (i.e. physical capacity). While the individual fitness and fatigue after-effects are independent, attention must be paid to the potential combined effect. A review by Borresen and Lambert (2009) discusses various mathematical models developed (see section 2.3) to explain these physiological responses to a given training stimulus (Banister et al., 1975; Busso, Carasso, & Lacour, 1991; Morton, Fitz-Clarke, & Banister, 1990).



**Figure 2-2** Two-factor theory (model) of training.

The immediate effect of a training session is characterised by the joint action of two processes, fitness and fatigue. Athlete preparedness improves because of fitness gain and worsened because of fatigue.

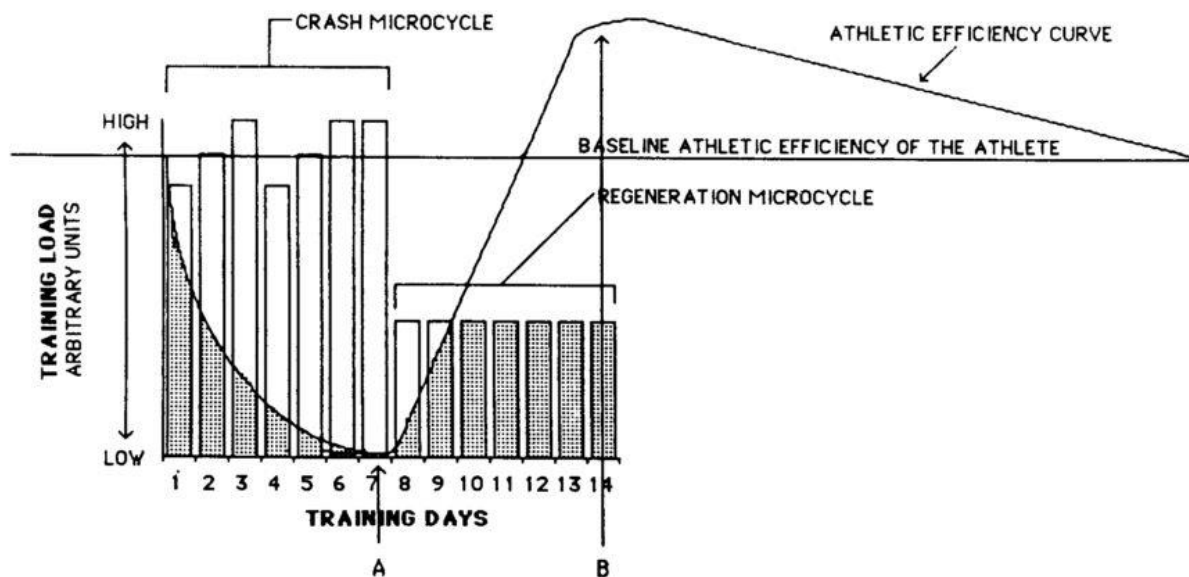
From Zatsiorsky, V. M. (1995). *Science and practice of strength training*. Champaign, IL: Human Kinetics.

It is clear that inducing fatigue via physical training is necessary for enhanced physical performance capacity, provided periods of recovery are sufficient to allow regeneration to occur (Budgett, 1990; Coutts, Reaburn, Piva, & Murphy, 2007; Halson & Jeukendrup, 2004; Koutedakis, Budgett, & Faulmann, 1990; Meeusen et al., 2006). This is the process of overload training (Richardson, Andersen, & Morris, 2008), of which the key to successful physical improvement is the sensitive manipulation of training stress and recovery (Bompa & Haff, 1999; Kellmann, 2002c, 2010). If a training stress is inadequate, there will be no fitness after-effect and athletes will fail to improve their physical condition; whereas a training stress that is too high, and/or with insufficient recovery, will have the negative effects of fatigue accumulation, and over time will lead to reduced performance potential (Busso, 2003; Kreider et al., 1998). This provides a challenge for sport scientists, coaches, and conditioning staff - to prescribe the right individual dose of training, complemented with a proportionate amount of recovery.

### **Overreaching and overtraining**

A common error leading to a negative training state in physical training programs is failure to include adequate recovery (Fry, Morton, & Keast, 1991; Kenttä & Hassmén, 1998). In elite sport, the mentality to work harder and do more to get 'fitter' leaves athletes and coaches responding to a performance plateau by increasing training loads (i.e. duration, intensity and frequency of training), arousing extensive interest in the concept of overtraining (Alves, Pena Costa, & Samulski, 2006; Fry et al., 1991; Halson & Jeukendrup, 2004; Lambert & Borresen, 2006). However, the continuous nature and unclear turning point between the positive (performance enhancement) and negative (performance decrement) aspects of overtraining results in indistinct concepts, and separating the cause/process (i.e. training stimulus) from the consequence (i.e. outcome state) is necessary (Fry et al., 1991; Hackney, Pearman, & Nowacki, 1990; Kuipers & Keizer, 1988; Morgan et al., 1987).

With the expressed need for an international standard definition of overtraining, a consensus statement from the European College of Sport Science provides some guidance regarding terminology (Meeusen et al., 2006). For the context of this review, overtraining (the process) is used to describe an imbalance between stress (training and non-training) and recovery (Lehmann, Foster, Gastmann, Keizer, & Steinacker, 1999; Mackinnon, 2000; Richardson et al., 2008). Successful application of overtraining, deliberately aiming to stimulate physiological adaptations is considered functional overreaching (outcome) (Zatsiorsky & Kraemer, 1995). Functional overreaching may involve transient performance incompetence, due to the induced fatigue, but results in an improved condition following short-term recovery periods (days or weeks) (Kuipers, 1998; Meeusen et al., 2006). Prolonged intense training with insufficient recovery, and where performance fails to rebound following a recovery period, is termed non-functional overreaching (Meeusen et al., 2006). Amongst the plethora of research investigating the signs and symptoms of non-functional overreaching, a gold-standard diagnosis is lacking (Meeusen et al., 2006). Indicators of non-functional overreaching include performance decrements, severe physical and psychological fatigue including muscle soreness, overuse injuries and increases in perceived effort, all of which may persist for months (Fry et al., 1991; Meeusen et al., 2006). Furthermore, physiological symptoms such as endocrine changes, increases in heart rate (HR), ventilation and blood lactate concentration for a given workload, increases in resting HR and the slow return of HR after exercise, decrease in maximal oxygen consumption ( $VO_{2max}$ ), decreases in sub-maximal and maximal blood lactate concentration, and decreased work capacity are observed (Hackney et al., 1990; Kenttä & Hassmén, 1998; Kuipers & Keizer, 1988). Importantly, separating acute changes to homeostasis as a response to overtraining from symptoms of non-functional overreaching is dependent on the timing of the assessment (Figure 2-3).



**Figure 2-3** Testing to identify non-functional overreaching.

Testing for non-functional overreaching at Point A may reveal a reduced performance capacity and identify variables that are significantly removed from homeostatic levels. The appropriate time to administer a testing regime to identify non-functional overreaching is when the athlete should, as defined by the training programme, be in a state of full recovery, Point B.

From Fry, R. W., Morton, A. R., & Keast, D. (1992). Periodization and the prevention of overtraining. *Canadian Journal of Sports Sciences*, 17(3), 241-248.

Overtraining syndrome, often used synonymously with staleness (Kuipers & Keizer, 1988), is the end state of chronic non-functional overreaching with sport-specific performance decrements accompanied by psychological symptoms in the absence of a diagnosable medical condition (Fry et al., 1991). The defining symptom is the inability to correct these with periods of recovery (i.e. the need for complete long-term rest of months or even years) (Hackney et al., 1990; O'Connor, 1997; Raglin, 1993). Overtraining syndrome has also been linked to a range of sympathetic and parasympathetic symptoms (Kuipers & Keizer, 1988; Lehmann et al., 1993). The sympathetic type relates to increased sympathetic activity at rest, such as increased HR, potentially leading to restlessness and excitation (Kuipers & Keizer, 1988). On the other hand, the parasympathetic type is characterised by a predominance in vagal tone or adrenal insufficiency, and dominating parasympathetic activity at rest and during exercise (e.g. reduced HR), related to inhibition and depression (Kuipers & Keizer, 1988). Similarly to non-functional

overreaching, the continuous nature of overtraining limits the ability of these isolated symptoms to differentiate overtraining syndrome from overtraining. One proposed method of differentiating overtraining syndrome from overreaching is using a two-bout protocol to examine changes in hormonal responses and time to exhaustion that may not be noticeable in a single exercise test (Meeusen et al., 2004). It appears that the second bout demonstrates differences in the adrenocorticotrophic and prolactin hormones between athletes who go on to reach overtraining syndrome and those who were non-functionally overreaching (Meeusen et al., 2010; Meeusen et al., 2004). However, while some physiological and biochemical markers have been shown to confirm staleness, they fail to prevent it due to continuous nature of overtraining and the delayed feedback often associated with such measures (e.g. time for laboratory analysis) (Hooper & Mackinnon, 1995; Kellmann, 2010).

The equivocal data surrounding physiological, biochemical and immunological measures, and their lack of feasibility and inability to separate functional and non-functional overreaching restricts their application. As such, currently the most effective and practical way of detecting non-functional overreaching or overtraining syndrome is thought to be via psychological markers and/or performance decrements (Coutts, Wallace, et al., 2007; Fry et al., 1991; Kellmann, 2002c; Morgan et al., 1987; Urhausen & Kindermann, 2002). However, by the time an athlete is exhibiting these, the best-known treatment might be complete inactivity which has a considerable negative training effect, limiting the use of these symptoms (Hooper & Mackinnon, 1995; Koutedakis et al., 1990). It is therefore paramount that training is carefully balanced, monitored and adjusted to prevent chronic overtraining or non-functional overreaching.

## **Optimising training for team sport**

An ideal training regime includes an exercise stimulus sufficient to elicit adaptation and proportionate recovery to allow the negative effects of fatigue to diminish (Bompa & Haff, 2009; Budgett, 1990). Periodisation, which is the planned and systematic variation of exercise parameters (duration, intensity and frequency), enhances this process by directing the adaptations to the training goals (Bompa & Haff, 1999; Matveyev, 1981; Rowbottom, 2000). However, traditional techniques of periodisation are based on athletes working towards peaking for a major competition in the season (Bompa & Haff, 1999; Matveyev, 1981; Noakes, 2000; Smith, 2003). In Australian team sports, the competitive season consists of regular competitive matches over several months plus a finals series if successful, requiring athletes to be optimally prepared for multiple matches across the season. Periodising training regimes in team sports to maintain or improve upon fitness achieved in pre-season remains challenging (Gamble, 2006; Jeong, Reilly, Morton, & Bae, 2011; Kelly & Coutts, 2007; Moreira et al., 2015; Ritchie, Hopkins, Buchheit, Cordy, & Bartlett, 2015).

Moreover, the body's ability to adapt to a given training load and cope with the level of fatigue induced will be influenced by an array of factors (Banister & Calvert, 1980; Lehmann et al., 1993). The individual differences in exercise capacity, recovery potential, non-training stressors and stress tolerance make it difficult to successfully manipulate the training stress and recovery, particularly in a team-sport setting (Impellizzeri et al., 2004; Kenttä & Hassmén, 1998). It is well established that athletes may respond differently to the same training program and that the outcome of training is influenced by the particular psychobiological predispositions of the individual athlete (Lehmann et al., 1993). It is therefore vital to understand each athlete's response to the training program. This allows for incorporation of their current state in the design of the subsequent training/recovery schedule, and provides opportunity to tailor training accordingly. To maximise physical capacity and skill gains, and limit unplanned fatigue,



training load must be carefully monitored and adjusted and there is a variety of practical suggestions on athlete monitoring in the literature (Borresen & Lambert, 2009; Cormack, Newton, & McGuigan, 2008; Coutts & Reaburn, 2008; Lambert & Borresen, 2010). However, there remains no criterion method for monitoring training, fatigue and athlete preparedness, particularly in team-sport athletes (Buchheit, Racinais, et al., 2013).

## **2.3. Monitoring Preparedness**

### **Mathematical models**

In an attempt to model training progress using the positive response of fitness and negative response of fatigue, Banister and colleagues (1975) developed the concept of a training impulse. By using weighting factors that account for the greater impact that a training impulse has on fatigue than on fitness, but having a longer decay constant for fitness, the difference between fitness and fatigue at any time was suggested to predict an athlete's performance capacity (Banister & Calvert, 1980; Calvert, Banister, Savage, & Bach, 1976). Initial estimates for the constants in the equation were given but adjustment to suit individual athletes once the model was fit to a real performance was suggested (Banister & Calvert, 1980). Simplified adaptations are also published where the number of components needed in the model are reduced (Busso et al., 1991; Morton et al., 1990). However, if an individual's training response is dependent upon numerous factors and different to other athletes therefore requiring individual constants (Banister & Calvert, 1980), then it is logical to assume that constants will vary not only between players but also within players over time (Busso, 2003; Busso, Benoit, Bonnefoy, Feasson, & Lacour, 2002; Busso, Denis, Bonnefoy, Geyssant, & Lacour, 1997). Alternative mathematical approaches exist, including the use of influence curves to determine the contribution of each training impulse to future performance (Fitz-Clarke, Morton, & Banister, 1991; Hayes & Quinn, 2009; Hellard et al., 2005; Morton, 1997).

More recently, reviews covering the various mathematical techniques developed to explain performance capacity from the fitness and fatigue after-effects of a given training stimulus, appear sceptical to such an approach (Borresen & Lambert, 2009; Hellard et al., 2006; Taha & Thomas, 2003). Although compelling concepts, these models tend to be highly varied with relatively weak correlations to actual performances (Busso et al., 1997; Hellard et al., 2006). The lack of a model with acceptable ability to predict future performance is attributed to a range of factors including: (1) the difficulty of quantifying training in real world athletes (2) the lack of consideration for factors outside of training; and (3) the assumption that there is an opposing negative and positive effect of training impacting on performance (which has yet to be unequivocally established using physiological responses), rather than stages or a sequence of responses leading to adaptation and hence, improved performance capacity (Borresen & Lambert, 2009; Lambert & Borresen, 2006; Morton, 1997). Moreover, this approach remains impractical, highly complex, and lacks the individuality that is a crucial component in determining training response in athletes (Borresen & Lambert, 2009; Mujika et al., 1996).

### **Contemporary practices**

It is accepted that the key to a successful training regime is the balance between stress and recovery (Bompa & Haff, 1999; Kellmann, 2002a). As such, monitoring procedures to enhance the understanding of the load elicited on an athlete, the response to that load and current training status, have become customary in the elite sport setting (Akenhead & Nassis, 2015; Borresen & Lambert, 2009; Buchheit, Racinais, et al., 2013; Halson, 2014; Taylor, Chapman, Cronin, Newton, & Gill, 2012; Twist & Highton, 2012). A survey across Australian and New Zealand high-performance personnel reported that 70% of responders indicated their monitoring system had an equal focus on load quantification and fatigue monitoring (Taylor et al., 2012). In regards to load quantification, there is now an abundance of research into the techniques, feasibility, validity and reliability of such methods (see section 2.4) (Akenhead & Nassis, 2015; Akubat,

Barrett, & Abt, 2014; Borresen & Lambert, 2008; Casamichana et al., 2013; Halson, 2014; Weaving, Marshall, Earle, Nevill, & Abt, 2014). However, despite the vested interest, a valid and reliable, non-invasive and non-exhaustive method for determining fatigue and/or recovery is yet to be established (see section 2.5) (Buchheit, Racinais, et al., 2013; Halson, 2014; Kellmann, 2002b; Kuipers, 1996; Urhausen & Kindermann, 2002).

Kenttä and Hassmén (2002) define three phases and important considerations of a contemporary monitoring system, (1) identifying the stimulus (2) the perception of the stimulus; and (3) the response to the stimulus. The first phase requires quantification of the stimulus and refers to a well-developed and prescribed program. The second phase involves an understanding of the actual magnitude of the training or competition load experienced by the athlete, focusing on individual perceptions. The third and final phase refers to how each athlete is responding to and coping with the imposed training (Kenttä & Hassmén, 2002). Furthermore, key features of effective monitoring practices are presented throughout the literature (Corcoran & Bird, 2012; Halson, 2014; Hooper & Mackinnon, 1995; Kenttä & Hassmén, 2002; Saw et al., 2015a, 2015b). Table 2-1 outlines the features of a sustainable monitoring system (Halson, 2014). Recurring themes include validity and reliability, cost effectiveness, ease of use and timely feedback (Corcoran & Bird, 2012; Hooper & Mackinnon, 1995).

**Table 2-1** Key features of a sustainable monitoring system.

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Ease of use/intuitive design
Efficient result reporting
Can be used with or without internet connection, <i>i.e.</i> able to be utilised effectively remotely
Data should be able to be translated into simple outcomes, such as effect sizes
The system should be flexible and adaptable for different sports and athletes
Identification of a meaningful change should be simple and efficient
Should include an assessment of cognitive function
Should be able to provide both individual responses and group responses

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From Halson, S. L. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine*, 44(2), 139-147.

## 2.4. Load

### Quantifying load

Load is determined by the interaction of exercise duration, intensity and frequency and can be quantified by external and/or internal parameters (Hals0n, 2014; Smith & Norris, 2002). External load describes the dose performed, such as distance run, and internal load represents the psychobiological response to a given load, such as HR load (Impellizzeri et al., 2005). Thorough load monitoring is common practice in professional sport, with 40 of 41 surveyed professional soccer teams reporting that they collect load data for every player during every field training session (Akenhead & Nassis, 2015). Overall, 56 different load variables were identified including both external and internal measures (Akenhead & Nassis, 2015). However, it has been suggested that a fundamental feature of a valid training load measure is a dose-response relationship and that changes in fitness and/or performance measures in response to load measures should be evident (Akubat et al., 2014; Akubat et al., 2012; Aughey et al., 2015; Manzi, Bovenzi, Impellizzeri, Carminati, & Castagna, 2013).

Despite the acknowledged differences between external and internal load, the utilisation of both constructs in athlete monitoring has been established (Halson, 2014; Impellizzeri et al., 2005; B. R. Scott et al., 2013). Since successful performance relies on an absolute external load being reached, it has been suggested that external load should be employed in prescribing and periodising training programs (Impellizzeri et al., 2004; Impellizzeri et al., 2005; Lovell et al., 2013). On the other hand, it is the internal training load that elicits adaptation and therefore should be used when monitoring an athlete's response (Impellizzeri et al., 2005; B. R. Scott et al., 2013). Although inter-individual variation in response to external training load is acknowledged, in team sport, training typically occurs as a collective and indeed is most commonly designed using external load measures such as session duration or running doses (Impellizzeri et al., 2004; Lambert & Borresen, 2010; Manzi et al., 2010).

Some research has suggested that in addition to the quantification of overall load, the distribution of that load is an important contributor to the outcome of a training program (Foster, 1998; Hulin et al., 2014; Hulin, Gabbett, Lawson, Caputi, & Sampson, 2015; Lehmann et al., 1992). With reference to overtraining syndrome, it is believed that a monotonous training load might be more detrimental than the load per se. One study on experienced runners, comparing increases in training intensity to increases in training volume, demonstrated that the parasympathetic signs of overtraining were associated with the increased training volume group, with substantially less daily variability (Lehmann et al., 1992). As an index of the day-to-day training variability, Foster (1998) defined training monotony as the daily mean load divided by the standard deviation of daily mean load over a week. It was reported that the product of load and monotony, termed training strain, could more successfully explain illnesses in speed skaters than load or monotony alone (Foster, 1998). Notably, spikes in training strain (89%) improved the explanation of illnesses by only 5% compared to training load (84%), and 59 and 55% of spikes in training strain and load, respectively, were not associated with illness

(Foster, 1998). Subsequently, limited research has examined the concept of strain and monotony, but the lack of a well-defined dose-response relationship between either variable and fitness, performance and/or injury/illness and obscure results relative to load, queries its validity (Anderson, Triplett-McBride, Foster, Doberstein, & Brice, 2003; Aughey et al., 2015; Brink, Visscher, et al., 2010; Cross, Williams, Trewartha, Kemp, & Stokes, 2016; Foster, 1998; Putlur et al., 2004). In youth soccer players, strain and monotony were associated with a significant increased risk of traumatic injury (odds ratio (OR); 95% confidence interval (CI) = 1.01; 1.00 to 1.01 and 2.59; 1.22 to 5.50, respectively), as was duration and load (Brink, Visscher, et al., 2010). Whether or not strain and monotony were more predictive of traumatic injury than load or duration alone is unclear and no association to overuse injuries or illness was seen. It is possible that one week is too short to detect overuse injuries which may be associated with repetitive stress over a longer period of time (Brink, Visscher, et al., 2010). In a recent study of loads in rugby union, strain was excluded from the analysis because of its strong relationship to monotony (multicollinearity) which was also reported in basketball ( $r = 0.67, P < 0.01$ ) and soccer (Anderson et al., 2003; Cross et al., 2016; Putlur et al., 2004). As for monotony in the rugby union study, an increase of two standard deviations reportedly had an unclear effect on injury risk (OR; 95% CI = 1.22; 0.84 to 1.78,  $P = 0.29$ ) (Cross et al., 2016).

Moreover, sudden increases or spikes in exercise load have been linked to increased injury risk (Gabbett & Ullah, 2012). This concept corresponds with the fitness-fatigue model, where fitness is said to accumulate over repeated bouts of training stimulus and has a slow decay curve, whereas the fatigue response is larger in magnitude but diminishes more quickly. If chronic load is representative of fitness and acute load is representative of fatigue, a spike in acute load would reflect a high magnitude fatigue response (Hulin et al., 2014). In cricket fast bowlers, the ratio of acute load to chronic load (often used synonymously with training-stress balance (TSB)) was found to impact injury risk in the subsequent week, with a relative risk of

4.5 (CI = 3.43 to 5.90,  $P = 0.009$ ) and 3.4 (CI = 1.56 to 7.43,  $P = 0.032$ ) when external and internal acute to chronic load, respectively, exceeded 200% (Hulin et al., 2014). In rugby league, the acute to chronic ratio was a better predictor of injury than either acute load of the current week, subsequent week or 2-week average which had inconsistent relationships or chronic load which had no load-injury relationship (Hulin et al., 2015). On the other hand, the acute to chronic load ratio showed no clear relationship with injuries over a rugby league season, where acute weekly load measures did (Windt, Gabbett, Ferris, & Khan, 2016). Similarly, in rugby union, acute weekly load and absolute change in week-to-week load proved associated with injuries when acute to chronic load ratio did not (Cross et al., 2016). Evidently, the use of metrics to reflect the distribution and continuity of training loads requires more research before their validity can be ascertained.

### **External load**

With the introduction of microtechnology devices, quantifying external load in team-sport settings has become substantially less arduous (than video-based time-motion analysis) and therefore, common practice in elite sport (Aughey, 2011; Cummins, Orr, O'Connor, & West, 2013; Gabbett, Jenkins, & Abernethy, 2012; Johnston et al., 2012a). There is considerable research examining the validity and reliability of microtechnology to assess a range of variables (Boyd, Ball, & Aughey, 2011; Castellano, Casamichana, Calleja-Gonzalez, Roman, & Ostojic, 2011; Coutts & Duffield, 2010; Gray, Jenkins, Andrews, Taaffee, & Glover, 2010; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010; Johnston, Watsford, Kelly, Pine, & Spurrs, 2014; Johnston et al., 2012b; Varley, Fairweather, & Aughey, 2012). It appears that higher sampling rate for the global positioning system (GPS) parameters drastically improves reliability and validity with as much as a 30 to 50% reduction in error for the 10 Hz unit compared to the 5 Hz (Jennings et al., 2010; Johnston et al., 2012b; Pyne, Petersen, Higham, & Cramer, 2010; Rampinini et al., 2015). Furthermore, error is reduced as distances increase, although as speeds

increase so too does the error (Jennings et al., 2010). For the 10 Hz systems, the typical error of measurement (TE) for distance covered during short, straight line running (15 and 30 m) has been reported as 10.9 and 5.1% respectively with a %TEM for inter-unit reliability of <1.5% (Castellano et al., 2011). For a simulated intermittent protocol with a radar measured mean total distance of 228 m, the %TEM was as low as 1.9% for 10 Hz units (Rampinini et al., 2015).

Movement profiles are often categorised into zones such as standing/walking, jogging/low-speed running, moderate-speed running, high-speed running (HSR) and very high-speed running (VHSR) /sprinting (Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Johnston et al., 2012a; Rampinini et al., 2015). However the arbitrary nature of the threshold which is used to determine such zones limits the ability to collate and compare results from different studies (Abt & Lovell, 2009; Dwyer & Gabbett, 2012). In one study using intermittent shuttle activities, 10 Hz units were reported with a %TEM of 4.7% for HSR measured at above 4.17 m·s<sup>-1</sup> and 10.5% for VHSR at above 5.56 m·s<sup>-1</sup> (Rampinini et al., 2015), similar to the 4.8 and 11.5% reported for distance above 3.89 m·s<sup>-1</sup> and 5.56 m·s<sup>-1</sup> respectively in a team sport simulation circuit (Johnston et al., 2014).

Compared to continuous non-contact sports, quantifying training load in high-intensity intermittent contact sports such as AF, is more complex. The unpredictable change of pace and direction and collisions that occur in AF, all contribute to the overall load experienced by the athlete (Takarada, 2003; Young, Hepner, & Robbins, 2012). The Player load<sup>TM</sup> (PL) (Catapult Innovations, Melbourne, Australia) algorithm from microtechnology, which combines rate of change in acceleration from three planes of movement, has also been reported to be reliable (Aughey, 2011; Boyd et al., 2011; Varley et al., 2012) and is suggested to incorporate all forms of activity including skill and contact-based activities relevant to intermittent contact sports (Aughey, 2011; Boyd, Ball, & Aughey, 2013). However, foot strikes (vertical plane



accelerations) and locomotor activity (forward acceleration) are reported to impact heavily on this parameter with research demonstrating very large correlations ( $r = 0.80$  to  $0.95$ ) between distance and PL (Aughey, 2011; Boyd et al., 2013; Boyd et al., 2010). Interestingly, recent research has demonstrated that neuromuscular fatigue alters the way PL is accumulated in AF matches (Cormack et al., 2012). Specifically, it was reported that fatigued players were able to maintain total distance and HSR but had a lower contribution of vertical accelerometer (mean  $\pm 90\%$  confidence limit (CL) =  $-5.8 \pm 6.1\%$ ) to PL due to likely impairments in contractile function associated with neuromuscular fatigue *i.e.* a physical performance limitation (Cormack et al., 2012). Furthermore, previous research found differences between playing positions for Player load slow<sup>TM</sup> (PL<sub>slow</sub>), which removes activity above  $2 \text{ m}\cdot\text{s}^{-1}$ , in elite AF matches (Boyd et al., 2013). It was proposed that traditional speed-based time-motion analysis may underrepresent low-speed activity (e.g. grappling, ruck contests) detected by PL<sub>slow</sub> (Boyd et al., 2013).

Due to the association between physiological capacity and external output, and the ability of some external exercise intensity metrics to separate elite players from sub-elite, external output is considered a valid measure of team performance (Helgerud, Engen, Wisløff, & Hoff, 2001; Manzi, Impellizzeri, & Castagna, 2014; Mohr, Krstrup, & Bangsbo, 2003). In soccer, top-class players, who performed better on the Yo-Yo intermittent recovery (Yo-Yo IR) level 1 test, were shown to have greater HSR and sprinting than moderate-class players (28 and 58%, respectively) (Mohr et al., 2003). Greater activity profiles for elite players compared to sub-elite were also seen in AF, with elite players covering 9% more total distance and having 21% more high-intensity efforts (Brewer, Dawson, Heasman, Stewart, & Cormack, 2010). While overall physical output was not different between elite and semi-elite players in rugby league, there were differences in the first half, with elite players again having increased high-intensity activities (Sirotic, Coutts, Knowles, & Catterick, 2009). This is further supported by the finding

that physical capacity, mediated by high-intensity activity, was related to increased number of ball disposals in AF (Mooney et al., 2011). Moreover, the annual match analysis report for the 2013 AF season demonstrated that the top four performing teams had a greater HSR (8.4%) than the bottom four teams, although this difference was not reproduced in the 2014 season (Wisbey & Montgomery, 2015; Wisbey, Pyne, Rattray, & Montgomery, 2014). Alternatively, less successful teams were seen to cover less HSR and sprinting distance in premier league soccer and Italian Serie A league (HSR: -4 and -11%; sprinting: -5 and -9%, respectively) (Di Salvo, Gregson, Atkinson, Tordoff, & Drust, 2009; Rampinini, Impellizzeri, Castagna, Coutts, & Wisløff, 2009). A breakdown of activity profiles of when the team was in possession of the ball versus not in possession, suggested that the less successful teams were covering greater HSR while not in possession (11%), likely as a result of trying to regain possession, while the successful team has greater work rate when in possession (Di Salvo et al., 2009; Rampinini et al., 2009).

In regards to individual performances, less HSR and less external output was associated with better objective performance (effective match involvements) in AF (Johnston et al., 2012a; Sullivan et al., 2014). In a comprehensive analysis of a range of microtechnology-derived parameters and performance in AF, the best predictors of objective performance for nomadic players was measures related to walking, with negative correlations (Bauer, Young, Fahrner, & Harvey, 2015). For fixed position players, the best predictor of objective performance was the number of sprinting entries with more efforts related to poorer performance. Interestingly, these findings were different for coaches subjective ratings of performance where an increase in percentage time HSR was the best predictor of increased performance (Bauer et al., 2015). However, previous research has found that players who had lower external match intensity were rated higher by coaches (Johnston et al., 2012a; Sullivan et al., 2014). It appears that the large contribution of skill execution to both objective and subjective performance and the complex

interaction of factors that impact physical output between matches limits the ability to determine the exact impact that external output has on performance in team sports (Kempton & Coutts, 2015; Rampinini, Coutts, Castagna, Sassi, & Impellizzeri, 2007; Sullivan et al., 2014).

## **Internal load**

### ***Objective internal load***

Internal training load represents the psychobiological response to a given external load and can be measured via numerous objective and subjective parameters. There are a variety of objective HR-based methods for determining a training impulse in steady-state exercise (Banister, 1991; Banister, Good, Holman, & Hamilton, 1986; Edwards, 1993; Lucia, Hoyos, Santalla, Earnest, & Chicharro, 2003). The original TRIMP method proposed by Banister (1986) centred around a dose-response relationship between HR and fitness improvements but failed to reflect the increased influence of high-intensity work with no consideration for the differing contributions of the aerobic and anaerobic energy systems. In order to account for the anaerobic component of high-intensity exercise, modifications to include a weighting factor based on standardised blood lactate curves were developed (Banister, 1991; Fitz-Clarke et al., 1991; Morton et al., 1990). Similarly, the summated HR method uses different factors to add weight accordingly to the accumulated time in five arbitrary HR zones (Edwards, 1993; Foster et al., 2001). Furthermore, Lucia et al. (2000) used individualised weighting factors based on blood lactate parameters to adjust time spent in three HR zones. While these adjustments aim to incorporate the influence of intensity into the calculation of internal training load, pronounced error exists when quantifying interval training because of the delayed kinetics of the cardiovascular system at the onset of exercise (Hayes & Quinn, 2009; Yoshida, Yamamoto, & Udo, 1993). Combined with the weaker correlations observed between HR and perceptual measures of load, in high intensity, short duration or intermittent activities compared to steady-state aerobic exercise, this

contributes to evidence that even with weighting factors, the use of these HR measures to measure load in team sports is limited (Alexiou & Coutts, 2008; Borresen & Lambert, 2009; Hellard et al., 2006; Impellizzeri et al., 2004; Scanlan, Wen, Tucker, Borges, & Dalbo, 2014).

More recently however, the use of HR to calculate TRIMP for team-sport athletes has been validated with modified TRIMP (TRIMP<sub>MOD</sub>) calculations (Akubat et al., 2012; Manzi et al., 2013; Stagno, Thatcher, & Van Someren, 2007). Weighting factors determined from blood lactate response curves of the team were applied to time spent in HR zones anchored around the lactate threshold and onset of blood lactate accumulation breakpoints (Stagno et al., 2007). Using professional hockey players, mean weekly TRIMP<sub>MOD</sub> was correlated to VO<sub>2max</sub> and velocity at onset of blood lactate accumulation ( $r = 0.80$ ,  $P = 0.017$  and  $r = 0.71$ ,  $P = 0.024$ , respectively) and hence, proposed as a valid internal training load measure (Stagno et al., 2007). Furthermore, a dose-response relationship was also evident in soccer players, using an individualised TRIMP (iTRIMP) calculation, first developed by Manzi et al. (2009) (Akubat et al., 2012; Manzi et al., 2013). There were large to very large correlations between iTRIMP and VO<sub>2max</sub>, velocity at lactate threshold, speed at 4 mmol.L<sup>-1</sup> of lactate accumulation and Yo-Yo IR level 1 performance ( $r = 0.64$  to  $0.78$ ) in professional soccer players (Manzi et al., 2013). In youth soccer players, iTRIMP was better correlated ( $r = 0.67$ ,  $P = 0.04$ ) to changes in lactate threshold than the TRIMP<sub>MOD</sub> 'team' method ( $r = 0.20$ ) (Akubat et al., 2012). With evidence of a dose-response relationship between these HR-based methods of training load and fitness changes, it appears that these adapted HR measures may be a valid measure of load even in team sport settings.

Notably, the method of determining the relationship between HR and blood lactate response from a continuous incremental test has been questioned since there is a significant difference in the relationship between a continuous and an intermittent protocol (Akubat & Abt, 2011).

Further limitations of these models have been reported, including the effect of other conditions (e.g. temperature) on physiological variables used (Borresen & Lambert, 2009; Lambert & Borresen, 2010). Also, the technical difficulty together with the time consuming data analysis, and the fact HR monitors are not always permitted in competition also restricts its use. Time spent in set HR bands has also been used as a stand-alone measure of internal load (Algroy, Hetlelid, Seiler, & Pedersen, 2011; Borresen & Lambert, 2008), with similar limitations to those described above (Borresen & Lambert, 2008; Lambert & Borresen, 2010).

### ***Subjective internal load (session rating of perceived exertion)***

The session rating of perceived exertion (s-RPE) is a popular subjective measure of internal load (Alexiou & Coutts, 2008; Coutts, Murphy, et al., 2003; Gastin, Meyer, et al., 2013; Impellizzeri et al., 2004; Ritchie et al., 2015). In 1995, Foster used a subjective rating of perceived exertion (RPE) multiplied by the duration of the session (as a measure of volume), giving a single arbitrary number representing internal load (Alexiou & Coutts, 2008; Foster et al., 2001; Foster et al., 1995). Based on the category-ratio scale of 0–10 (CR-10) developed by Borg et al., a modified 0–10 scale is used to obtain a self-reported RPE (Borg, 1982; Borg, Ljunggren, & Ceci, 1985; Foster et al., 2001). The conventional CR-10 scale categorised 10 as *extremely strong*, with a dot representing the final category of perception that is beyond 10, where as in the modified scale, 10 is anchored by *maximal* and adjustments were made to the nomenclature to reflect American idiomatic English (Eston, 2012; Lambert & Borresen, 2006). Moderate to very large correlations ( $r = 0.45$  to  $0.91$ ) are reported between s-RPE and objective HR-based measures in team sports (Casamichana et al., 2013; Clarke, Farthing, Norris, Arnold, & Lanovaz, 2012; Impellizzeri et al., 2004; Lovell et al., 2013; B. R. Scott et al., 2013; T. J. Scott, Black, Quinn, & Coutts, 2013).

The strength of the associations between s-RPE load and TRIMP methods appear variable however, and must be considered within the context of the activity examined and specific

method used (Scanlan et al., 2014; Weaving et al., 2014). Lower correlations between s-RPE load and TRIMP methods are seen in high-intensity, intermittent activities compared to endurance exercise, highlighting the fact that there are other contributors to global perception of effort in team-sport activity that is not accounted for by HR or oxygen consumption (Alexiou & Coutts, 2008; Herman, Foster, Maher, Mikat, & Porcari, 2006; Impellizzeri et al., 2004; Lovell et al., 2013). Although the complex interaction of psychobiological contributors to perception of effort seems pertinent when using the s-RPE method as a measure of the magnitude of training load experienced by the athlete, in some situations for some athletes, this very property may impact its association with TRIMP methods (Borresen & Lambert, 2008; Impellizzeri et al., 2004; Impellizzeri et al., 2005). Accordingly, load measured by the s-RPE method was shown to have a dose/response relationship with performance in endurance athletes (Foster, Daines, Hector, Snyder, & Welsh, 1996) but failed to correlate to changes in aerobic fitness parameters in youth soccer players and in collision sport athletes (Akubat et al., 2012; Brink, Nederhof, Visscher, Schmikli, & Lemmink, 2010; Gabbett & Domrow, 2007). Furthermore, only small correlations ( $r = -0.27$  to  $-0.30$ ,  $P < 0.05$ ) were seen in rugby league players between s-RPE and  $VO_{2max}$  and squat jump performance (Coutts, Reaburn, Murphy, Watsford, & Spurrs, 2003). Since it has been demonstrated that impacts/collisions can influence RPE (in rugby league), it is likely that only a portion of the s-RPE load is contributing to the fitness improvements (Lovell et al., 2013). Alternately in rugby league, s-RPE training load did have a significantly strong dose-response relationship ( $r = -0.84$ ,  $P < 0.001$ ) with fitness measured by a multi-stage fitness test (Coutts, Reaburn, Piva, & Murphy, 2007) and evidence of a dose-response relationship between s-RPE load and injury is prominent (Gabbett, 2004; Gabbett & Jenkins, 2011; Veugelers, Young, Fahrner, & Harvey, 2015).

Moreover, weekly load was likely greater preceding wins compared to losses even when controlled for days between matches (Aughey et al., 2015). The TSB was also possibly greater

positive (higher four week mean load compared to current week) in wins also when controlled for ladder position of the opposition or days between matches in AF (Aughey et al., 2015). Interestingly, TSB calculated from strain (the product load and monotony), was the best discriminator of wins versus losses. It seems that while higher weekly loads were linked to wins, spikes in acute weekly load, and even more so strain, were associated with losses (Aughey et al., 2015). This highlights the delicate balance of an optimal training program, where higher weekly loads are important for tactical preparation but an acute load/strain that exceeds chronic load/strain results in fatigue detrimental to performance.

Although moderate to strong correlations exist between s-RPE and HR-based measures of internal load, neither method is established as a criterion ‘gold standard’, limiting the interpretation of such results. Furthermore, with non-perfect correlations, there is unquestionably an unexplained portion of the relationship between HR-based methods and s-RPE. Although the subjective nature of perception encourages a global interaction of psychobiological contributors to effort, depending on how meticulously RPEs are collected, there is potential for external influences such as conformity, or anticipation of coaches’ intention. Moreover, a lower between-match variability of s-RPE compared to other external load measures, such as high-intensity running distance, has been reported in rugby league matches (McLaren, Weston, Smith, Cramb, & Portas, 2016). This allows s-RPE to be reliably used as a measure of match load and meaningful changes more accurately detected, but may also suggest that s-RPE lacks sensitivity in detecting subtle variations in external match load. Importantly, recent research concentrating on improving the application and interpretation of traditional s-RPE in team sport is emerging (Veugelers et al., 2015; Weston, Siegler, Bahnert, McBrien, & Lovell, 2015).

In order to increase sensitivity of RPE in evaluation of AF match loads, a differential s-RPE has been proposed (Weston et al., 2015). The small differences reported between local and central ratings (mean  $\pm 90\%$  CL =  $13.5 \pm 1.5\%$ ), local and tactical ratings ( $5.5 \pm 1.9\%$ ), and tactical and central ratings ( $1.9 \pm 1.9\%$ ), verifies the notion that there are distinct sensory inputs to an overall RPE. Furthermore, the combination of these differential ratings explained 76% of overall match s-RPE, suggesting differential ratings may enhance understanding of match exertion relative to separate constructs (Weston et al., 2015). Examining the difference between overall s-RPE training load compared with field-based (only outdoor sessions performed on the field such as running and skill-based training) load and RPE (without the inclusion of duration) to detect injury and illness in AF players, it was found that the inclusion of duration did not improve the prediction of either injury or illness, and overall RPE was a better predictor of injury while field RPE was a better indicator of illness (Veugelers et al., 2015). Irrespective of the restrictions associated with subjective internal load, the validity, reliability, simplicity and feasibility of s-RPE are maintained (Haddad et al., 2014; Impellizzeri, 2011).

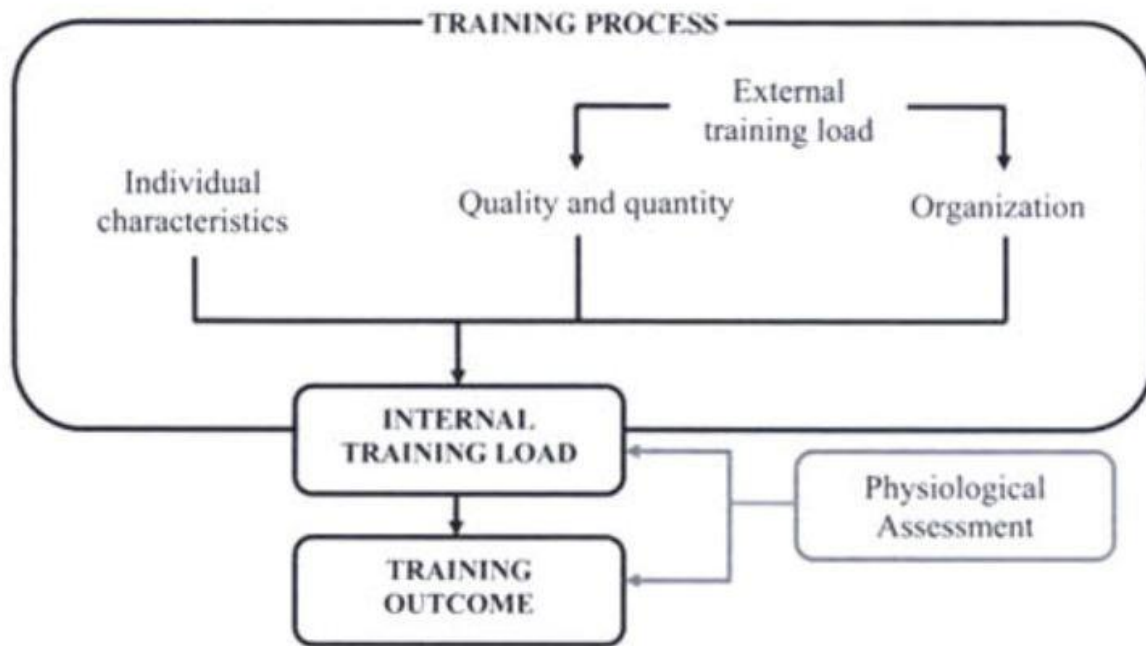
### **The relationship between external and internal load**

With the intensified utilisation of microtechnology devices in team sports, there is an accumulating amount of research into the relationship between external parameters and internal load measures (Casamichana et al., 2013; Gaudino et al., 2015; Lovell et al., 2013; B. R. Scott et al., 2013; T. J. Scott et al., 2013). In particular, Edwards's TRIMP method had a very large correlation to total distance and PL in soccer training ( $r = 0.72$  and  $0.70$ , respectively) (Casamichana et al., 2013). Alternatively, Weaving et al. (2014) demonstrated that correlations between iTRIMP and Bodyload™ (an algorithm measuring accelerations, decelerations, change of directions and impacts built into the manufacturers [GPSports, Fyshwick, Canberra] software) ranged from trivial to large for different training modes in rugby league. A trivial correlation was seen during wrestling practice, a small correlation for skills training, moderate correlations for speed and strongman activities and large correlations for small-sided games and



conditioning. For HSR, trivial correlations were seen between iTRIMP and wrestling, strongman activities, and speed training, moderate correlations for skills and conditioning and a large correlation for small-sided games practice (Weaving et al., 2014). Furthermore, very large correlations ( $r = 0.74$  to  $0.81$ ) have been reported between s-RPE and total distance in high-intensity, intermittent team sports, and large ( $r = 0.64$  to  $0.70$ ) correlations between s-RPE and HSR (Casamichana et al., 2013; Gaudino et al., 2015; Lovell et al., 2013; T. J. Scott et al., 2013). s-RPE has also been reported to share small to very large common variance ( $r = 0.23$  to  $0.84$ ) with PL (Casamichana et al., 2013; Gomez-Piriz, Jimenez-Reyes, & Ruiz-Ruiz, 2011; Lovell et al., 2013; T. J. Scott et al., 2013). These studies provide evidence that the relationship between external and internal load is dependent on particular activity types and parameters examined.

Additionally, evidence currently exists documenting the impact of physiological fitness on perceived exertion in both trained endurance runners, professional futsal players and professional basketball players with fitter players reporting lower mean s-RPE training load (Garcin, Mille-Hamard, & Billat, 2004; Manzi et al., 2010; Milanez et al., 2011). When exploring the relationship between external load and the s-RPE method, an athlete's psychological characteristics and current psychological state including mood and motivation also impacts the relationship (Blanchfield, Hardy, de Morree, Staiano, & Marcora, 2014). This complex interaction of concepts is shown in an illustration which demonstrates how the makeup of an external load elicits internal load influenced by the individual characteristics of an athlete (Figure 2-4) (Impellizzeri et al., 2005). Seemingly, determining the impact of individual characteristics on internal load will provide a better understanding of the response that a prescribed external training load might elicit.



**Figure 2-4** Training Process.

The training outcome is the consequence of the internal training load determined by (1) individual characteristics, such as genetic factors and previous training experience, and (2) the quality, quantity and organizations of the external training load.

From Impellizzeri, F. M., Rampinini, E., & Marcora, S. M. (2005). Physiological assessment of aerobic training in soccer. *Journal of Sports Sciences*, 23(6), 583-592.

The concept of integrating external and internal load has been also been explored in long-distance running and team sports (Akubat et al., 2014; Lambert, Mbambo, & St Clair Gibson, 1998; Weaving et al., 2014). The notion is based on the theory that exercise economy *i.e.* the oxygen cost for a given external work load, can be used as a measure of fitness/efficiency (Lambert et al., 1998). Using the readily available internal (iTRIMP) and external (total distance and HSR) loads collected in team-sport training, it was shown that the iTRIMP: total distance and iTRIMP: HSR ratios were better correlated ( $r = 0.58$  to  $0.69$ ) to fitness measures (velocity at onset of blood lactate accumulation and velocity at lactate threshold) than external load alone (Akubat et al., 2014). With a constant and standardised external load, changes in the internal to external load ratio would theoretically reflect changes in the individual characteristics of the

athlete impacting their efficiency. Therefore, perhaps this parameter could contribute to the information used when making decisions about athlete training status.

## **2.5. Training Status**

### **Fatigue**

While acute fatigue, defined as a reduction in capacity, is a side-effect of training to stimulate positive adaptation (functional overreaching), an imbalance between the stress and recovery doses can result in unplanned fatigue (non-functional overreaching) which is characterised by a failure of exercise capacity to rebound following recovery (Fry et al., 1992; Meeusen et al., 2006). Discussions surrounding the mechanisms of fatigue have been well documented for many decades with the continuing lack of a standard definition highlighting its complexity (Abbiss & Laursen, 2007; Noakes, 2000; St Clair Gibson et al., 2003). A range of theories including cardiovascular/anaerobic, energy supply/depletion, and neuromuscular models exist with the most consistent feature in the varying definitions, being the failure to maintain maximal/required force generation (Abbiss & Laursen, 2005; Halson, 2014; Kent-Braun, 1999; Noakes, 2000). Although the mechanisms behind fatigue may provide fundamental knowledge, the more crucial focus for contemporary athlete monitoring is the impact that fatigue has on training and performance. Due to the breadth of contributing mechanisms to fatigue, a variety of parameters, including both objective and subjective markers to monitor training status are reported in the literature (Halson, 2014; Meeusen et al., 2006; Rietjens et al., 2005; Urhausen & Kindermann, 2002).

### **Objective markers of training status**

Physiological parameters including cardiovascular (Buchheit, 2014), endocrine (Cormack, Newton, McGuigan, et al., 2008), inflammatory (Coutts, Reaburn, Piva, & Murphy, 2007),

and/or immunological (Fry et al., 1994) markers have all been connected to training status, with arguably the most frequently measured being neuromuscular fatigue (Cormack et al., 2012; Mclean et al., 2010). Measuring changes in the autonomic nervous system using HR indices is also prevalent (Achten & Jeukendrup, 2003; Bosquet, Merkari, Arvisais, & Aubert, 2008; Daanen, Lamberts, Kallen, Jin, & Van Meeteren, 2012). Recently, a review by Buchheit (2014) explored HR indices at rest, during exercise, following exercise and recovery from exercise for determining training status. An extensive list of methods and indices as well as a guide to interpreting changes within the context of the training was provided with 5 min of resting HR and submaximal exercise HR concluded as the most valuable. Specifically, HR at rest might be useful for assessing acute and chronic training status while HR during exercise seems to reflect chronic positive adaptations (Buchheit, 2014).

Hormonal levels as a measure of the neuroendocrine response to training, particularly in team sport, have also been extensively researched with varying results (Cormack, Newton, & McGuigan, 2008; Coutts, Reaburn, Piva, & Murphy, 2007; Elloumi, Maso, Michaux, Robert, & Lac, 2003; Filaire, Lac, & Pequignot, 2003; Hoffman, Kang, Ratamess, & Faigenbaum, 2005; Maso, Lac, Filaire, Michaux, & Robert, 2004; Mclean et al., 2010). Cortisol and testosterone as independent indices, as well as the testosterone to cortisol ratio to reflect the imbalance between the anabolic and catabolic states, are potential indicators of training status (Coutts, Reaburn, Piva, & Murphy, 2007; Kraemer et al., 2004). Although the very high intra-class coefficient ( $r = 0.995$ ) between serum and saliva samples has reduced the invasiveness of collecting endocrine measures, the research on their ability to detect training imbalances remains inconclusive (Coutts, Reaburn, Piva, & Rowsell, 2007; Mclean et al., 2010; Meeusen et al., 2006; Neary, Malbon, & McKenzie, 2002; Schmikli, Brink, de Vries, & Backx, 2011). Similarly to endocrine markers, immunological and inflammatory parameters, as well as intramuscular enzymes as indirect markers of muscle damage (e.g. creatine kinase), are also

commonly explored (Coutts, Reaburn, Piva, & Murphy, 2007; Fry et al., 1994; Mackinnon, 2000; Shephard & Shek, 1994). Despite considerable research, the conclusions regarding physiological markers of fatigue are inconsistent and complex due to the nature of the overtraining continuum and the uncertainty regarding the direction of the physiological response depending on where along the continuum an athlete might be (Halson, 2014; Meeusen et al., 2006; Saw et al., 2016).

In the neuromuscular model, central factors which disturb transmission between the central nervous system and muscle membrane, and peripheral factors which involve altered conditions within the muscle are both considered contributors to fatigue (Giannesini, Cozzone, & Bendahan, 2003). Markers of low-frequency neuromuscular fatigue (categorised by force reduction at frequencies below 50 Hz) appear relevant to performance while high-frequency fatigue is uncommon in voluntary activation. Research suggests that low-frequency fatigue results from repeated stretch-shortening cycle contractions and has a slow recovery period (hours or days) (Fowles, 2006; Jones, 1996). Various electromyography and mechanomyogram techniques to detect exercise induced neuromuscular fatigue are available (Hug, Faucher, Kipson, & Jammes, 2003; Sjøgaard, Blangsted, Jørgensen, Madeleine, & Sjøgaard, 2003). However, the complexity, expense and impracticality of these techniques has led to research on the use of practical and functional movements based on stretch-shortening cycle activities (Cormack, Newton, McGuigan, et al., 2008; Fowles, 2006). In AF, the ratio of flight time to contraction time during a single counter-movement jump (CMJ) is reported to be reduced post-match compared to pre-match and 48 hours pre-match (Cormack, Newton, & McGuigan, 2008). With acceptable overall intra/inter-day reliability (%TEM = 8.2%) and a time-course of return to baseline by 72 hours, it is suggested to allow for timely intervention if there's a delay in neuromuscular fatigue recovery (Cormack, Newton, & McGuigan, 2008).

With failure to maintain maximal force generation a defining characteristic of fatigue, performance decrements are widely accepted as a symptom (Buchheit & Laursen, 2013a, 2013b; Coutts, Reaburn, Piva, & Rowsell, 2007; Halson, 2014; Kent-Braun, 1999). Although there is no consensus as to the magnitude of performance decrement required to suggest a training imbalance, a decrement as small as 0.5 to 2.0% was proposed by Lehmann et al. (1999). In a group of athletes identified as overtraining, submaximal performance decreased 6% in soccer players and 8% in middle-distance runners (Schmikli et al., 2011). Furthermore, sprint velocity and total distance in a match simulation was significantly reduced during a high training period compared to low training period in trained team-sport athletes (Slattery, Wallace, Bentley, & Coutts, 2012). In deliberately overreached team-sport athletes, it was shown the performance on a multi-stage fitness test was significantly reduced (-12.3%) following a 6-week training period before significantly improving following a 7-day taper (Coutts, Reaburn, Piva, & Murphy, 2007). A similar pattern was seen for isokinetic strength and power at slow speeds and a range of physical performance variables including vertical jump, 3-repetition max bench press, 3-repetition max squat and maximum chin-ups, reached minimum clinically important differences in the same fashion (Coutts, Reaburn, Piva, & Murphy, 2007). The research suggests that a sport-specific maximal performance test which is standardised and reproducible is the most likely to reflect changes in training status (Halson & Jeukendrup, 2004; Meeusen et al., 2006). The practicality is questionable however, as most maximal tests are not team sport-specific and imposing a maximal test, particularly at regular intervals, while trying to minimise fatigue during the competition phase may be unfeasible.

### **Psychometric Inventories**

Psychological markers of training status are well supported with behavioural symptoms such as disturbed sleep and mood changes described as signs of non-functional overreaching (Coutts & Reaburn, 2008; Hooper et al., 1995; Main & Grove, 2009; Meeusen et al., 2006; Morgan et al., 1987; Saw et al., 2016). Measured using the Profile of Mood States (POMS) (McNair, Lorr,

& Droppleman, 1992), mood disturbances have been related to both performance decrements and physiological markers of overtraining in a range of studies (Fry et al., 1994; Morgan et al., 1987; O'Connor, Morgan, Raglin, Barksdale, & Kalin, 1989; Raglin, 1993; Raglin & Morgan, 1994). While increases in depression seem to be related to stale athletes, changes in the vigour and fatigue factors are most sensitive to training loads (Morgan et al., 1987; O'Connor, Morgan, & Raglin, 1991; Schmikli et al., 2011). This is supported by research demonstrating that the ratio of POMS vigour to fatigue, termed 'energy index', was related to changes in training load and hormone levels in athletes (Kenttä, Hassmén, & Raglin, 2006; Odagiri, Shimomitsu, Iwane, & Katsumura, 1996). In order to actively measure the recovery process as well as the stress imposed by training, the Recovery-Stress Questionnaire (RESTQ-Sport) and Recovery-Cue were developed (Kallus, 1995; Kellmann & Kallus, 2000; Kellmann, Patrick, Botterill, & Wilson, 2002). Also having a dose-response relationship with training load, physiological markers and other psychological assessments, they are proposed as valid tools to measure training status (Coutts & Reaburn, 2008; Kellmann, Altenburg, Lormes, & Steinacker, 2001; Kellmann & Gunther, 2000). Correlations between POMS and RESTQ-Sport indices have been reported in detail for collegiate swimmers and elite rowers (Kellmann et al., 2001; Kellmann & Gunther, 2000; Kellmann & Kallus, 2000). In each study, the vigour scale from the POMS was positively correlated to the recovery scales in the RESTQ-Sport while tension, depression, anger, fatigue and confusion negatively correlate to recovery.

The Daily Analysis of Life Demands for Athletes (DALDA) is designed to measure everyday sources of stress for an athlete in part A as well as identifying stress-reaction symptoms in part B (Rushall, 1990). Research has found that part B of the questionnaire shows significantly more 'worse than normal' responses during overtraining and was able to distinguish an intensified training group of triathletes from a normal training group (Coutts, Slattery, & Wallace, 2007; Halson et al., 2002). Using a range of existing tools including the Perceived Stress Scale

(Cohen, Kamarck, & Mermelstein, 1983), the Brunel Mood State Scale (Terry, Lane, & Fogarty, 2003), the Training Stress Scale (Grove et al., 2005) and Athlete Burnout Questionnaire (Raedeke & Smith, 2001), a six-factor multi-component model of training distress was established (Table 2-2) (Main & Grove, 2009). The research unequivocally endorses psychometric measures as indicators of training status and an advantage of all questionnaires is that they are non-invasive and inexpensive. Yet established tools can be too lengthy to foster compliance from athletes, impractical for daily use and non-specific, particularly in team-sport athletes (Twist & Highton, 2012).



**Table 2-2** Training distress factors.

Depression (DEP)	<ul style="list-style-type: none"><li>- miserable</li><li>- unhappy</li><li>- bitter</li><li>- downhearted</li><li>- depressed</li></ul>
Vigour (VIG)	<ul style="list-style-type: none"><li>- energetic</li><li>- lively</li><li>- active</li><li>- alert</li></ul>
Physical Symptoms (SYM)	<ul style="list-style-type: none"><li>- muscle soreness</li><li>- heavy arms or legs</li><li>- stiff/sore joints</li></ul>
Sleep disturbances (SLE)	<ul style="list-style-type: none"><li>- difficulty falling asleep</li><li>- restless sleep</li><li>- insomnia</li></ul>
Stress (STR)	<ul style="list-style-type: none"><li>- stressed</li><li>- could not cope</li><li>- difficulties piling up</li><li>- nervous</li></ul>
Fatigue (FAT)	<ul style="list-style-type: none"><li>- tired</li><li>- sleepy</li><li>- worn-out</li></ul>

From Main, L. C., & Grove, J. R. (2009) A multi-component assessment model for monitoring training distress among athletes. *European Journal of Sport Science*, 9(4), 195-202.

### **Athlete self-report measures**

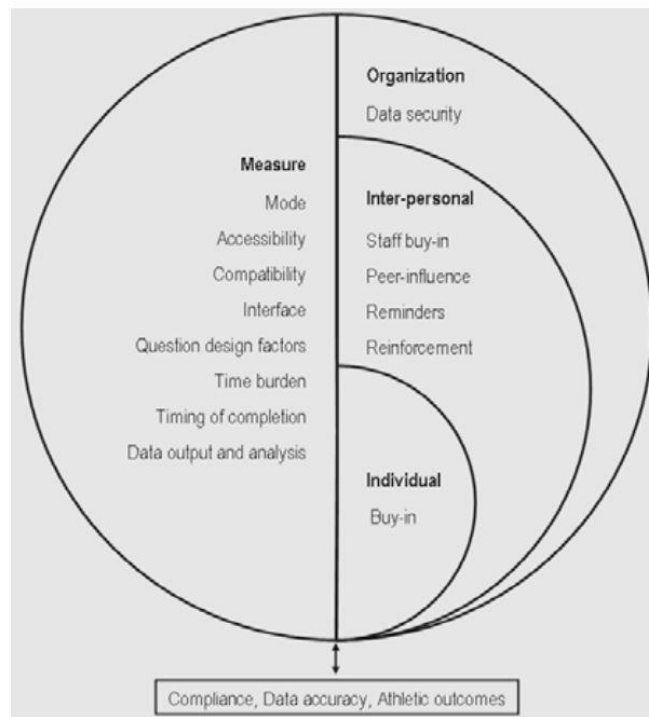
With the mounting evidence in support of psychological markers of training status and in order to foster compliance and improve specificity, practitioners have been encouraged to incorporate customised, shortened versions of these instruments into their monitoring practices (Buchheit, Racinais, et al., 2013; Coutts & Reaburn, 2008; Gastin, Meyer, et al., 2013; Hooper &

Mackinnon, 1995; Mclean et al., 2010; Saw et al., 2016). A survey of Australian and New Zealand high-performance sport practitioners on current trends of fatigue monitoring revealed that 84% of responders use self-report questionnaires, majority (80%) of which use custom designs consisting of 4 to 12 items (Taylor et al., 2012). Reinforcing the factors determined from the Main and Grove (2009) model, muscle soreness, sleep quality and general wellness measured on a Likert scale were the most common elements used. Due to the fact that individual athletes might react differently to the same external load and physiological stress, and that psychology plays a substantial role in performance, these athlete self-report measures seem fundamental to the interpretation of preparedness (Saw et al., 2016).

In a study exploring self-reported wellness in response to AF matches, days-to-game was a significant coefficient for a range of wellness items, suggesting that perceived wellness improves as the next game day approaches (Gastin, Meyer, et al., 2013). In a separate study examining the effect of match and training load on perceived soreness in AF players, soreness peaked (Cohen's effect size ( $d$ ) = 0.37) immediately following a match and declined steadily in the days after, with subsequent training load having no substantial contributions to perceived muscular soreness (Montgomery & Hopkins, 2013). Similarly, recovery index calculated from individual wellness items displayed a decay-curve response to matches in AF despite the imposed load from training (Bahnert et al., 2013). It was also reported that except for 1 d post match, recovery index significantly decreased (improved recovery) across the season, potentially explained by reduced training loads between matches as the season progressed (Bahnert et al., 2013). Alternatively, another study in AF reported that overall self-reported wellness was sensitive to subtle changes in the previous days training load during an intensified training camp (Buchheit, Racinais, et al., 2013). In rugby league, perceived wellness was also significantly reduced 1 d post match regardless of the length of the micro-cycle (5-, 7- or 9-days between matches) but only remained reduced at 2 d post match for the 7- and 9-day cycles

(McLean et al., 2010). At 2 d post match, there was significantly better overall wellness for the 5-day micro-cycle than the 7- or 9-day cycles. During the competition phase, significant correlations ( $r$ ; 95% CI =  $-0.51$ ;  $-0.39$  to  $-0.62$ ) between self-reported fatigue and total HSR distance was seen in professional soccer players, while no significant relationship was evident with sleep quality, and muscle soreness (Thorpe et al., 2015). It appears that athlete self-report measures are sensitive to match loads but training doses during competition phases do little to impact this response even though a substantial portion of variability in self-report measures remains unaccounted for.

Although research supporting the use of athlete self-report measures is accumulating, these tools rely heavily on athlete honesty and compliance as there is the risk of response distortion (Saw et al., 2015a). In a comprehensive collection of work, Saw and colleagues (Saw et al., 2015a, 2015b, 2016) thoroughly examined the use of self-report measures for monitoring athletes. Following a qualitative investigation involving athletes, coaches and sport science staff from a national institute, the inter-relations of the factors associated with their implementation was explored (Saw et al., 2015a). Displayed in Figure 2-5 eight considerations relating to the measure itself were established, with six considerations for the social environment. Furthermore, a four step process in utilising self-report measures was determined as: (1) record data (2) review data (3) contextualise; and (4) act (Saw et al., 2015b). The 'act' component of their utilisation is suggested to include feedback to the athlete/coach and training prescription modification. While athlete self-report measures are proposed as valid indicators of training status, their impact on subsequent exercise output is yet to be determined. None-the-less, it is apparent that with well-developed designs and considered processes, an item as simple as athlete self-report measures may effectively enhance a training program (Hooper & Mackinnon, 1995; Saw et al., 2015b).



**Figure 2-5** Factors perceived to influence the implementation of athlete self-report measures.

Factors associated with the measure (left) and social environment (right) interrelate and influence the outcomes of implementation (compliance, data accuracy and athlete outcomes).

From Saw, A. E., Main, L. C., & Gastin, P. B. (2015a). Monitoring athletes through self-report: Factors influencing implementation. *Journal of Sports Science & Medicine*, 14(1), 137-146.

## 2.6. Athlete Monitoring and Performance

In the team-sport environment, performance is measured on the number of matches won and ultimately, premiership success. While actual performance is dependent on a range of factors (e.g. list management, opposition, tactics, skill execution and decision making), the role of a conditioning coach or sports scientist is to optimally prepare the playing group for competition. Preparedness is the immediate ability of the athletes to perform and refers to the interaction between fitness and fatigue (both physical and psychological). The fitness-fatigue model proposed that peak preparedness will occur at a delayed time point from the last intense training phase, when fitness effects are high and fatigue responses have diminished (Banister & Calvert, 1980). Examining the direct relationship between preparedness and match performance is difficult in team sports due to the complexity in quantifying both preparedness and performance

(Borresen & Lambert, 2009; Halson, 2014). Mathematical models to quantify preparedness, and the ability of these models to predict actual performance, have been discussed in a previous section (see section 2.3) (Borresen & Lambert, 2009; Busso et al., 1991; Mujika et al., 1996; Suzuki, Sato, Maeda, & Takahashi, 2006). Limited research exploring contemporary monitoring practices and performance in team sports exists (Aughey et al., 2015; Cormack et al., 2012; Gastin, Fahrner, et al., 2013; Mooney et al., 2012).

In a full AF season, it was shown that neuromuscular fatigue, measured via flight time to contraction time ratio from counter-movement jumps, may have a one match ( $r \pm 90\% \text{ CL} = -0.16 \pm 0.13$ ) to two match ( $r = -0.24 \pm 0.13$ ) delayed impact on coaches ratings of performance (Cormack, Newton, McGuigan, et al., 2008). More recently in AF, it was shown that neuromuscular fatigue, again measured with CMJs, did not affect external match output variables of PL or HSR (when corrected for physical capacity - measured by the Yo-Yo IR level 2) (Mooney et al., 2012). However, neuromuscular fatigue did have a negative effect on the relationship between HSR and PL ( $r = -0.43 \pm 0.29$ ) and between PL and performance ( $r = -0.73 \pm 0.43$ ) (coaches' ratings). It was suggested that a change in mechanical efficiency (increase in lateral movements) might result in altered movement patterns that produce the same player output, but are seen negatively by coaches. It also appeared that the movements contributing to PL were less dependent on physical capacity because the relationship between Yo-Yo IR level 2 and PL ( $r = -0.44 \pm 0.26$ ) was altered under fatigue (Mooney et al., 2012). This was further corroborated in Cormack et al. (2012), where neuromuscular fatigue reduced the contribution of the vertical accelerometer vector to PL. Due to the observed reduction in the relationship between HSR and PL (Mooney et al., 2012), it is possible that a greater proportion of load is being accrued at lower HSR and/or more steady pace potentially related to impairments in contractile function under neuromuscular fatigue (Cormack et al., 2012).

Interestingly, another study in AF determined that external load was not related to team objective match performance (measured using an impact ranking system), although at an individual level, that relationship was moderated by repeat sprint performance (Gastin, Fahrner, et al., 2013). Players who performed better on a repeated sprint test responded negatively to increases in training load, showing a reduction in player rank. However, due to the individualised speed zones used in the external load calculation, the faster athletes were training at higher speeds and possibly taking longer to recover from a greater eccentric load (Gastin, Fahrner, et al., 2013). Exploring the relationship of both load and wellness to performance in professional soccer players, it was determined that team performance (wins vs losses) and the iceberg profile from the POMS was not impacted following increased high-intensity training despite a decrease in testosterone to cortisol ratio suggesting an increased catabolic state (Filaire et al., 2001). Alternatively, a recent study found that weekly load was likely greater preceding wins compared to losses even when controlled for days between matches in AF (Aughey et al., 2015). Moreover, TSB was possibly greater positive (higher four week mean load compared to current week) in wins versus losses also when controlled for ladder position of the opposition or days between matches (Aughey et al., 2015). However, given the multitude of factors that contribute to winning a match in AF, the validity of using win/loss as the performance outcome measure is uncertain. Furthermore, while winning is the ultimate goal, the performance outcome of wins versus losses has the potential to conceal individual performance responses to training load and examination into the individual interaction between athlete preparedness (load and training status) and performance is lacking.

## **2.7. Australian Football**

Australian football originated in 1858 in Victoria, Australia. Today AF is played at all levels, from junior to professional, throughout 30 countries worldwide. The premier league of AF is run by the Australian Football League (AFL), which is recognised by the Australian Sports

Commission as a national sporting organisation. Played in all seven states and territories in Australia, in 2015 the 200<sup>+</sup> AFL matches drew close to 7-million attendees. Australian football has evolved over many decades and in the modern game 18 teams make up the professional league. The season consists of 23 home and away rounds (1 bye per team) followed by four rounds in the finals series. The last match of the season is the grand final where two teams play off for the premiership cup. Matches are played weekly, usually from Friday to Sunday, between March and October. During a match of four 20-min quarters (not including stoppages in play and with two 6-min quarter time breaks and one 20-min half time break), the two teams contest play, with the aim of scoring more points than the other team (Gray & Jenkins, 2010). Each team has a squad list of approximately 46 professional male players. Each round, 22 players are selected to play the upcoming match. The remaining available (uninjured) players play in their corresponding state league. Eighteen players from each team are on the field at one time. Three of the remaining 4 players make up the interchange bench, allowed to rotate with players on the field at any time. The 22<sup>nd</sup> player is a substitute who can be activated at any time during the match. Once the substitute has been activated, the player who was substituted off can take no further part in the match.

Australian football is a field-based intermittent running game, requiring aerobic endurance, speed, strength and skill. In the 2014 season, the annual match analysis report revealed minimal changes from the 2013 season with a mean ( $\pm$  standard deviation) total distance per match of  $12.8 \pm 1.8$  km and a mean speed of  $7.2 \pm 0.6$  km·hr<sup>-1</sup> across the competition (Wisbey & Montgomery, 2015). Up to 30% of this distance is shown to be covered at high speed with significant changes in movement profile as a match progresses (Aughey, 2010; Coutts et al., 2010). A match is also interspersed with repeated accelerations and decelerations, change of directions and collision incidents with high metabolic cost (Boyd et al., 2013; Coutts et al., 2014). Positional differences in movement profiles are evident with nomadic players generally

having higher external output for mean speed and HSR than fixed positions (Wisbey, Montgomery, Pyne, & Rattray, 2010).

The unique requirements of AF provide challenges for coaches and sport scientists. The intermittent collision nature of the movement demands as well as the concurrent training techniques used to develop endurance, speed, strength and skill complicates load quantification. Furthermore, the congested competition schedule of weekly matches is distinct from traditional periodisation techniques of peaking for one major competition and prescribing optimal training and recovery doses for 26 matches in 27 weeks is delicate. Finally, when dealing with a squad of ~46 athletes, consideration for the inter-individual variations between athletes is crucial and feasibility of any instrument employed is paramount.

## **2.8. Summary**

There is a general consensus that a successful training program to enhance preparedness for competition is dependent on the attainment of precise stress and recovery doses (Bompa & Haff, 2009; Meeusen et al., 2006). It is also accepted that this balance will vary between and within athletes in a training regime based on a complex interaction of factors (Lehmann et al., 1993). The limitations of proposed mathematical models to predict preparedness and hence, performance, in response to training doses and the theoretical fitness and fatigue after-effects in a team sport have been discussed (Hellard et al., 2006). As such, the contemporary approach of monitoring athlete preparedness by quantifying exercise load and determining training status is used to complement training and recovery prescriptions in applied sport settings (Kenttä & Hassmén, 2002). It is currently recognised that external and internal loads are relevant components of load quantification, each with their own contribution to an effective monitoring system (Akubat et al., 2014). The commonly used subjective internal s-RPE method has been shown to correlate to both external load and other objective measures of internal load, with an



awareness that variables, such as activity type, will moderate this relationship (Gaudino et al., 2015; Lovell et al., 2013). To enhance the application of external and internal loads, a comprehensive understanding of their relationship relative to specific characteristics that may impact on this relationship for certain athletes, is necessary.

On the basis of the strong evidence presented for psychometric indices as markers of training status, the use of customised athlete self-report measures in professional sport has expanded (Hooper et al., 1995; Saw et al., 2016). Research findings support the validity of athlete self-report measures in response to load (Bahnert et al., 2013; Buchheit, Simpson, et al., 2013; Gastin, Meyer, et al., 2013). However, further exploration of the response of self-report measures relative to varying conditions within the competitive season (e.g. match-to-match micro-cycle) is required. Furthermore, the proposed practice of using athlete self-report measures to adjust subsequent training prescription requires exploration of the association between pre-training self-report measures and subsequent activity profiles.

An effective athlete monitoring system will complement training and recovery prescriptions, lead to enhanced preparedness, and ultimately improve performance. Few studies have reported the relationships between individual monitoring parameters and measures of performance (Aughey et al., 2015; Filaire et al., 2001). However, research to substantiate the use of a variety of contemporary monitoring measures by examining their direct effect on individual match performance is lacking. The overall objective of this research program was to investigate contemporary athlete monitoring practices in professional AF. This research sheds light on the application of such contemporary monitoring practices, by coaches and sport scientists to optimally prepare athletes for competition. This, in turn, will increase performance potential and aid in achieving the goal of any training program, *i.e.* competition wins and team success.



## **Chapter 3. Study 1: Characteristics impacting on session rating of perceived exertion training load in Australian footballers**

### **Publication Statement**

This chapter is comprised of the following manuscript which is published in Journal of Sports Sciences:

Gallo, T., Cormack, S. J., Gabbett, T. J., Williams, M. D., & Lorenzen, C. (2015). Characteristics impacting on session rating of perceived exertion training load in Australian footballers. *Journal of Sports Sciences*, 33(5), 467-475. doi: 10.1080/02640414.2014.947311.

### **Linking Paragraph**

As established in section 2.3, the first step of a contemporary monitoring system requires the quantification of load. While various methods of load quantification exist, the complementary employment of external and internal load prescription and monitoring has not been fully established. Although it is reasonable to consider internal load as the key to eliciting adaptations, prescribing training with internal load (in particular s-RPE which is a global measure of perceived exertion influenced by a range of factors), is impractical in a team sport setting. As such, a clearer understanding of the s-RPE a prescribed external load might elicit in a high-intensity intermittent, collision sport, will allow more accurate prescription. Acknowledging that between individual variations exist in the internal load an external load will produce, the aim of this study was to determine if easily identifiable characteristics in a team sport setting (playing position, experience and time-trial performance) influence s-RPE and as such, can be used to improve training prescription.

## Abstract

The relationship between external training load and session rating of perceived exertion (s-RPE) training load and the impact that playing experience, playing position and 2-km time-trial performance had on s-RPE training load was explored. From 39 Australian Football players,  $6.9 \pm 4.6$  training sessions were analysed, resulting in 270 samples. Microtechnology devices provided external training load (distance, mean speed, high-speed running distance, Player load<sup>TM</sup> (PL), and Player load slow<sup>TM</sup> (PL<sub>slow</sub>)). The external training load measures had moderate to very large associations ( $r$ ; 95% CI) with s-RPE training load; mean speed (0.45, 0.35–0.54), high-speed running distance (0.51, 0.42–0.59), PL<sub>slow</sub> (0.80, 0.75–0.84), PL (0.86, 0.83–0.89) and distance (0.88, 0.85–0.90). Differences were described using effect sizes ( $d \pm 95\%$  CL). When controlling for external training load, the 4- to 5-year players had higher s-RPE training load than the 0- to 1- ( $0.44 \pm 0.33$ ) and 2- to 3-year players ( $0.51 \pm 0.30$ ), ruckmen had moderately higher s-RPE training load than midfielders ( $0.82 \pm 0.58$ ), and there was a 0.2% increase in s-RPE training load per 1 s increase in time-trial (95% CI: 0.07–0.34). Experience, position, and time-trial performance impacted the relationship between external training load and s-RPE training load. This suggests that a given external training load may result in different internal responses between athletes, potentially leaving individuals at risk of overtraining or failing to elicit positive adaptation. It is therefore vital that coaches and trainers give consideration to these mediators of s-RPE training load.

**Keywords:** external training load, internal training load, prescribing training, athlete monitoring, team sport

## Introduction

To maximise physical capacity and manage fatigue, training should be accurately planned, monitored, and adjusted (Borresen & Lambert, 2009; Lambert & Borresen, 2010). Training load is determined by exercise volume and intensity (Smith & Norris, 2002), and can be quantified by external and/or internal parameters with external training load representing the dose performed and internal training load representing the psycho-physiological response experienced by the athlete (Impellizzeri et al., 2005). Despite the fact that there is inter-individual variation in response to external training load, in team sports, training is typically planned using external parameters and mostly occurs as a collective. Consequently, the prescribed external training load may result in internal training loads that lead to a training imbalance, leaving some athletes at risk of overtraining and others failing to reach a training stimulus adequate for positive adaptation (Borresen & Lambert, 2009; Impellizzeri et al., 2005; T. J. Scott et al., 2013). Therefore, to plan an effective training regime, coaches and trainers must understand the internal response an external training load will elicit in each of their athletes.

Microtechnology devices provide external training load measures including total distance travelled and distances in various speed zones. However, in high-intensity intermittent contact sports, such as Australian football (AF), quantifying training load is more complex than in continuous non-contact sports because the unpredictable change of pace and direction and collisions that occur in AF, all contribute to the overall load (Takarada, 2003; Young et al., 2012). The Player load<sup>TM</sup> (PL) algorithm from microtechnology, which combines rate of change in acceleration from three planes of movement, is suggested to incorporate all forms of activity including skill and contact-based activities relevant to intermittent contact sports (Aughey, 2011; Boyd et al., 2013). However, the large correlations between distance and PL suggest that the foot strikes (vertical plane accelerations) and locomotor activity (forward acceleration)

impact heavily on this parameter (Boyd et al., 2013; Boyd et al., 2010; Casamichana et al., 2013). Recent research differentiated Player load slow<sup>TM</sup> (PL<sub>slow</sub>), which removes activity above 2 m·s<sup>-1</sup>, from PL in elite AF matches (Boyd et al., 2013). It was proposed that PL<sub>slow</sub>, provides different information about low-speed activity (e.g. grappling and ruck contests), which is currently underrepresented in traditional speed-based time-motion analysis (Boyd et al., 2013).

While successful performance relies on a specific external training load being reached, it is the internal training load that elicits adaptations (Impellizzeri et al., 2004; Impellizzeri et al., 2005; Lovell et al., 2013; B. R. Scott et al., 2013; T. J. Scott et al., 2013). Internal training load has been quantified using heart-rate-based methods for determining a training impulse for endurance athletes (Banister & Calvert, 1980; Busso et al., 1991; Edwards, 1993; Lucia et al., 2003) and modified for team-sport athletes (Akubat & Abt, 2011; Akubat et al., 2012; Manzi et al., 2013; Stagno et al., 2007). However, due to its simplicity and strong validity, many AF (and other team-sport) clubs have adopted the session rating of perceived exertion (s-RPE) method to quantify internal training load (Coutts, Murphy, et al., 2003; Foster et al., 2001; Impellizzeri et al., 2004; T. J. Scott et al., 2013).

An abundance of literature exists reporting small to very large correlations between external training load measures and s-RPE training load in a range of settings (Akubat et al., 2014; Borresen & Lambert, 2008; Casamichana et al., 2013; Lovell et al., 2013; B. R. Scott et al., 2013; T. J. Scott et al., 2013; Weaving et al., 2014). However, potential mediators (i.e. existing fatigue, fitness, and task proficiency) of this relationship have received much less attention (Haddad et al., 2013; Manzi et al., 2010; Milanez et al., 2011). When the internal training load is quantified using s-RPE training load, the relationship is further impacted by an athlete's psychological characteristics and current psychological state including mood and motivation

(Blanchfield et al., 2014). Understanding the potential influence of characteristics impacting s-RPE training load may provide coaches and trainers with a better understanding of the response that a given external training load might elicit in their athletes and therefore enhance training prescription and athlete monitoring.

Evidence currently exists documenting the influence of fitness on perceived exertion in trained endurance runners and professional futsal players (Garcin et al., 2004; Milanez et al., 2011). Similar results were seen in professional basketball players where those who performed better on the Yo-Yo IR level 1 reported lower mean s-RPE training load (Manzi et al., 2010). Since time-trials ranging from 1500 to 3000 m are common performance measures in AF (Le Rossignol, Gabbett, Comerford, & Stanton, 2014; Lorenzen, Williams, Turk, Meehan, & Cicioni Kolsky, 2009), establishing if time-trial performance has an impact on the relationship between external and internal training load would encourage coaches to consider time-trial results when prescribing and/or monitoring training loads.

Furthermore, a recent Australian Football League (AFL) report revealed higher injury incidence and prevalence in first-year players than more mature players (Ullah & Finch, 2010). The first-year players may not be fully prepared, either physically or mentally, for the high loads of professional AF, compared with the older players who have been exposed to multiple years of training in a professional program (Veale, Pearce, Buttifant, & Carlson, 2010). It is possible that AFL experience influences s-RPE training load, highlighting the risk of a training imbalance in younger players. A recent study in AF also demonstrated differences in external training load measures between playing positions in both matches and training (Boyd et al., 2013). It was reported that in an elite AF match, midfielders had the highest PL, whereas for the PL<sub>slow</sub> variable, ruckmen had higher external training load than all other positions (Boyd et al., 2013). This suggests that the different movement patterns of playing positions expose

athletes to different physical stress, and external training load variables measuring locomotor activity, such as distance, high-speed running distance and even PL, may underestimate or overestimate exercise intensity for certain positions (Boyd et al., 2013). Understanding how players of different playing positions might respond to the prescribed external training load can advance training design.

This study further examined the relationship between external and internal training load in a high-intensity, intermittent collision sport by exploring characteristics that might impact s-RPE training load. The aim was to determine whether experience, playing position and time-trial performance impacted s-RPE training load.

## **Methods**

### **Participants**

Following approval from the University's Ethics Committee, the entire squad of one AFL club (the highest level of AF) was invited to participate in this study. Informed consent was obtained from 41 non-injured male AF players (mean  $\pm$  s: 22.6  $\pm$  3.0 years, 186.4  $\pm$  7.5 cm, 85.5  $\pm$  8.4 kg, 4.8  $\pm$  3.2 years in AF, 45.4  $\pm$  60.6 senior matches). This study examined external (microtechnology variables) and internal (s-RPE) training load from 14 skill-based training sessions during mid to late pre-season in 2012 (week 11 to 22). A 25-min warm-up preceded each training session comprising of different drills (technical drills, tactical drills, small-sided games, and match practice scenarios).

### **Procedures**

#### ***External training load***

During each main training session of the study period, 19.3  $\pm$  1.0 randomly selected players wore a commercially available microtechnology device, with tri-axial accelerometers



(MinimaxX, Team 2.5, Catapult Innovations, Scoresby, Australia). The device was worn in a custom made vest, fitting the unit tightly against the posterior side of the upper torso between the shoulder blades. The satellite data sampled at a rate of 10 Hz, which is reported to have improved reliability and validity for short sprints compared to the 1 and 5 Hz units (Varley et al., 2012). The accelerometers sampled at 100 Hz and are also reported to be reliable and valid (Boyd et al., 2013). Using Catapult Sprint 5.0.6 software; data were downloaded, with transition time in between training drills removed, as to not underestimate the proportion of distance in speed zones or mean speed (White & MacFarlane, 2013). External training load was measured using distance, mean speed, high-speed running distance, PL and PL<sub>slow</sub>. High-speed running distance was defined as the distance run above a set threshold (individualised as each player's mean 2-km time-trial speed, with a group mean of 18.1 km·hr<sup>-1</sup> and range of 16.9 km·hr<sup>-1</sup> to 19.7 km·hr<sup>-1</sup>) (Abt & Lovell, 2009). Player load<sup>TM</sup> is a vector magnitude of the accelerometer data from the microtechnology device. The arbitrary unit of measurement represents the square root of the sum of the squared instantaneous rate of change in acceleration in the X, Y and Z axis divided by 100 (Boyd et al., 2011). Player load<sub>slow</sub><sup>TM</sup> is the vector magnitude of the accelerometer data when speed is < 2 m·s<sup>-1</sup>.

### ***Internal training load: Session rating of perceived exertion***

Internal training load for each session was determined for every player using the s-RPE training load method (Foster et al., 2001). Exercise duration, defined as the sum of individual drill times, was multiplied by a RPE for each player (Wallace, Slattery, Impellizzeri, & Coutts, 2014). Individual drill time, with transition time removed, was used to provide comparable volume to the external training load measures. Players were shown the modified Borg RPE scale approximately 30 min upon completing the session (Foster et al., 2001). Education was provided on the RPE scale, with players encouraged to give a global rating of the session using any intensity cues they deemed relevant. Players had been using the RPE scale for over 12 months leading up to the study period. This commonly used method has been reported to be

reliable and has previously been shown to be correlated with other measures of internal and external training load in a range of settings (Casamichana et al., 2013; Coutts, Murphy, et al., 2003; Eston, 2012; Impellizzeri et al., 2004).

### ***Identifiable characteristics***

As per usual club practices, players completed a series of 2-km time-trials in the early phase of pre-season. The time-trials were completed on an outdoor polyurethane athletics track. A standardised dynamic warm-up consisting of a 5-min jog, 5-min of back mobility exercises, 6  $\times$  80 m strides and 3  $\times$  50 m run-throughs preceded the time-trial. Time was recorded using a stopwatch by fitness staff. The time-trial results from week 11 of pre-season were used in the analysis, as it was during the first week of the data collection period and hence most representative of performance during the time frame being analysed. Ambient air temperature was 20.0<sup>0</sup> C and relative humidity was 53%. If the player did not complete the time-trial on that day, the result from the previous test (week 6) was used (ambient air temperature of 24.4<sup>0</sup> C and relative humidity of 57%). The number of years on the playing list of an AFL club was used to classify players into experience groups (0- to 1-years, 2- to 3-years, 4- to 5-years, and 6<sup>+</sup> years) (Rogalski, Dawson, Heasman, & Gabbett, 2013). In order to obtain a sufficient sample size in each category, players were split into 2-year intervals. To determine whether internal training load was affected by playing position, players were classified as key position, nomadic, midfielders or ruckmen as per their role in the team (Boyd et al., 2013).

### **Statistical Analyses**

Statistical analysis was performed using SPSS (version 19.0.0.1; SPSS Inc., Chicago, USA). Values are reported as mean and standard deviations (*s*). Statistical significance was set at the 0.05 level and all effect sizes reported with 95% confidence limits (CL). Pearson's correlation coefficient (*r*) was used to determine relationships between s-RPE training load and external training load measures (distance, mean speed, high-speed running distance, PL and PL<sub>slow</sub>) and

reported with 95% confidence intervals (CI). The magnitude of the correlation was described as < 0.1 trivial, 0.1 to 0.3 small, 0.3 to 0.5 moderate, 0.5 to 0.7 large, 0.7 to 0.9 very large, and 0.9 to 0.99 nearly perfect (Hopkins, 2002).

To determine whether s-RPE training load was affected by any of the characteristics when controlling for the variance explained by external training load, the analysis was performed in two stages. First, in order to model s-RPE training load against external training load, principal components analysis (PCA) was performed using the external load variables (distance, mean speed, high-speed running distance, PL and PL<sub>slow</sub>). A correlation matrix of the five external training load measures, Bartlett's test of sphericity and Kaiser-Meyer-Olkin measure of sampling adequacy were used to determine the suitability of the data for PCA (Hair, Anderson, Tatham, & Black, 1998). When a number of related variables are measured, it is possible that some are measuring the same concept leading to redundancy in the variables - violating collinearity. The purpose of PCA was to reduce the number of related variables into a smaller number of independent principal components. The new components are optimally weighted linear combinations of the original variables and account for most of the variance in the original values. The eigenvalue reflects the amount of variance accounted for by that component. Since the sum of the eigenvalues is equal to the number of variables in the PCA, an eigenvalue greater than 1 accounts for more variance than any one original variable. Therefore, an eigenvalue greater than 1 and the scree test were used as criteria to determine the number of meaningful components to be retained (O'Rourke & Hatcher, 2013).

The next stage of the analysis involved multivariate linear modelling. To examine if the effect of external training load ( $X_1$ ) on s-RPE training load ( $Y$ ) depends on playing position or AF experience ( $X_2$ ), full factorial linear models were performed and the interaction between the external training load principal component and each characteristic was examined. If there was

no interaction, the model was refit allowing the data to be pooled and a single regression line fitted. If there was a significant main effect, post hoc analysis (Tukey's HSD) was carried out to examine where the difference/s occurred. To make inferences about true values of the difference, effect size ( $d$ ) was reported and the uncertainty was expressed as  $d \pm 95\%$  CL. The magnitude of  $d \pm 95\%$  CL was described as  $< 0.2$  trivial,  $0.2$  to  $0.6$  small,  $0.6$  to  $1.2$  moderate,  $1.2$  to  $2.0$  large,  $2.0$  to  $4.0$  very large (Hopkins, 2002). For the continuous variable (time-trial performance), s-RPE training load was log transformed in order to report the difference in s-RPE training load per difference in time-trial as a percentage change. The coefficient of  $X_2$  was taken as the value of the effect of time-trial on s-RPE training load when external training load was held constant.

## Results

A total of 39 players completed the time-trial in either week 11 (28 players) or week 6 (11 players). Players wore a microtechnology device  $6.9 \pm 4.6$  times, resulting in 270 individual data sets being analysed. Mean values for training duration, s-RPE training load, distance, mean speed, high-speed running distance, PL and PL<sub>slow</sub> were  $59.2 \pm 14.3$  min,  $485 \pm 148$  au,  $5105 \pm 1524$  m,  $86.1 \pm 12.1$  m·min<sup>-1</sup>,  $933 \pm 367$  m,  $433 \pm 130$  au and  $114 \pm 34$  au, respectively. There were moderate to very large correlations between s-RPE training load and distance ( $r = 0.88$ ; 95% CI: 0.85–0.90), mean speed ( $r = 0.45$ ; 95% CI: 0.35–0.54), high-speed running distance ( $r = 0.51$ ; 95% CI: 0.42–0.59), PL ( $r = 0.86$ ; 95% CI: 0.83–0.89) and PL<sub>slow</sub> ( $r = 0.80$ ; 95% CI: 0.75–0.84).

A correlation matrix of the five external training load microtechnology variables revealed correlations greater than 0.3 among all of the variables (Table 3-1). Bartlett's test of sphericity was significant ( $P < 0.001$ ) and the Kaiser-Meyer-Olkin measure of sampling adequacy value acceptable at 0.79. The PCA was then performed using the external training load variables

(distance, mean speed, high-speed running distance, PL and PL<sub>slow</sub>). The resultant eigenvalues and percentage of variance explained by each of the 5 components are displayed in Table 3-2. Only the first component displayed an eigenvalue greater than 1 and the results of the scree test supported only retaining the first component.

**Table 3-1** Correlation matrix ( $r$ , 95% CI) for the external training load variables.

External training load variables	Distance	Meanspeed	High-speed running distance	PL
<b>Meanspeed</b>	0.73 (0.67–0.78)			
<b>High-speed running distance</b>	0.67 (0.60–0.73)	0.66 (0.59–0.72)		
<b>PL</b>	0.97 (0.96–0.98)	0.71 (0.65–0.76)	0.65 (0.58–0.71)	
<b>PL<sub>slow</sub></b>	0.79 (0.74–0.83)	0.38 (0.27–0.48)	0.30 (0.19–0.40)	0.80 (0.75–0.84)

95% CI: 95% confidence interval; PL: Player load<sup>TM</sup>; PL<sub>slow</sub>: Player load<sub>slow</sub><sup>TM</sup>.

**Table 3-2** Resultant eigenvalues and percentage variance explained by each of the components in the PCA of the five external training load variables.

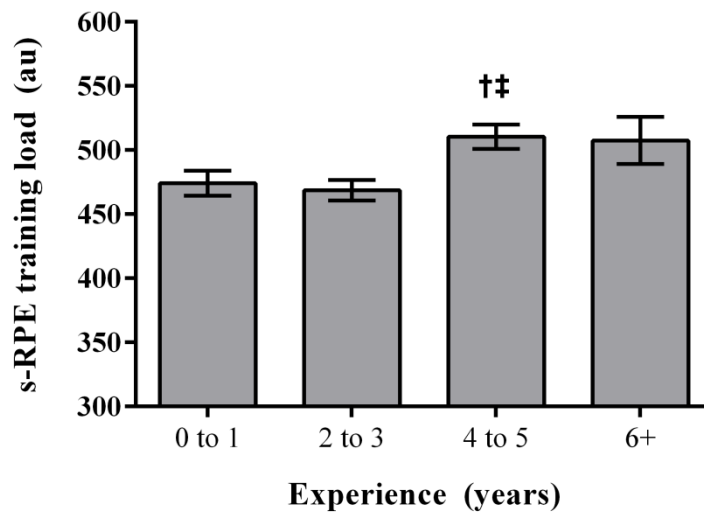
Component	Eigenvalue	Percentage variance explained
<b>1</b>	3.7	74.1
<b>2</b>	0.8	16.5
<b>3</b>	0.3	6.8
<b>4</b>	0.1	2.0
<b>5</b>	0.0	0.6

PCA: principal component analysis.

The relationship between the principal component of external training load and s-RPE training load did not differ as a function of any of the characteristics (experience:  $F_{2, 265} = 1.15$ ,  $P =$

0.33; position:  $F_{2,262} = 0.70, P = 0.55$ ; time-trial:  $F_{2,266} = 1.33, P = 0.25$ ). External training load combined with either experience, position and time-trial explained 70, 69 and 71% of the variance in s-RPE training load, respectively. When external training load was controlled for, the main effect on s-RPE training load was significant for experience ( $F_{2,265} = 4.62, P = 0.004$ ), position ( $F_{2,265} = 2.94, P = 0.03$ ), and time-trial ( $F_{2,267} = 8.96, P = 0.003$ ).

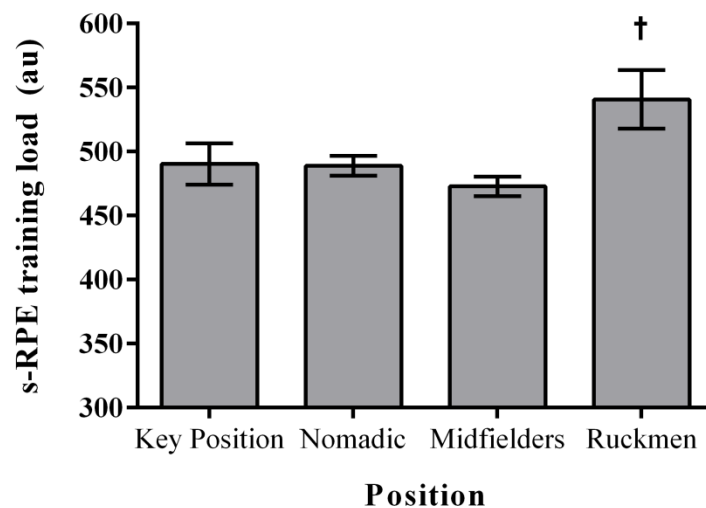
Post hoc analysis revealed that the 4- to 5-year group had a higher s-RPE training load than the 0- to 1-year ( $d = 0.44 \pm 0.33$ , small) and the 2- to 3-year ( $d = 0.51 \pm 0.30$ , small) groups (Figure 3-1). The ruckmen had a higher s-RPE training load than the midfielders when external training load was accounted for ( $d = 0.82 \pm 0.58$ , moderate) (Figure 3-2). For time-trial, the  $X_2$  coefficient revealed that there was a 0.2% au increase in s-RPE training load per 1 s increase in time-trial time (95% CI: 0.07–0.34) when external training load was held constant.



**Figure 3-1** The difference in s-RPE training load between each of the experience groups (0- to 1-year,  $n = 70$ ; 2- to 3-years,  $n = 105$ ; 4- to 5-years,  $n = 75$ ; 6+ years,  $n = 20$ ) when external training load is controlled. Error bars represent the standard error of measurement.

Notes: † Significantly different ( $P < 0.05$ ) from 0- to 1-years.

‡ Significantly different ( $P < 0.05$ ) from 2- to 3-years.



**Figure 3-2** The difference in s-RPE training load between each of the playing positions (key position,  $n = 27$ ; nomadic,  $n = 112$ ; midfielders,  $n = 118$ ; ruckmen,  $n = 13$ ) when external training load is controlled. Error bars represent the standard error of measurement.

*Note:* † Significantly different ( $P < 0.05$ ) from midfielders.

## Discussion

The relationship between external and internal training load in AF players was investigated. The main finding was that experience, position, and time-trial performance all had an effect on s-RPE training load when controlled for the variance explained by external training load. While there is no criterion measure for external training load, PCA was used to control for the variance in the external training load variables of distance, mean speed, high-speed running distance, PL and PL<sub>slow</sub>. The results of this study reinforce previous research that personal characteristics will impact an individual's response to training and emphasises the challenge for coaches when prescribing and monitoring training load in team-sport athletes (Garcin et al., 2004; Impellizzeri et al., 2005; Milanez et al., 2011).

There was a small difference between the 4- to 5-year group and the 0- to 1- and 2- to 3-year groups with the 4- to 5-year group having higher s-RPE training loads for a constant external

training load. It has previously been reported that in an AFL club, first-year players and 7<sup>+</sup> year players had a lower training load across the season than the 2- to 3-year and 4- to 6-year groups (Rogalski et al., 2013). It is possible that because of the higher training age, the 4- to 5-year players participated in more overall training (or greater intensities) and therefore entered main skills sessions in a more fatigued state, resulting in them perceiving the external training load as harder. Another explanation might be that the 4- to 5-year players took more time (within the session) to achieve the same external output as the less experienced players who may have been involved in unnecessary and inefficient running. This could be due to better developed physical qualities and enhanced movement efficiency in the closed, set load training drills and/or superior pattern recall, achieved with experience, in the game-related training drills (Gorman, Abernethy, & Farrow, 2012).

When controlling for external training load, there was a difference in s-RPE training load between playing positions. While there are usually only 2 to 3 ruckmen in the squad of an AFL club, limiting the sample size when comparing them to the other positions, the results suggested that the ruckmen had moderately higher s-RPE training load than the midfielders. As reported in a recent study, in elite AF matches the ruckmen have a different activity profile to the other positions, with more low speed movement (Boyd et al., 2013). It is possible that the high contribution of locomotor activity (distance) in the training sessions analysed in this study resulted in a higher perception of effort from the ruckmen who are less familiar with high locomotor loads (Boyd et al., 2013; Brewer et al., 2010). An exploration of the differences in perception of effort between playing positions during a range of training drills including those involving more contact and multi-planar movements at a relatively low speed (i.e. more similar to match activity profile of a ruckmen) is warranted.



The results of the time-trial model showed that as time-trial time increased by 1 s, s-RPE training load increased by 0.2% au for the same external training load. To determine the magnitude of this result, using an effect size of  $d = 0.20$  as a minimum, a difference of 6.9% in s-RPE training load would be considered a small effect (Hopkins, 2002). Therefore, a small difference would be seen in s-RPE training load between athletes who have more than 34.5 s between their time-trial results. The larger the gap between their time-trial results, the larger the effect of the difference in s-RPE training load. The very large correlation between s-RPE training load and distance, suggests that the locomotor or running load impacted heavily on the training drills in this study. It is therefore not surprising that athletes with superior running ability perceived the same external training load easier, particularly in the type of training drills examined in this study.

Consistent with previous research in AF, semi-professional and professional soccer and professional rugby league, s-RPE training load had a very large association with the external load measures of distance and PL (Casamichana et al., 2013; Lovell et al., 2013; B. R. Scott et al., 2013; T. J. Scott et al., 2013). This further validates the use of s-RPE training load to quantify training load in a high-intensity, intermittent collision sport such as AF (Coutts, Murphy, et al., 2003; Foster et al., 2001; Impellizzeri et al., 2004; T. J. Scott et al., 2013). The very large correlation between s-RPE training load and PL and a nearly perfect correlation between PL and distance also validates the potential use of PL as a surrogate measure of locomotor load (Aughey, 2011; Boyd et al., 2013; Casamichana et al., 2013). Using both the satellite derived information and the accelerometer data to capture a complete picture of load would be ideal, however in cases where satellite variables are not available (e.g. indoor sessions or sessions in urban canyon environments), PL could remain a useful indicator of load when comparing it to PL from other sessions. Although it is likely that the strength of this relationship would depend on the type of training performed (Weaving et al., 2014). Training drills with

high locomotor doses would result in stronger correlations between distance and PL than drills with more impacts, collisions, and/or multi-planar movement.

While  $PL_{slow}$  also had a very large correlation with s-RPE training load, it was not as strongly correlated to distance as PL. Similar to the results of Boyd (2013), this suggests that  $PL_{slow}$  provides different information to PL. Specifically, this variable may be a more representative measure of load in training drills where little distance is covered but there are large amounts of multi-planar movements at a relatively low speed (Boyd et al., 2013). Another variable available from the microtechnology device, which was not examined in this study, is the 2D PL. This version of PL incorporates the acceleration vectors from two planes only (medio-lateral and antero-posterior) and could also provide insight into non-locomotor load aspects. Excluding the vertical vector potentially reduces the influence of foot strikes and hence, locomotion on the PL parameter. High-speed running distance was strongly associated with s-RPE training load. This association is larger than reported by Casamichana et al. (2013) who used a similar definition of high-speed running distance ( $18 \text{ km}\cdot\text{hr}^{-1}$ ) in semi-professional soccer players. It is likely that the method of measuring high-speed running distance relative to each athlete's own 2-km time-trial speed impacted this result. Using relative thresholds to calculate high-speed running distance in training seems appropriate as a measure of effort as it represents dose performed relative to capacity (Abt & Lovell, 2009). However, because this method individualises the external training load to each athlete's capacity, it is likely to improve the correlation with s-RPE training load because RPE is also relative to an individual's capacity.

It is evident that prescribing training based on absolute external training load measures will result in different internal responses that may lead to a training imbalance, leaving some athletes at risk of overtraining and others failing to reach a training stimulus sufficient to elicit positive adaptations. However, prescribing training intensities individually using internal physiological

measures, such as heart rate, is not feasible in skill-based training sessions in a team sport, where these sessions aim to improve physical capacities and skill, game sense, decision making, and team tactics. Despite this, RPE as an alternative internal training load parameter to prescribe training may be innately flawed because players will adjust their output based on a global perception which includes individual characteristics, current physical condition (fitness/fatigue) and their psychological state (mood, motivation) (Blanchfield et al., 2014; Garcin et al., 2004). This may result in different external training loads between players but also variations within a player on different days and may leave some athletes at risk of too high a training dose and others failing to reach a threshold of training required for success. Planning training based only on RPE may overlook the absolute capacity the athlete requires.

Prescribing training using external training load with consideration of individual physiological capacity and other factors (e.g. experience and position) maximises the likelihood of achieving the desired training effect. Coaches might plan relevant sessions for individual athletes based on their positions, experience and/or time-trial performance. For example, for a controlled conditioning session, the group might be split into groups based on time-trial results with the faster players having less rest or covering more distance in the set time than the slower players. The response to this external training load can then be monitored using s-RPE training load and subsequent training adjusted accordingly to optimise an athlete's stress/recovery balance. By recording and evaluating each athlete's s-RPE training load, markedly high or low individuals can be flagged for intervention, whether it might be to reduce or increase subsequent training load. The results of this study emphasises the value of using RPE as an individual perception of effort and s-RPE training load to quantify and monitor global internal training load. It also highlights the limitations of using RPE as an intensity rating of an activity for a whole team or s-RPE training load to plan a training regime in a high-intensity, intermittent contact sport.

This study examined 14 skill-based sessions from pre-season training in an AFL club. Further studies may expand on this finding by exploring the impact these factors have through different phases of the season and also during other types of sessions. Given that during the season, matches contribute the heaviest portion of the load, determining characteristics that impact s-RPE training load in matches would provide valuable information to coaches as they can factor in mediators (e.g. playing position and experience) when designing and prescribing training. Due to club procedures, this study was constrained to pre-existing testing protocols, limiting the characteristics able to be investigated. In particular, a limitation of this study is the lack of construct validity of 2-km time-trials in AF; therefore, using a validated fitness test such as the Yo-Yo IR level 2 or a direct fitness measure such as a laboratory-based  $\text{VO}_{2\text{max}}$  test would be valuable. Other identifiable characteristics such as lower-body strength, anaerobic endurance, and psychological state may also impact s-RPE training load and should be explored. Moreover, it is possible that fitness will improve during pre-season, and hence the fitness tests of week 11, or even more so of week 6, may not be as representative by the last week of the study (week 22). Future research might explore the link between external and internal training load, individual player characteristics, and its resulting impact on performance (Akubat et al., 2014).

## **Conclusion**

The results of this study suggest that experience, position, and time-trial performance are mediators of the relationship between external training load and s-RPE training load. When external training load was controlled, the 4- to 5-year group had a higher s-RPE training load than the 0- to 1-year and 2- to 3-year groups and ruckmen had a higher s-RPE training load than midfielders. For time-trial, there was an increase in s-RPE training load per increase in time-trial time when external training load was held constant. It is vital that coaches and trainers are aware of the relationship between external training load and s-RPE training load and that

consideration is given to potential mediators of s-RPE training load such as experience, playing position, and time-trial performance.



## **Chapter 4. Study 2: Self-reported wellness profiles of Australian footballers during the competition phase of the season**

### **Publication Statement**

This chapter is comprised of the following manuscript which is under review for Journal of Strength and Conditioning Research:

Gallo, T., Cormack, S. J., Gabbett, T. J., & Lorenzen, C. Self-reported wellness profiles of Australian footballers during the competition phase of the season. *Journal of Strength and Conditioning Research*.

### **Linking Paragraph**

Study 1 provided insight into the impact that easily identifiable characteristics have on the relationship between external load and s-RPE load. This allows practitioners to implement external load parameters with greater consideration for individual characteristics and periodise prescribed training accordingly. An equally vital component of a successful monitoring system is the ability to determine an athlete's training status in order to modify/adjust training prescription if warranted. While psychometric inventories are supported as valid and sensitive to training load, the weekly profile and response of commonly used self-reported wellness measures to matches, is yet to be established. The purpose of study 2 was therefore to explore and profile weekly wellness responses within the context of the competition phase of an AF season by determining weekly wellness profile relative to internal match load, the length of the match-to-match micro-cycle or the stage of the season.

## Abstract

With the prevalence of customised, self-report measures in high-performance sport, and the incomplete understanding of athlete's perceived wellness in response to matches and training load, the objective of this study was to explore weekly wellness profiles within the context of the competitive season of professional Australian football. Internal match load, measured through the session rating of perceived exertion method, match-to-match micro-cycle, stage of the season and training load were included in multivariate linear models in order to determine their effect on weekly wellness profile ( $n = 1,835$ ). There was a lower weekly training load on a 6-day micro-cycle (mean  $\pm s = 1813 \pm 291$  au) compared to a 7- ( $1898 \pm 327$  au,  $d$ ; 95% CI = 0.28; 0.14–0.43, *likely small*) and 8-day ( $1900 \pm 271$  au,  $d = 0.29$ ; 0.15–0.44, *likely small*) micro-cycle. Match load ( $1179 \pm 230$  au) had no significant impact on weekly wellness profile, whilst there was an interaction between micro-cycle and days-post-match. There was *likely* to be a *moderate* decrease in wellness Z-score 1 d post match for an 8-day micro-cycle (Z-score; 95% CI =  $-1.79$ ;  $-2.02$ – $-1.56$ ) compared to a 6- ( $-1.19$ ;  $-1.30$ – $-1.08$ ) and 7-day ( $-1.22$ ;  $-1.34$ – $-1.09$ ) cycle ( $d$ ;  $\pm 95\%$  CI =  $-0.82$ ;  $-1.3$ – $-0.36$ ,  $-0.78$ ;  $-1.3$ – $-0.28$ ). The second half of the season saw a *possibly small* reduction in overall wellness Z-score than the first half of the season (0.22; 0.12–0.32). Finally, training load had no effect on wellness Z-score when controlled for days-post-match, micro-cycle and stage of the season. These results provide information on the status of players in response to matches and fixed conditions. Knowing when wellness Z-score returns to baseline relative to the length of the micro-cycle may lead practitioners to prescribe the heaviest load of the week accordingly. Furthermore, wellness 'red flags' should be made relative to the micro-cycle and stage of the season, in order to determine an athlete's status relative to their typical weekly profile.

**Key Words:** monitoring training, psychometric tools, internal load



## **Introduction**

It is widely accepted that to improve performance capacity, an exercise stimulus sufficient to elicit adaptation must be complemented by proportionate recovery to allow the negative effects of fatigue to diminish and regeneration to occur (Kuipers & Keizer, 1988; Smith, 2003). This process is enhanced by periodisation, which is the planned and systematic variation of exercise volume and intensity in order to direct the adaptations to the training goals (Gamble, 2006; Rowbottom, 2000). However, the majority of research on periodisation is based on traditional techniques for athletes aiming to peak for a major competition (Noakes, 2000; Smith & Norris, 2002). The unique challenge of periodising training regimes in team sports, such as Australian football, is that the competitive season consists of regular matches over several months plus a finals series, requiring athletes to be optimally prepared for over 6 months (Gamble, 2006; Kelly & Coutts, 2007).

During the competition phase of the season, maintaining fitness achieved in pre-season while managing fatigue poses a challenge for coaches and sports science practitioners (Coutts & Reaburn, 2008; Coutts, Reaburn, Piva, & Rowsell, 2007). Undoubtedly, the high physical demand of an Australian football match represents the highest single load of the week. In order to apportion the load required for competition, the training load is planned around the weekly match schedule (Weston et al., 2015). It is therefore advantageous to understand the response to a match within the context of the season and incorporate the current training status of the athletes in the design of the training/recovery program for the subsequent week. While there are a variety of practical suggestions on athlete monitoring in the literature, there is still no criterion method for monitoring fatigue and training status in team sport athletes (Buchheit, Racinais, et al., 2013; Cormack, Newton, & McGuigan, 2008; Coutts & Reaburn, 2008; Hooper & Mackinnon, 1995).

Psychological markers of training status are well supported in the literature as a tool to assess for training imbalances (Borresen & Lambert, 2009; Saw et al., 2016; Urhausen & Kindermann, 2002). There are a small number of established sport-specific questionnaires aimed to assess how an athlete is coping with training, all with the advantage of being non-invasive and inexpensive (Kellmann et al., 2002; Main & Grove, 2009; Raedeke & Smith, 2001; Rushall, 1990). To foster compliance and improve specificity, practitioners are known to incorporate customised, shortened athlete self-report measures into their training monitoring practices (Buchheit, Racinais, et al., 2013; Coutts & Reaburn, 2008; Gastin, Meyer, et al., 2013; Hooper & Mackinnon, 1995; Mclean et al., 2010). In fact, a survey of Australian and New Zealand high-performance sport practitioners on current trends of fatigue monitoring revealed that 84% of responders use self-report measures, 80% of which use custom designs consisting of 4 to 12 items (Taylor et al., 2012). Muscle soreness, sleep duration and quality and general wellness measured on a Likert scale were the most common elements used.

A range of studies in team sport describe decreases in perceived wellness following matches and steady improvements in subsequent days (Gastin, Meyer, et al., 2013; Mclean et al., 2010; Montgomery & Hopkins, 2013; Thorpe et al., 2016). In elite soccer players, self-reported fatigue, sleep quality and muscular soreness all decreased 1 d post match and improved in the days following (Thorpe et al., 2016). Similarly, overall perceived wellness was significantly reduced 1 d post match regardless of the length of the micro-cycle (5-, 7- or 9-days between matches) in rugby league (Mclean et al., 2010). Interestingly however, at 2 d post match, there was significantly better overall wellness for a 5-day micro-cycle than a 7- or 9-day cycle. It appears that days-to-game may be an important predictor of self-reported responses with perceived wellness improving as game day approaches (Gastin, Meyer, et al., 2013). Self-reported soreness also peaked immediately following an Australian football match and declined steadily in the days after, with training load having no substantial contributions to perceived

muscular soreness (Montgomery & Hopkins, 2013). On the other hand, overall self-reported wellness was sensitive to subtle changes in the previous days training load during an intensified training camp for Australian footballers (Buchheit, Racinais, et al., 2013). In professional soccer players, significant correlations were reported between objective load (total high-intensity running distance) and self-reported fatigue during the competition phase, while no significant relationship with sleep quality, and muscle soreness was found (Thorpe et al., 2015). Evidently the typical profile of wellness responses is yet to be established, particularly with consideration of match-to-match micro-cycle and load.

With the prevalence of customised, self-report measures in high-performance sport, and the incomplete understanding of athlete's perceived wellness in response to matches and training load, the objective of this study was to explore weekly wellness profiles within the context of the competitive season of professional Australian football (Saw et al., 2016). The specific aims of this study were to establish if internal match load, the length of the match-to-match micro-cycle or the stage of the season, altered the weekly wellness profile. Furthermore, the effect of internal training load on weekly wellness profile was also assessed.

## **Methods**

### **Experimental approach to the problem**

This study explored the weekly wellness profile of professional Australian football players with an analytical cohort design. The dependent variable was perceived wellness measured with a customised, self-report questionnaire during the 23-week competition phase of the 2013 season. The independent variables included internal match load, match-to-match micro-cycle, stage of the season, and training load. The standard weekly schedule of matches in Australian football involves match-to-match micro-cycles of 6-, 7-, or 8-days. On occasions where a player was on

an extended break from matches (e.g. injured, suspended), data were removed from the analysis until they returned to regular match-to-match micro-cycles of 6-, 7- or 8-days. The data was only analysed for the players that were playing in the upcoming senior match. The competition phase was split into first (weeks 2 to 11) and second half (weeks 13 to 23) using the mid-season bye as the cut-off point. Load variables were determined as internal load which better reflects the psychophysiological load experienced by the athlete compared to external load measures (Impellizzeri et al., 2005; B. R. Scott et al., 2013). Subjects had been exposed to all experimental protocols for a minimum of 4 months leading into the study period.

## **Participants**

Following approval from the University's Ethics Committee, the entire squad of one AFL club (the highest level of Australian football) was invited to participate in this study. All the players received information about the research design and requirements, as well as risks and benefits of the investigation. Data from 33 male players who gave written informed consent were retained for analysis (mean  $\pm$  s: 23.9  $\pm$  3.4 years, 187.5  $\pm$  6.7 cm, 87.1  $\pm$  7.1 kg, 5.6  $\pm$  3.6 years in AFL, 67.0  $\pm$  76.2 senior matches).

## **Procedures**

### ***Perceived wellness questionnaire***

Players were instructed to complete a customised self-report wellness questionnaire on each morning of the study period (except on match days), any time before physical training commenced. Players were able to complete their wellness in private using an online system on their own smart device/computer or a computer available upon arrival at the club. The questionnaire was designed to be short, specific and based on physical, psychological and social components common in the psychological tools used to assess for training imbalances in the literature (Gastin, Meyer, et al., 2013; Hooper & Mackinnon, 1995; Mclean et al., 2010). The items included, sleep quality, stress, fatigue, mood, and muscle soreness on a seven-point Likert

scale ranging from 1 - strongly agree to 7 - strongly disagree (Gastin, Meyer, et al., 2013; Mclean et al., 2010). The entry screen displayed each statement (e.g. I'm in a good mood), one after another with a dropdown menu with the seven Likert options (Figure 4-1). The stress, fatigue and muscle soreness scales were reverse scored. Players were instructed to respond as how they were currently feeling. An overall daily wellness score was determined by averaging the five items. Wellness scores were reported relative to individual's absolute mean and normal variation from the duration of the study period by reporting them as Z-scores. In order to use Z-scores, only data from individuals whose wellness scores were deemed normally distributed were used (Peat & Barton, 2008). The questionnaire was considered to have good face validity by the both sport science staff and authors and exploratory factor analysis was used to confirm the unidimensionality of the items. A Cronbach's alpha of 0.70 suggests there was an acceptable interrelatedness between the items.

**I had a quality sleep last night**

▼

1- Strongly disagree

2- Disagree

3- Somewhat disagree

4- Neither agree nor disagree

5- Somewhat agree

6- Agree

7- Strongly agree

**Figure 4-1** Example of the scale used for each wellness item.

#### ***Internal training load: Session rating of perceived exertion***

Internal training load for each session (including skills training, field-based conditioning, cross-training and strength training) was determined using the session rating of perceived exertion (s-RPE) method (Foster et al., 2001). Players were shown the modified CR-10 Borg rating of perceived exertion (RPE) scale approximately 30 min upon completing the session, and prompted with the question "How was your session?" (Foster et al., 2001). Education was

provided on the RPE scale, with players encouraged to give a global rating of the entire session using any intensity cues they deemed relevant. Referencing the anchors, a rating of 0 was deemed as rest and 10 as the hardest exercise exertion ever performed. The RPE was multiplied by exercise duration defined as the sum of individual drill times, with transition time removed (Wallace et al., 2014). This commonly used method has been reported to be reliable and correlates with other measures of internal training load in a range of settings (Coutts, Murphy, et al., 2003; Impellizzeri et al., 2004; T. J. Scott et al., 2013). To represent the athletes physical status using training load, a training-stress balance (TSB) was determined using the difference between acute load (1-week total) and chronic load (4-week mean) (Hulin et al., 2014).

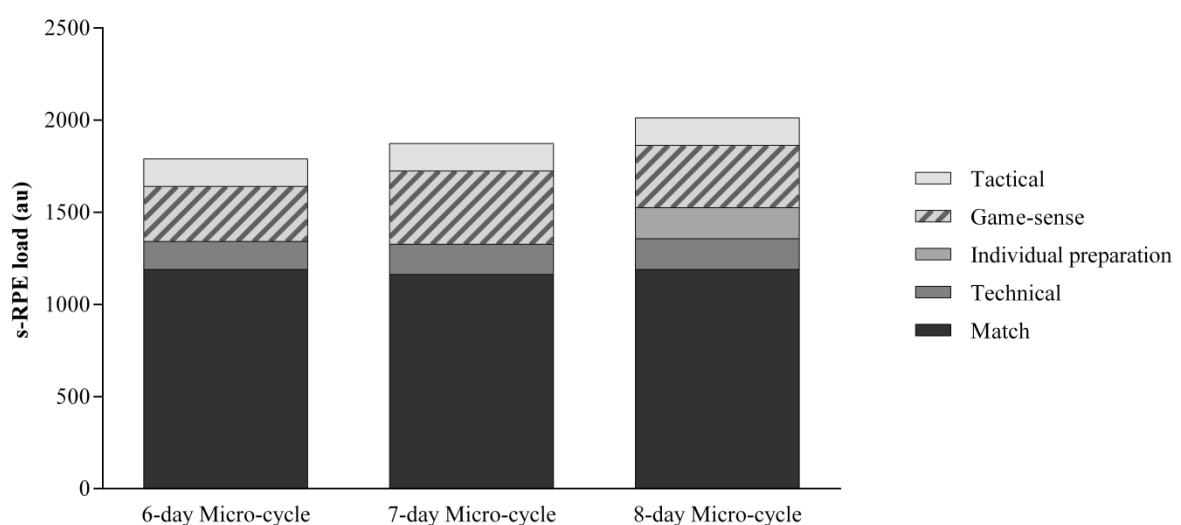
### **Statistical Analyses**

Exploratory data analyses were conducted to examine data distributions, check for normality and identify outliers, with descriptive data presented as mean  $\pm$  standard deviation (s). The weekly perceived wellness profiles were determined with days-post-match entered into multivariate linear models using JMP (Version 10.0.2; SAS Institute, USA). Full factorial linear models were used to establish the impact that match load, match-to-match micro-cycle length and stage of the season had on weekly wellness profile, with the interaction between days-post-match and each independent variable examined. Where there was no interaction, the models were refit allowing the data to be pooled to a single regression line. If there was a significant effect, Tukey's HSD post hoc analysis was used to determine where the difference/s occurred. The magnitude of the differences were reported as Cohen's effect sizes ( $d$ ) with 95% confidence intervals (CI) described as <0.2 trivial, 0.2 to 0.6 small, 0.6 to 1.2 moderate, 1.2 to 2.0 large and 2.0 to 4.0 very large (Hopkins, 2002). Qualitative interpretation of the uncertainty of the effects was determined with magnitude-based inferences as <25% unlikely,  $\geq$ 25% possibly, >75% likely, >95% very likely, >99.5% most likely that there was a clear effect of that magnitude (Batterham & Hopkins, 2006). An effect where there was >5% chance of the change being positive and negative was deemed as unclear. Two further multivariate linear models

were used to assess if previous days training load or TSB had a significant effect on self-reported wellness when accounting for the variation explained by days-post-match, match load, micro-cycle and/or stage of the season. Significance was set at the  $P < 0.05$  level.

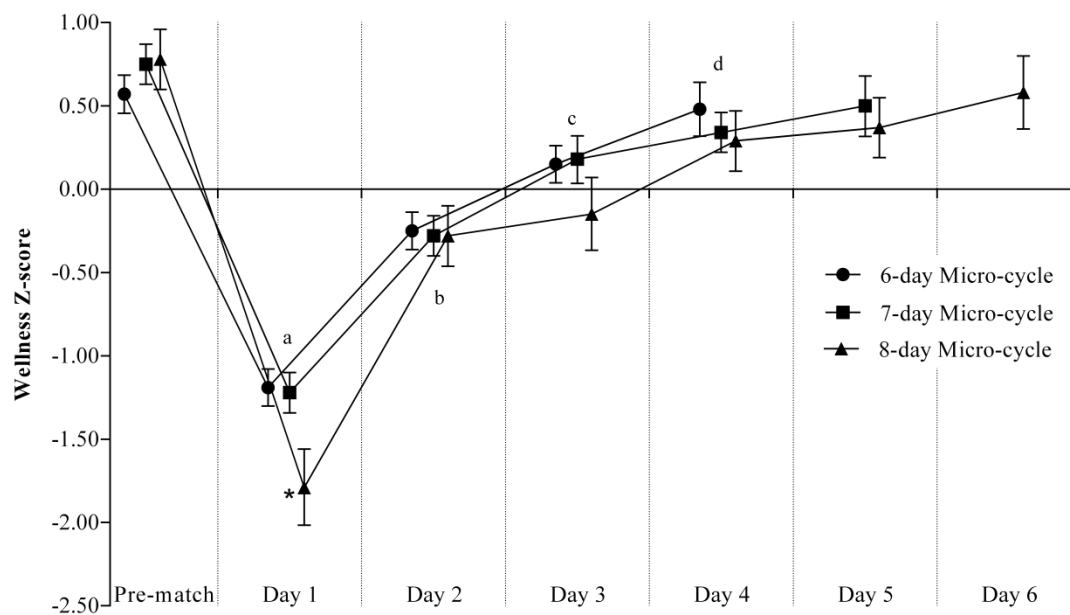
## Results

A total of 1,835 wellness responses from 20 rounds (excluding rounds 1, 9 and 12 which did not fall into a 6-, 7- or 8-day micro-cycle) were analysed in this study. This represents a mean of  $92 \pm 35$  completions per week from a 132 opportunities ( $70 \pm 26\%$  squad compliance per week). Of the 33 players that played an AFL match, the mean number of completions was  $56 \pm 28$ . There were 731, 727 and 377 samples from 6-, 7- and 8-day micro-cycles, respectively. There was a lower weekly training load on a 6-day micro-cycle ( $1813 \pm 291$  au) compared to a 7- ( $1898 \pm 327$  au,  $d = 0.28$ ; 0.14–0.43, *likely small*) and 8-day ( $1900 \pm 271$  au,  $d = 0.29$ ; 0.15–0.44, *likely small*) micro-cycle. Figure 4-2 shows the weekly breakdown of load for each micro-cycle. There was no difference in match load ( $1179 \pm 230$  au) between the micro-cycles or stage of the season.



**Figure 4-2** Weekly load breakdown of a 6-, 7- and 8-day micro-cycle.

There was no interaction effect between days-post-match and match load on wellness Z-score ( $F_{2,1821} = 0.39, P = 0.89$ ). The refit model revealed no significant main effect of match load on weekly wellness profile ( $F_{2,1827} = 1.27, P = 0.26$ ). There was a significant interaction between days-post-match and length of the micro-cycle ( $F_{2,1817} = 3.30, P = 0.0005$ ), explaining 46% of the variance in perceived wellness Z-score. Figure 4-3 shows the weekly perceived wellness profiles for a 6-, 7- and 8-day micro-cycle. Tukey's HSD showed that wellness Z-score was lower at 1 d post match for the 8-day micro-cycle compared to a 6- (*likely moderate*) and 7-day (*likely moderate*) micro-cycle (Table 4-1). The difference effect of days-post match for each micro-cycle is reported in Table 4-2.



**Figure 4-3** Weekly wellness profile for a 6-, 7- and 8-day micro-cycle.

Notes: \*Significantly different ( $P < 0.05$ ) from the 6- and 7-day cycle.

<sup>a</sup> Significantly different ( $P < 0.05$ ) from pre-match for each cycle.

<sup>b</sup> Significantly different ( $P < 0.05$ ) from pre-match and previous day for each cycle.

<sup>c</sup> Significantly different ( $P < 0.05$ ) from pre-match for each cycle and previous day for 6- and 7-day cycle.

<sup>d</sup> Significantly different ( $P < 0.05$ ) from pre-match for the 7- and 8-day cycle.



**Table 4-1** The wellness Z-score (95% CI), magnitude of differences (*d*; 95% CI) and qualitative description of the effect of micro-cycle length.

	6-day micro-cycle	7-day micro-cycle	Δ 7- to 6-day micro-cycle	8-day micro-cycle	Δ 8- to 7-day micro-cycle	Δ 8- to 6-day micro-cycle
<b>pre-match</b>	<b>0.57</b> (0.46–0.69)	<b>0.75</b> (0.63–0.87)	Unclear	<b>0.78</b> (0.59–0.96)	0.04 (–0.53–0.60) Likely trivial	Unclear
<b>1 d post match</b>	<b>–1.19</b> (–1.30––1.08)	<b>–1.22</b> (–1.34––1.09)	Unclear	<b>–1.79</b> (–2.02––1.56)	–0.78 (–1.3––0.28) Likely moderate ↓	–0.82 (–1.3––0.36) Likely moderate ↓
<b>2 d post match</b>	<b>–0.25</b> (–0.36–0.13)	<b>–0.28</b> (–0.40–0.16)	Unclear	<b>–0.28</b> (–0.46–0.10)	0.01 (–0.09–0.10) Most likely trivial	Unclear
<b>3 d post match</b>	<b>0.15</b> (0.04–0.26)	<b>0.18</b> (0.03–0.32)	Unclear	<b>–0.15</b> (–0.37–0.07)	Unclear	Unclear
<b>4 d post match</b>	<b>0.48</b> (0.32–0.64)	<b>0.34</b> (0.22–0.46)	Unclear	<b>0.29</b> (0.10–0.47)	Unclear	Unclear
<b>5 d post match</b>	-	<b>0.50</b> (0.32–0.69)	-	<b>0.37</b> (0.19–0.55)	Unclear	-
<b>6 d post match</b>	-	-	-	<b>0.58</b> (0.36–0.80)	-	-

Magnitudes (*d*; 95% CI) categorised as <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large and 2.0–4.0 very large (Hopkins, 2002). Qualitative interpretation determined as <25% unlikely, ≥25% possibly, >75% likely, >95% very likely, >99.5% most likely that there was a clear effect of that magnitude (Batterham & Hopkins, 2006). An effect where there was >5% chance of the change being positive and negative was deemed unclear. 95% CI: 95% confidence interval.

**Table 4-2** The magnitude of differences (*d*; 95% CI) and qualitative description of the effect of days-post-match.

		6-day micro-cycle	7-day micro-cycle	8-day micro-cycle
<b>1 d post match</b>	$\Delta$ pre-match	-2.4 (-3.6--1.2)	-2.7 (-4.0--1.4)	-3.5 (-5.2--1.8)
	( <i>d</i> ; 95% CI)	Possibly very large ↓	Very likely large ↓	Very likely very large ↓
<b>2 d post match</b>	$\Delta$ previous day	1.3 (0.65–1.9)	1.3 (0.65–1.9)	2.1 (1.1–3.1)
	( <i>d</i> ; 95% CI)	Possibly large ↑	Possibly large ↑	Possibly very large ↑
	$\Delta$ pre-match	-1.1 (-1.7--0.56)	-1.4 (-2.1--0.71)	-1.4 (-2.2--0.74)
	( <i>d</i> ; 95% CI)	Very likely moderate ↓	Possibly large ↓	Likely large ↓
<b>3 d post match</b>	$\Delta$ previous day	0.54 (0.26–0.82)	0.62 (0.27–0.97)	Unclear
	( <i>d</i> ; 95% CI)	Very likely small ↑	Possibly moderate ↑	
	$\Delta$ pre-match	-0.58 (-0.87--0.29)	-0.78 (-1.2--0.39)	-1.3 (-1.9--0.65)
	( <i>d</i> ; 95% CI)	Most likely small ↓	Likely moderate ↓	Possibly large ↓
<b>4 d post match</b>	$\Delta$ previous day	0.46 (-0.08–1.00)	Unclear	0.6 (-0.39–1.6)
	( <i>d</i> ; 95% CI)	Likely small ↑		Likely small ↑
	$\Delta$ pre-match	Unclear	-0.56 (-0.87--0.25)	-0.67 (-1.3--0.07)
	( <i>d</i> ; 95% CI)		Very likely small ↓	Possibly moderate ↓
<b>5 d post match</b>	$\Delta$ previous day	-	Unclear	Unclear
	( <i>d</i> ; 95% CI)			
	$\Delta$ pre-match	-	Unclear	-0.56 (-1.4–0.27)
<b>6 d post match</b>	( <i>d</i> ; 95% CI)			Likely small ↓
	$\Delta$ previous day	-	-	Unclear
	( <i>d</i> ; 95% CI)			
<b>6 d post match</b>	$\Delta$ pre-match	-	-	Unclear
	( <i>d</i> ; 95% CI)			

Magnitudes (*d*; 95% CI) categorised as <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large and 2.0–4.0 very large (Hopkins, 2002). Qualitative interpretation determined as <25% unlikely, ≥25% possibly, >75% likely, >95% very likely, >99.5% most likely that there was a clear effect of that magnitude (Batterham & Hopkins, 2006). An effect where there was >5% chance of the change being positive and negative was deemed unclear. 95% CI: 95% confidence interval.

The relationship between days-post-match and wellness Z-score did not differ across the early and late stages of the season and therefore the model was refit without the interaction term. The new model of days-post-match and stage of season revealed a significant main effect for stage of the season ( $F_{2, 1827} = 20.3, P < 0.0001$ ). There was a possibly small ( $d = 0.22$ ; 0.12–0.32) reduction in wellness Z-score during the second half of the season.

Neither the previous day's load nor TSB had significant effects on the weekly wellness profiles when modelled with days-post-match, micro-cycle and stage of the season ( $F_{5, 1815} = 1.20, P = 0.27$  and  $F_{5, 1815} = 0.35, P = 0.56$  respectively).

## Discussion

This study explored weekly wellness profiles within the context of the competitive season for professional Australian football players. The main findings were that days-post-match was the best predictor of wellness Z-score. Furthermore, internal match load had no effect on weekly wellness profile while match-to-match micro-cycle had a significant interaction with days-post-match. It was revealed that for 1 d post match, an 8-day micro-cycle had a moderate reduction in wellness compared to a 6- and 7-day micro-cycle. There was also a trend towards wellness being reduced at 3 d post match for an 8-day micro-cycle. Another finding was that while there was no interaction, stage of the season had a small significant effect on the weekly wellness profile, with the second half of the season (weeks 13 to 23) having lower overall wellness Z-scores than the first half (weeks 2 to 12). Interestingly, when modelled with days-post-match, micro-cycle and stage of the season, training load had no effect on wellness profile.

The results of this study are in agreement with previous work which demonstrated that days-to-game was a significant coefficient for wellness in Australian footballers (Gastin, Meyer, et al., 2013). It has also been previously reported that differences in weekly wellness profile exist between micro-cycles in rugby league players (McLean et al., 2010). Similar to the current study, an accelerated recovery was seen in the shorter micro-cycle (5-days). It appears that players' perception of wellness is related to days-to-game, with there being unclear differences in perceptual wellness the day before a match whether on a 6-, 7- or 8-day micro-cycle. It is indeed possible that the lower training load on a 6-day micro-cycle, aided in accelerating recovery in order for players to return to a positive Z-score by 3 d post match compared to 4 d post match in an 8-day micro-cycle. For a 7-day micro-cycle however, there was no difference in weekly load compared to an 8-day micro-cycle yet players returned to a positive Z-score 1 day earlier. During the 8-day micro-cycle, players are scheduled with an extra 'day off' over the weekend which has the potential to be detrimental to recovery, either due to complacency with recovery methods including inferior nutrition/hydration practices and/or partaking in activities unfavourable for recovery (Barnes, Mündel, & Stannard, 2010).

Although wellness was not substantially reduced during the shorter micro-cycles, due to the subjective nature of psychometric measures, it is possible that differences in physiological fatigue between the micro-cycles would have been exposed by physiological markers of fatigue/recovery. Perhaps the ability to tolerate extreme conditions is a trait which lends itself to professional athletes. Their motivation and focus on the upcoming match may override any latent physiological response, resulting in players perceiving themselves as recovered and prepared for the upcoming match (Gastin, Meyer, et al., 2013).

Match load also appeared to have no effect on wellness in this study, while in professional soccer players, self-reported ratings of fatigue were shown to be sensitive to high-intensity

running distance (Thorpe et al., 2015). Good correlations between external load measures and s-RPE method exist, with stronger relationships between external measures of volume load such as total distance and player load, rather than intensity measures such as high-intensity running (Casamichana et al., 2013; T.J. Scott et al., 2013). Moreover, a lower between-match variability of s-RPE compared to other external load measures, such as high-intensity running distance, has been reported in rugby union matches (McLaren et al., 2016). Although this allows s-RPE to be reliably used as a measure of match load and meaningful changes more accurately detected, it suggests that s-RPE may lack sensitivity in detecting subtle variations in match load (McLaren et al., 2016). As such, differences in external load measures such as high-speed running or accelerations/decelerations (which are not detected by s-RPE) may have explained some of the variation between micro-cycles for 1 d post match.

The finding that wellness was significantly lower during the second half of the season contradicts the results from Gastin (2013) who reported improvements in wellness over the course of the season in Australian football. It was proposed that the repeated bouts of exercise may have stimulated adaptation or that the ability of athletes to cope with the training was improved across the season (Gastin, Meyer, et al., 2013). Fitness markers do not generally improve during the season in team sports (Akubat et al., 2012; Impellizzeri et al., 2005), while wellness has previously been reported as sensitive to load (Buchheit, Racinais, et al., 2013; Coutts, Reaburn, Piva, & Murphy, 2007). With no load data reported in this study, perhaps variations across the season impacted wellness. If weekly load diminished across the season, an increase in recovery is likely to result in improved wellness perceptions (Saw et al., 2016). Furthermore, the success of the team was not considered in either study and could indeed influence subjective wellness across the season.

An acknowledged application, and fundamental benefit, of self-report measures is using irregularities in athlete profiles as a warning sign, often labelled as 'red flags' (Saw et al., 2015b). The manipulation of training load in response to red flags is common practice in applied sport and presents as a potential limitation to research designs in these settings. As such, caution should be employed when interpreting the results from this study which suggest that wellness was not impacted by training load when controlled for the fixed conditions of the week (days-post-match, micro-cycle length and stage of the season). A plausible explanation for this finding is that this data involved training load which was methodically prescribed around the weekly conditions and even altered in response to athlete status to minimise fatigue and enhance preparedness. It is therefore likely that successful load management resulted in no adverse responses to training load observable through wellness. Similar results were seen in another study with Australian footballers, where training load contribution to muscular soreness was negligible (Montgomery & Hopkins, 2013).

Previous studies where wellness has been reported sensitive to training load involved a short-duration intensified pre-season training camp where perhaps fitness gains rather than recovery and preparedness was the focus (Buchheit, Racinais, et al., 2013). Generally, these fitness gains achieved in pre-season are not enhanced during the competition phase where focus is shifted to recovery from matches and preparedness for competition. However, in circumstances where fitness achieved in pre-season may not suffice for successful performance, it seems reasonable to consider that if current training load has no impact on perception of wellness, players may be able to tolerate elevated training loads which may contribute to fitness improvements (Montgomery & Hopkins, 2013).

## Practical Applications

The weekly wellness profile of professional Australian footballers was altered according to the length of the match-to-match micro-cycle and stage of the season. An enhanced understanding of the status of players in response to matches and fixed conditions provides information on appropriate training prescription. For example, it appears that perceptions of wellness return to a positive Z-score at 3 d post match for a 6- and 7-day micro-cycle but not until 4 d post match for an 8-day micro-cycle. This may lead practitioners to prescribe the largest load of the week accordingly, leaving high loads until at least day 4 on an 8-day micro-cycle. Furthermore, the revelation that the second half of the season had lower overall perceived wellness, may provide reason to reduce training load and increase opportunities for recovery later in the season. A further practical application of these results involves the interpretation of wellness responses. It would be reasonable to consider that judgments for wellness ‘red flags’ should be made to comparative micro-cycles and stage of the season in order to determine an athlete’s status relative to their typical weekly profile. The finding that players showed no signs of distress in response to training load, possibly as a consequence of manipulating load based on these ‘red flags’, suggests that adjusting load prescription informed by wellness status is valid.





## **Chapter 5. Study 3: Pre-training self-reported wellness impacts training output in Australian footballers**

### **Publication Statement**

This chapter is comprised of the following manuscript which is accepted for publication in Journal of Sports Sciences:

Gallo, T., Cormack, S. J., Gabbett, T. J., & Lorenzen, C. (2015). Pre-training self-reported wellness impacts training output in Australian footballers. *Journal of Sports Sciences*. doi: 10.1080/02640414.2015.1119295.

### **Linking Paragraph**

Study 2 examined self-reported wellness responses during the competition phase of the season and demonstrated that days-post-match, match-to-match micro-cycle and stage of the season all impacted weekly wellness profiles. Although these findings contribute to research that self-reported wellness is sensitive to (match) load, in order to use self-reported wellness as marker of training status and modify/adjust training prescription accordingly, evidence that changes in wellness are related to changes in external load output is required. The aim of study 3 was to determine if altered pre-training wellness impacts training output in skill-based team training sessions.

## Abstract

The impact of perceived wellness on a range of external load parameters, rating of perceived exertion (RPE) and external load: RPE ratios, was explored during skill-based training in Australian footballers. Fifteen training sessions involving 36 participants were analysed. Each morning before any physical training, players completed a customised perceived wellness questionnaire (sleep quality, fatigue, stress, mood, and muscle soreness). Microtechnology devices provided external load (mean speed, high-speed running distance, Player load<sup>TM</sup> (PL), and Player load slow<sup>TM</sup> (PL<sub>slow</sub>)). Players provided RPE using the modified Borg category ratio 10 RPE scale. Mixed-effect linear models revealed significant effects of wellness Z-score on PL and PL<sub>slow</sub>. Effects are reported with  $\pm 95\%$  CL. A wellness Z-score of  $-1$  corresponded to a  $-4.9 \pm 3.1$  and  $-8.6 \pm 3.9\%$  reduction in PL and PL<sub>slow</sub>, respectively, compared to those without reduced wellness. Small significant effects were also seen in the mean speed: RPE and PL<sub>slow</sub>: RPE ratio models. A wellness Z-score of  $-1$  corresponded to a  $0.43 \pm 0.38$  metres $\cdot$ min<sup>-1</sup>, and  $-0.02 \pm 0.01$  au $\cdot$ min<sup>-1</sup> change in the mean speed: RPE and PL<sub>slow</sub>: RPE ratios, respectively. Magnitude-based analysis revealed that the practical size of the effect of a pre-training perceived wellness Z-score of  $-1$  would have on PL<sub>slow</sub> was *likely* negative. The results of this study suggests that monitoring pre-training perceived wellness may provide coaches with information about the intensity of output that can be expected from individual players during a training session.

**Keywords:** athlete monitoring, external training load, team sport

## Introduction

Psychological markers of training status are well supported in the literature as a tool to monitor the condition of athletes (Borresen & Lambert, 2009; Raglin, 2001; Urhausen & Kindermann, 2002). There are a small number of established sport-specific psychometric questionnaires aimed to assess how an athlete is coping with training, such as the Recovery-Stress Questionnaire (REST-Q) (Kallus, 1995), Recovery-Cue (Kellmann, Patrick, Botterill, & Wilson, 2002), Athlete Burnout Questionnaire (Raedeke & Smith, 2001), Daily Analysis of Life Demands for Athletes (Rushall, 1990), and Athlete Distress Questionnaire (Main & Grove, 2009). While an advantage of all questionnaires is that they are non-invasive and inexpensive, most established tools are often considered too lengthy to foster compliance from athletes, non-specific and impractical for daily use, particularly in team sport athletes (Twist & Highton, 2012). Consequently, practitioners have been encouraged to incorporate customised, shortened questionnaires into their monitoring practices (Buchheit, Racinais, et al., 2013; Coutts & Reaburn, 2008; Gastin, Meyer, et al., 2013; Hooper & Mackinnon, 1995; Mclean et al., 2010; Meeusen et al., 2006; Saw et al., 2015a).

A survey of Australian and New Zealand high-performance sport on current trends of fatigue monitoring revealed that 84% of responders used self-report questionnaires, 80% of which were customised designs consisting of 4–12 items (Taylor et al., 2012). The research investigating the relationship between training and these customised psychometric tools typically explores perceived wellness in response to training and/or match load (Buchheit, Racinais, et al., 2013; Gastin, Meyer, et al., 2013; Mclean et al., 2010; Montgomery & Hopkins, 2013; Saw et al., 2015b; Thorpe et al., 2015). In rugby league, overall subjective wellness, measured using a customised questionnaire, was significantly reduced ( $P < 0.01$ ,  $d = -1.64$ ) 1 d post match regardless of the length of the micro-cycle (5-, 7- or 9-days between matches) and only remained reduced at 2 d post match for the 7- day and 9- day cycles ( $P < 0.05$ ,  $d = -1.53$ ;  $P <$

0.05,  $d = -0.18$ , respectively) (Mclean et al., 2010). Comparably, a study exploring perceived wellness in response to Australian football matches reported days to match as a significant coefficient for a range of wellness items, demonstrating that subjective ratings of wellness improve as game day approaches (Gastin, Meyer, et al., 2013). In a separate study examining the effect of match and training load on perceived soreness in AF players, soreness peaked ( $d = 0.37$ ) immediately following a match and declined steadily in the days after, with training load having no substantial contributions to perceived muscular soreness (Montgomery & Hopkins, 2013). A study of professional soccer players during the competition phase reported significant correlations ( $r = -0.39$  to  $-0.62$ ) between self-reported fatigue and total high-intensity running distance, while finding no significant relationship with sleep quality, and muscle soreness (Thorpe et al., 2015). Alternatively, another study in Australian football reported that overall wellness, measured using a customised questionnaire, was sensitive to subtle changes in the previous days training load during an intensified training camp (Buchheit, Racinais, et al., 2013). While this research has demonstrated perceived wellness to be sensitive in response to match load and training load during an intensive training camp, it is also important to understand the influence perceived wellness has on future training output.

Training load can be quantified by external and/or internal parameters and in soccer players, the ratio between the two has been shown to be a stronger correlate to fitness measures than external load alone (Akubat et al., 2014). Since external training load represents the dose performed and internal training load represents the psycho-physiological response experienced by the athlete, it is the internal load that elicits adaptation to training (Impellizzeri et al., 2005). Research into potential mediators of the relationship between internal and external load also exists, reporting factors such as training mode, fitness and experience as relevant, as well as self-talk, particularly when measuring internal load using the rating of perceived exertion (RPE) method (Blanchfield et al., 2014; Gallo, Cormack, Gabbett, Williams, & Lorenzen, 2015;

Milanez et al., 2011; Weaving et al., 2014). One study reported that RPE was not affected by perceived wellness during submaximal exercise in soccer players (Haddad et al., 2013). However, the submaximal exercise was an aerobic test that may not be reflective of the type of skill-based training, comprising small-sided games and match-play practice, which is a large proportion of training in team sports (Gabbett et al., 2009). It is possible that these types of sessions present an opportunity for athletes to self-regulate their external exercise intensity based on perceived exertion (i.e. to maintain RPE) rather than maintain external load and report a higher RPE (Marcora & Staiano, 2010). If the impact that perceived wellness has on external load parameters and their relationship with RPE was known, coaches may be able to better understand the training response a planned session might elicit in their athletes.

With the prevailing popularity of customised, self-report questionnaires in high-performance sport, and the large proportion of skill-based training sessions, the objective of this study was to examine the relationship between self-reported pre-training wellness scores and exercise intensity in subsequent skill-based training sessions. The impact of perceived wellness on a range of external load parameters, RPE and the external: internal load ratio in Australian footballers was explored.

## **Methods**

### **Participants**

Following approval from the University's Ethics Committee, the entire squad of one AFL club (the highest level of AF) was invited to participate in this study. Data from 36 male Australian football players who gave informed consent was used (mean  $\pm$  s: 22.0  $\pm$  2.5 years, 188.5  $\pm$  6.1 cm, 86.3  $\pm$  6.5 kg, 35.7  $\pm$  42.6 senior matches, 4.3  $\pm$  2.3 years in the AFL system, 3 first-year, 12 second- and third-year-, 11 fourth- and fifth-year-, 8 sixth- and seventh- year and 2 eight<sup>+</sup> -

year players). The study period of 10 weeks involved skill-based training sessions during the pre-competition phase of the 2013 season. A total of 376 data sets from 15 training sessions were examined. Participants had been exposed to all experimental protocols for a minimum of 2 months leading into the study period.

## **Procedures**

### ***Perceived wellness questionnaire***

Players were instructed to complete a customised perceived wellness questionnaire before any physical training, on each morning of the study period, except days off. The questionnaire was designed to be short, specific and based on the components common in the shortened psychological tools used to assess training imbalances in the literature (Gastin, Meyer, et al., 2013; Hooper & Mackinnon, 1995; Mclean et al., 2010). The items included muscular soreness, sleep quality, fatigue, stress and mood, on a seven-point Likert scale ranging from 1 (Strongly disagree) to 7 (Strongly agree). The five individual wellness responses for a given day were averaged to provide a quantitative score of overall perceived wellness for each player. Overall wellness scores were reported relative to individual's absolute mean and normal variation from the duration of the study period by reporting them as Z-scores. In order to use Z-scores, only data from individual's whose wellness scores were deemed normally distributed were used (Peat & Barton, 2008). Calculated using the following formula: (individual players score — individual players mean) / individual players standard deviation, a Z-score is the number of standard deviations the response is above or below the mean of the distribution.

### ***External training load***

During the 15 skill-based training sessions of the study period, players wore a commercially available microtechnology device, with tri-axial accelerometers (MinimaxX, Team 2.5, Catapult Innovations, Scoresby, Australia). The device was worn in a custom-made vest, fitting the unit tightly between the shoulder blades. The reliability of distance and high-speed running

distance of this 10 Hz device has been deemed acceptable with a coefficient of variation of 1.3% and 4.8%, respectively (Johnston et al., 2014). Furthermore, using a radar system as the criterion method to examine the validity of total distance and high-speed running, the coefficient of variation was reported as 1.9% and 4.7% respectively (Rampinini et al., 2015). The accelerometers sampled at 100 Hz are also reported to be reliable (1.9%) and valid for quantifying external load in field settings (Boyd et al., 2013). Using Catapult Sprint 5.0.6 software, data were downloaded, with transition time in between training drills removed, as to not underestimate the proportion of distance in speed zones, or mean speed (White & MacFarlane, 2013). External training load was measured using mean speed per minute ( $\text{metres} \cdot \text{min}^{-1}$ ), high-speed-running per minute ( $\text{metres} \cdot \text{min}^{-1}$ ), Player load<sup>TM</sup> (PL) per minute ( $\text{au} \cdot \text{min}^{-1}$ ) and Player load slow<sup>TM</sup> (PL<sub>slow</sub>) per minute ( $\text{au} \cdot \text{min}^{-1}$ ). High-speed running distance was defined as the distance run above a set threshold (individualised as each player's mean 2-km time-trial speed, with a group mean of  $18.1 \text{ km} \cdot \text{h}^{-1}$  and range of  $16.9 \text{ km} \cdot \text{h}^{-1}$  to  $19.7 \text{ km} \cdot \text{h}^{-1}$ ) (Abt & Lovell, 2009). The PL algorithm is a vector magnitude which combines rate of change in acceleration from three planes of movement, and is suggested to incorporate all forms of activity including skill and contact-based activities relevant to intermittent contact sports (Aughey, 2011; Boyd et al., 2013). Recent research has proposed that PL<sub>slow</sub>, which removes activity above  $2 \text{ m} \cdot \text{s}^{-1}$ , provides different information about low-speed activity (e.g. grappling, ruck contests) which is currently under-represented in traditional speed-based time-motion analysis (Boyd et al., 2013; Cormack et al., 2012).

### ***Rating of perceived exertion***

Players were shown the modified Borg category ratio 10 RPE scale approximately 30 min upon completing the session, prompted with the question "How was your session?" (Foster et al., 2001). Education was provided on the RPE scale, with players encouraged to give a global rating of the entire session using any intensity cues they deemed relevant. Referencing the anchors, a rating of 0 was deemed as rest and 10 as the hardest exercise exertion ever performed.

This commonly used method has been reported to be reliable and has previously been shown to be correlated with other measures of internal training load in a range of settings (Casamichana et al., 2013; Coutts, Murphy, et al., 2003; Eston, 2012; Impellizzeri et al., 2004).

### **Statistical Analyses**

To examine the effect of wellness Z-score on the external load parameters and RPE, mixed-effect linear models were performed using JMP (Version 10.0.2; SAS Institute, USA). To control the differences in training output seen between playing positions (Boyd et al., 2013) and prescribed load between training sessions, players were categorised as key position, nomadic, midfielders or ruckman as per their role in the team with position and session id entered as random effects. Wellness Z-score was entered as the fixed effect. The load parameters were log-transformed in order to report the change in load as a percentage change per 1 Z-score wellness change. The coefficient of wellness Z-score  $\pm 95\%$  CL was then taken as the value of the effect of wellness on load within a session. To examine the relationship between external: internal load ratios and wellness Z-score, mixed-effect linear models were performed with subject entered as the random effect. Significance was set at the  $P < 0.05$  level. The magnitudes of the effects were reported as Cohen's effect sizes ( $d$ ) with  $d \pm 95\%$  confidence limits (CL) described as  $< 0.2$  trivial,  $0.2-0.6$  small,  $0.6-1.2$  moderate,  $1.2-2.0$  large,  $2.0-4.0$  very large (Hopkins, 2002). The qualitative interpretation that the true value of the effect represented an important change was determined with magnitude-based inferences as  $< 75\%$  trivial,  $\geq 75\%$  likely,  $> 95\%$  very likely,  $> 99.5\%$  almost certainly that the effect size exceeded 0.20 (Batterham & Hopkins, 2006). An effect where there was  $> 5\%$  chance of the change being positive or negative was deemed as unclear.



## Results

The mean  $\pm$  *s* training time of the 15 sessions was  $77.7 \pm 16.1$  min with mean external load variables of  $87.2 \pm 10.7$  metres·min<sup>-1</sup> mean speed,  $12.8 \pm 4.4$  metres·min<sup>-1</sup> of high-speed running,  $7.7 \pm 1.3$  au·min<sup>-1</sup> of PL,  $1.9 \pm 0.3$  au·min<sup>-1</sup> of PL<sub>slow</sub>, and a mean RPE of  $8.4 \pm 0.8$ . Table 5-1 summarises the mixed-effect linear models demonstrating that perceived wellness Z-score had a significant effect test in the PL and PL<sub>slow</sub> models. The coefficient of the fixed effect test revealed that a wellness Z-score of -1 would correspond to a  $2.0 \pm 2.2$ ,  $-7.8 \pm 8.6$ ,  $-4.9 \pm 3.1$ ,  $-8.6 \pm 3.9$  and  $0.4 \pm 1.9\%$  change in mean speed, high-speed running, PL, PL<sub>slow</sub>, and RPE, respectively. The effect size of these differences and the likelihood that the true effect represents an important change is reported in Table 5-2.

**Table 5-1** The R<sup>2</sup> of the linear models for each load parameter, model intercept, Z-score coefficient and *P* value of the fixed effect test on wellness Z-score (*n* = 376).

Parameters	R <sup>2</sup>	Intercept ±95% CL	Coefficient ±95% CL	<i>P</i> Value
Mean speed (metres·min <sup>-1</sup> )	0.61	4.47 ±0.07	-0.02 ±0.02	0.069
HSR (metres·min <sup>-1</sup> )	0.35	2.43 ±0.16	0.08 ±0.09	0.076
PL (au·min <sup>-1</sup> )	0.57	1.97 ±0.16	0.05 ±0.03	0.002*
PL <sub>slow</sub> (au·min <sup>-1</sup> )	0.38	0.57 ±0.14	0.09 ±0.04	< 0.001*
RPE	0.59	2.12 ±0.07	-0.004 ±0.02	0.680

\*Significant fixed effect test at the *P* < 0.05 level.

HSR: high-speed running; PL: Player load<sup>TM</sup>; PL<sub>slow</sub>: Player load<sub>slow</sub><sup>TM</sup>; RPE: rating of perceived exertion; 95% CL: 95% confidence limits.

**Table 5-2** The size ( $d \pm 95\%$  CL), magnitude descriptor and qualitative inference of the effect that a Z-score of  $-1$  in wellness would have on external load variables and RPE.

Parameters	$d \pm 95\%$ CL	Descriptor	Qualitative Inference
Mean speed (metres·min <sup>-1</sup> )	$0.26 \pm 0.28$	Small	Trivial
HSR (metres·min <sup>-1</sup> )	$-0.25 \pm 0.28$	Small	Trivial
PL (au·min <sup>-1</sup> )	$-0.45 \pm 0.28$	Small	Trivial
PL <sub>slow</sub> (au·min <sup>-1</sup> )	$-0.61 \pm 0.28$	Moderate	Likely Negative
RPE	$0.06 \pm 0.28$	Trivial	Trivial

\*Significant fixed effect test at the  $P < 0.05$  level.

HSR: high-speed running; PL: Player load<sup>TM</sup>; PL<sub>slow</sub>: Player load<sub>slow</sub><sup>TM</sup>; RPE: rating of perceived exertion; 95% CL: 95% confidence limits.

Table 5-3 summarises the mixed-effect linear models of the external: internal load ratios demonstrating that perceived wellness Z-score had a significant effect test in the mean speed: RPE and PL<sub>slow</sub>: RPE ratio models. The coefficient of the fixed effect test revealed that a wellness Z-score of  $-1$  would correspond to an increase in mean speed of  $0.43 \pm 0.38$  metres·min<sup>-1</sup> and a decrease in PL<sub>slow</sub> of  $-0.02 \pm 0.01$  au·min<sup>-1</sup>, per unit of RPE. The effect size that a wellness Z-score of  $-1$  would have on the external: internal load ratios is reported in Table 5-4.

**Table 5-3** The  $R^2$  of the linear models for each external load: RPE ratio, model intercept, Z-score coefficient and  $P$  value of the fixed effect test on wellness Z-score ( $n = 376$ ).

Parameters	$R^2$	Intercept $\pm 95\%$ CL	Coefficient $\pm 95\%$ CL	$P$ Value
Mean speed: RPE (metres·min <sup>-1</sup> )	0.27	10.7 $\pm$ 0.34	-0.43 $\pm$ 0.38	0.025*
HSR: RPE (metres·min <sup>-1</sup> )	0.46	1.53 $\pm$ 0.13	-0.01 $\pm$ 0.11	0.826
PL: RPE (au·min <sup>-1</sup> )	0.41	0.91 $\pm$ 0.04	0.03 $\pm$ 0.03	0.052
PL <sub>slow</sub> : RPE (au·min <sup>-1</sup> )	0.26	0.22 $\pm$ 0.01	0.02 $\pm$ 0.01	< 0.001*

\*Significant fixed effect test at the  $P < 0.05$  level.

HSR: high-speed running; PL: Player load<sup>TM</sup>; PL<sub>slow</sub>: Player load<sub>slow</sub><sup>TM</sup>; RPE: rating of perceived exertion; 95% CL: 95% confidence limits.

**Table 5-4** The size ( $d \pm 95\%$  CL), magnitude descriptor and qualitative inference of the effect that a Z-score of -1 in wellness would have on external: RPE ratios.

Parameters	$d \pm 95\%$ CL	Descriptor	Qualitative Inference
Mean speed: RPE (metres·min <sup>-1</sup> )	0.33 $\pm$ 0.29	Small	Trivial
HSR: RPE (metres·min <sup>-1</sup> )	0.03 $\pm$ 0.29	Trivial	Trivial
PL: RPE (au·min <sup>-1</sup> )	-0.29 $\pm$ 0.29	Small	Trivial
PL <sub>slow</sub> : RPE (au·min <sup>-1</sup> )	-0.49 $\pm$ 0.29	Small	Trivial

\*Significant fixed effect test at the  $P < 0.05$  level.

HSR: high-speed running; PL: Player load<sup>TM</sup>; PL<sub>slow</sub>: Player load<sub>slow</sub><sup>TM</sup>; RPE: rating of perceived exertion; 95% CL: 95% confidence limits.

## Discussion

The purpose of this study was to examine the relationship between pre-training perceived wellness and subsequent exercise intensity during skill-based training sessions in Australian footballers. The main finding was that pre-training wellness Z-score had a significant effect on the external load parameters of PL and PL<sub>slow</sub>. A second finding was that the integrated external: internal load ratio of mean speed: RPE and PL<sub>slow</sub>: RPE was also significantly impacted by pre-training wellness Z-scores. With significant effects of pre-training wellness Z-score on PL and PL<sub>slow</sub>, magnitude-based analysis was included to allow for practical interpretation of the size

of the effects and qualitative inference about their true values. Using a wellness Z-score of  $-1$  ( $1\text{ s}$  below the mean) allowed for interpretation of the effect that a standard reduction in wellness would have on output compared to normal (mean) wellness. For a wellness Z-score of  $-1$ , a small effect was seen on PL and a moderate effect on  $PL_{\text{slow}}$ . However, only  $PL_{\text{slow}}$  had a true value which is likely negative. Similarly with the external: internal load ratios, while a small difference was seen in mean speed: RPE, and  $PL_{\text{slow}}$ : RPE ratios with a wellness Z-score of  $-1$ , both of these effects appear to be trivial due to their large confidence intervals. These magnitude-based inferences suggest that a very large reduction in wellness Z-score would need to exist for confidence that the effect it has on PL or mean distance: RPE and  $PL_{\text{slow}}$ : RPE ratios was meaningful. Nonetheless, these results suggest that pre-training perceived wellness could influence the exercise output of Australian footballers during skill-based training sessions.

It has previously been reported that perceived wellness did not impact RPE in submaximal aerobic exercise (Haddad et al., 2013). The current study also found no impact of wellness on absolute RPE however, the significant effect of wellness in the PL and  $PL_{\text{slow}}$  models suggests that when controlled for position, as wellness Z-score decreases, external output within a session might also decrease. The externally paced nature of the protocol used in the Haddad study presented no opportunity for self-pacing whereas the skill-based sessions in this study provided opportunity for athletes to regulate their exercise intensity (Marcora & Staiano, 2010). It is likely that reduced wellness Z-scores reflect players who were feeling ‘worse than normal’ and therefore rated their perceived exertion similarly to their counterparts even though they may have accumulated less PL and  $PL_{\text{slow}}$ . This is further evident in the results from the external: internal load ratio analysis where reduced wellness resulted in a reduction in  $PL_{\text{slow}}$ : RPE ratio. In other words, a low pre-training wellness score may result in players modifying their external load in order to maintain RPE.

While there were significant effects for two of the external load parameters, the two running variables were not significantly affected by pre-training wellness Z-score. These results might be explained by the nature of activity that makes up the PL and PL<sub>slow</sub> parameters. The PL variable is suggested to incorporate all forms of activity, including change of speed, direction and impacts and the PL<sub>slow</sub> variable provides information about low-speed activity such as grappling and body work (Boyd et al., 2013). Previous research has demonstrated that fatigue alters the way PL is accumulated in Australian football matches (Cormack et al., 2012; Mooney et al., 2011). Specifically, it was reported that fatigued players were able to maintain total distance and high-speed running but had a lower contribution of vertical acceleration to PL due to likely impairments in contractile function (i.e. a physical performance limitation) (Cormack et al., 2012). Whether or not similar decrements in contractile function existed in the athletes in the current study is unknown, however the results suggest that perceived wellness also modifies the accumulation of PL via the alteration of movement strategy.

Alternatively, it is possible that as a method of pacing, players with reduced wellness Z-scores maintain the running variables that they deem critical to performance but modify other aspects of activity profile such as change of speed, low speed running and/or body contact (Coutts et al., 2010). This concept may be further verified by the results of the external: internal load ratios where a decrease in wellness Z-score corresponded to an increase in mean speed: RPE ratio but a decrease in PL<sub>slow</sub>: RPE ratio. These results show that while mean speed and RPE within a session was not significantly affected by pre-training wellness Z-score, the relationship between the two might be impacted. It appears that players with low wellness Z-score might have higher mean speed per unit of RPE. This is an interesting finding particularly when considered with the finding that PL<sub>slow</sub>: RPE ratio was significantly impacted by pre-training perceived wellness in the opposite direction. It is certainly feasible that players with low perceived wellness, and therefore altered movement strategy might find themselves needing to make-up for lower output

at low-velocities and 'chase' or 'catch up' to their opponents resulting in higher mean speed than those who do the work early (at contests) and prevent the opposition from creating space between them.

Customised wellness questionnaires are prominent in high-performance sport, and there remains no consensus as to how they should be used to enhance a training program design or implementation (Saw et al., 2015b; Taylor et al., 2012). One of the more commonly proposed applications is to use wellness scores as an indicator of fatigue and to adjust subsequent training in response (Kellmann, 2002a). However, the impact of reduced wellness on subsequent exercise output has not yet been reported in the literature as the previous research in team sport settings has reported perceived wellness in response to training (Buchheit, Simpson, et al., 2013; Gastin, Meyer, et al., 2013; Mclean et al., 2010). Therefore, as well as incorporating a self-report wellness tool into monitoring practices to prompt targeted conversations between staff and athletes (Saw et al., 2015b), the results of this study suggest that perceived wellness does indeed impact external training output and external: internal load ratios, in particular  $PL$ ,  $PL_{slow}$ , mean speed: RPE and  $PL_{slow}$ : RPE ratios, especially when there is a large reduction in wellness Z-score.

Monitoring pre-training perceived wellness for both individual athletes and the whole team may offer an indication on the quality of the external output that might be produced prior to a session and provides coaches with the ability to make adjustments if warranted. If a large proportion of the team have reduced wellness Z-scores, it might be decided to accept that  $PL_{slow}$  will be compromised and continue with the planned session. Alternatively, to encourage intended exercise intensity, the volume of the session might be adjusted or the content of the planned session might be revised to provide a metabolic exercise stimulus without peripherally demanding activities (e.g. high-speed accelerations, grappling, contact) that may be linked to

the  $PL_{slow}$  variable (Boyd et al., 2013; Buchheit & Laursen, 2013a, 2013b; Cormack et al., 2012). The decision on how to intervene when an individual player or a large proportion of the team have reduced wellness Z-scores will most likely be influenced by other factors (e.g. match-to-match micro cycle, skill and tactical position and coaching philosophy). The use of perceived wellness to gain an understanding of the external output the athletes might produce will enhance the coaches' ability to adjust training sessions to best prepare their athletes.

This study examined 15 skill-based sessions from pre-season training in an AFL club. Future research might categorise skill-based training into the differing modes such as small-sided games and match-play practice which have been shown to have differences in output between positional types (Boyd et al., 2013). Also, further studies may expand on this finding by exploring the impact of perceived wellness on external load during other types of sessions. In particular, determining if match output is related to perceived wellness would add valuable knowledge in the area. Recent research has also suggested that differential RPEs have improved precision to reflect central, local and technical internal load and as such may be more sensitive to wellness scores and warrants future research (Weston et al., 2015). Similarly, using individual wellness indices as an overall measure of perceived wellness may restrict the ability to identify specific relationships between individual wellness components and different external load variables and may be a valuable direction for future research (Thorpe et al., 2015). These results are potentially impacted by issues surrounding the reliability and validity of microtechnology parameters (Boyd et al., 2011; Johnston et al., 2014; Rampinini et al., 2015) and accurate and honest self-reporting by players (Saw et al., 2015a). It is also acknowledged that the relationship between load and wellness may be non-linear and therefore, linear modelling techniques limited in their ability to reflect such relationships (Gabbett, Whyte, Hartwig, Wescombe, & Naughton, 2014). Furthermore, while the variability between players speed at which they begin to run at high-intensity warrants the use of individualised high-speed

running thresholds (Abt & Lovell, 2009), this study was constrained to pre-existing club testing procedures, limiting the protocol used to determine individualised high-speed running threshold as each player's mean 2-km time-trial speed. The recommended method of using the speed at which the second ventilatory threshold is reached may have resulted in different outcomes.

## **Conclusion**

This study showed that external exercise intensity in skill-based training sessions was related to pre-training self-reported wellness scores in AF players. Reductions in wellness Z-scores corresponded to reductions in PL and PL<sub>slow</sub>. External to internal load ratios were also examined and reductions in wellness Z-scores were associated with increases in mean speed: RPE ratio and decreases in PL<sub>slow</sub>: RPE ratio. Magnitude-based analysis allowed inferences to be made about the practical size of the effects and the impact that a pre-training perceived wellness Z-score of -1 would have on PL<sub>slow</sub> was likely negative. The results of this study suggest that monitoring perceived wellness could give coaches information about the training output players might produce for a session.



## **Chapter 6. Study 4: Effects of internal load measures and athlete self-reported wellness on match performance in Australian football**

### **Publication Statement**

This chapter is comprised of the following manuscript which is preparation for submission:

Gallo, T., Cormack, S. J., Gabbett, T. J., Tran, J. & Lorenzen, C. (2015). Effects of internal load measures and athlete self-reported wellness on match performance in Australian football.

### **Linking Paragraph**

The first experimental chapter of this thesis explored the relationship between external micro-technology derived parameters and s-RPE, finding that individual characteristics such as fitness, experience and playing position influence the relationship. Secondly, the weekly profile of self-reported wellness was explored with days-post-match, match-to-match micro-cycle and stage of the season all influencing the weekly profile. Study 3 demonstrated that pre-training wellness does indeed impact subsequent training external load output. Thus suggesting that self-reported wellness may be a useful tool to monitor training status and adjust training prescription accordingly. Despite advances in research and contemporary monitoring practices, the contribution of these techniques to enhancing elite sports performance remains unknown. The aim of the final study of this thesis was to examine the effects of s-RPE training load, combined with athlete self-reported wellness, on subjective and/or objective measures of individual match performance in professional AF.

## Abstract

The effects of internal load, combined with athlete self-reported wellness, on subjective and/or objective measures of match performance in 20 rounds of professional AF was examined. Acute weekly load was determined using the session rating of perceived exertion (s-RPE) method for each independent training modality. Chronic load was calculated as the rolling 4-week mean and a training-stress balance (TSB) was ascertained by dividing the acute load (1-weekly total) by the chronic load (4-week mean) expressed as a percentage. Load from every training modality was used to calculate an overall acute load ( $acute_{all}$ ), overall chronic load ( $chronic_{all}$ ), and overall TSB ( $TSB_{all}$ ) and only outdoor skills and conditioning sessions were used to calculate a field-based acute load ( $acute_{field}$ ), a field-based chronic load ( $chronic_{field}$ ) and field-based TSB ( $TSB_{field}$ ). The mean of the overall daily wellness scores from a 5-item (sleep quality, fatigue, stress, mood, and muscle soreness) athlete self-report questionnaire was used to quantify weekly wellness. An iterative linear mixed modelling approach demonstrated that load and wellness variables had minimal impact on subjective performance ratings (coaches' votes). Conversely, objective performance, measured via Champion Data© ranking points was positively associated with load, although the magnitude of this effect was greater for field-based loads ( $acute_{field}$  and  $chronic_{field}$ :  $\beta = 7.4$  and  $9.1$ , respectively) compared to overall loads ( $\beta = 0.9$ ). Furthermore, athletes with high loads reporting low wellness, ranked better in objective performance than those reporting high wellness with high load. Whereas an increase in wellness was associated with better objective performance when accompanied by lower loads. These results confirm the value of quantifying load and determining training status using self-reported measures and highlight the importance of a mixed-method approach to comprehensively assess athlete status.

**Key Words:** acute load, chronic load, RPE, monitoring training

## Introduction

In order to achieve success in professional sport, a training regime which accurately balances stress and recovery doses is vital to enhance performance (Halson, 2014; Taylor et al., 2012; Twist & Highton, 2012). Contemporary monitoring of athlete preparedness, including quantifying training and competition load and determining fatigue/training status, are therefore commonly used to complement training prescription and recovery programs (Kenttä & Hassmén, 2002). A survey across Australian and New Zealand high-performance personnel reported that 70% of responders indicated their monitoring system had an equal focus on load quantification and fatigue monitoring (Taylor et al., 2012). In regards to load monitoring practices in soccer, 40 of the 41 professional teams surveyed collect load data for every player during every field training session (Akenhead & Nassis, 2015). Strong support for psychological markers as a tool to assess training status has lead practitioners to incorporate customised athlete self-report measures into their monitoring practices (Buchheit, Racinais, et al., 2013; Gastin, Meyer, et al., 2013; Hooper & Mackinnon, 1995; Mclean et al., 2010). It was reported that 84% of Australian and New Zealand high-performance sport practitioners use self-report questionnaires, 80% of which use custom designs consisting of 4 to 12 items (Taylor et al., 2012).

Exercise load is determined by exercise volume and intensity and can be quantified by external (indicating the output performed) and/or internal (representing the response experienced by the athlete) load parameters, with an absence of a gold-standard (Impellizzeri et al., 2005). A popular measure of internal load used in many professional sport settings is the session-rating of perceived exertion (s-RPE) (Alexiou & Coutts, 2008; Gastin, Meyer, et al., 2013; Impellizzeri et al., 2004). Using a subjective rating of perceived exertion (RPE), multiplied by the duration of the session (as a measure of volume), a single arbitrary number represents internal load (Alexiou & Coutts, 2008; Foster et al., 2001). This method is shown to have

moderate to very large correlations ( $r = 0.45$  to  $0.91$ ) with objective heart rate-based measures of internal training load in team sports (Lovell et al., 2013; B. R. Scott et al., 2013; T. J. Scott et al., 2013). However, there is opinion that in order for a training load measure to be considered valid, it should exhibit a fundamental principal of training i.e. a dose-response relationship, and that changes in fitness and/or performance measures in response to exercise load should be evident (Akubat et al., 2012; Aughey et al., 2015; Manzi et al., 2013).

While an increase in load quantified by the s-RPE method was shown to improve performance in endurance athletes (Foster et al., 1996), s-RPE failed to correlate to changes in aerobic fitness parameters in youth soccer players and collision sport athletes (Akubat et al., 2012; Brink, Nederhof, et al., 2010; Gabbett & Domrow, 2007). Similar results were seen in rugby league players with s-RPE only demonstrating weak correlations ( $r = -0.27$  to  $-0.30$ ) with  $VO_{2max}$  and squat jump performance (Coutts, Reaburn, et al., 2003). Alternatively, s-RPE load had a significant relationship ( $r = -0.84$ ) with performance measured via a multi-stage fitness test in rugby league players (Coutts, Reaburn, Piva, & Murphy, 2007). Specific research on the dose-response relationship between s-RPE and performance in Australian football (AF) has only recently been explored (Aughey et al., 2015). It was found that weekly load was likely greater preceding wins compared to losses even when controlled for ladder position of the opposition (Aughey et al., 2015). Moreover, the training-stress balance (TSB) was possibly greater positive (higher 4-week mean load compared to current week) in wins versus losses also when controlled for ladder position of the opposition or days between matches (Aughey et al., 2015). However, given the multitude of factors that contribute to winning a match in AF, the validity of using win/loss as the performance outcome measure is uncertain.

Notably, evidence of a dose-response relationship between s-RPE and injury is more prominent (Gabbett & Jenkins, 2011; Veugelers et al., 2015). It has been reported that high overall s-RPE

training loads as well as spikes in load relative to the previous week, expose players to a greater risk of injury (Gabbett & Ullah, 2012; Rogalski et al., 2013). The effects of different methods of calculating s-RPE have also been examined with one study reporting that field-based load (only outdoor sessions performed on the field such as running and skill-based training) had a significant relationship with injury in rugby league (Gabbett & Jenkins, 2011). Alternatively in Australian football, overall RPE was a better predictor of injury while field RPE was a better indicator of illness (Veugelers et al., 2015). Moreover, the inclusion of duration in the calculation of s-RPE did not improve the prediction of either injury or illness compared to RPE (without the inclusion of duration) (Veugelers et al., 2015).

The relationship between athlete self-report measures and load has been examined with days-to-game reported as a significant coefficient for a range of subjective wellness items in AF (Gastin, Meyer, et al., 2013; Mclean et al., 2010). A collection of studies have reported that wellness dips in response to matches and steadily improves as the next match day approaches with little influence of subsequent training load (Bahnert et al., 2013; Gallo, Cormack, Gabbett, & Lorenzen, 2016; Montgomery & Hopkins, 2013). Alternatively, athlete self-report measures were sensitive to s-RPE training load during a pre-season training camp and also sensitive to the external load measure of high-speed running in soccer (Buchheit, Simpson, et al., 2013; Thorpe et al., 2015). While athlete self-report measures appear to respond to match loads, training doses measured as s-RPE may have little influence on this response in the competition phase. Exploring the relationship in the other direction has found that RPEs were not affected by self-reported wellness during submaximal exercise in soccer players (Haddad et al., 2013). Although in AF players, it was recently reported that pre-training wellness had a significant effect on external load parameters, with players with low wellness producing lower accelerometer derived values (Player load<sup>TM</sup> and Player load slow<sup>TM</sup>) in skill-based training sessions (Gallo, Cormack, Gabbett, & Lorenzen, 2015). Furthermore, integrated external:

internal load ratios were significantly impacted by self-reported pre-training wellness (Gallo, Cormack, Gabbett, & Lorenzen, 2015). It was suggested that pre-training self-reported wellness might influence the external activity profile with athletes potentially modifying their external load while maintaining RPE.

The complex interaction between the fitness and fatigue responses of a training regime, equates to the preparedness of an athlete, which is the immediate ability to perform. The difficulty of quantifying both preparedness and match performance impedes research exploring the effect of contemporary monitoring practices on match performance in team sports (Aughey et al., 2015; Cormack et al., 2012; Gastin, Fahrner, et al., 2013; Mooney et al., 2012). In a full AF season, it was shown that neuromuscular fatigue, measured via flight time: contraction time ratio from counter-movement jumps, may have a one to two match delayed impact on coaches ratings of performance (Cormack, Newton, McGuigan, et al., 2008). While neuromuscular fatigue did not affect external match output variables of Player load<sup>TM</sup> or high-speed running, there was a negative effect on the relationship between high-speed running and Player load<sup>TM</sup> and between Player load<sup>TM</sup> and subjective performance (coaches ratings) (Mooney et al., 2012). It was suggested that a change in mechanical efficiency (increase in lateral movements) might result in altered movement patterns that produce the same player output, but are seen negatively by coaches. This was further verified by Cormack et al. (2012), where fatigued players had a lower contribution of the vertical accelerometer vector to Player load<sup>TM</sup>, attributed to impairments in contractile function under neuromuscular fatigue. One study exploring the relationship of both load and self-report measures to performance in professional soccer players, determined that team performance (wins vs losses) and the iceberg profile from the profile of mood states (POMS) was not impacted following increased high-intensity training despite a decrease in testosterone: cortisol ratio suggesting a catabolic state (Filaire et al., 2001).

Research examining the effect of common load measures and self-reported wellness on individual performance in AF is lacking as a performance outcome measure of wins versus losses has the potential to conceal individual performance responses to training load. Therefore, the objective of this study was to corroborate the use of various athlete monitoring variables (load and wellness) based on their relationship to individual athlete performance. The specific aim of this study was to examine the effects of s-RPE training load, combined with athlete self-reported wellness, on subjective and/or objective measures of match performance in professional AF.

## **Methods**

### **Participants**

Following approval from the Australian Catholic University's Ethics Committee, the entire squad of one AFL club (the highest level of AF) was invited to participate in this study. Forty-three players were recruited after providing written informed consent, however only athletes who played AFL matches throughout the season were used in the analysis ( $n = 33$ ; mean  $\pm s$ :  $23.9 \pm 3.4$  years,  $187.5 \pm 6.7$  cm,  $87.1 \pm 7.1$  kg,  $5.6 \pm 3.6$  years' experience in the AFL,  $67.0 \pm 76.2$  senior matches).

### **Procedures**

#### ***Athlete self-reported wellness***

Players were asked to complete a self-reported wellness questionnaire before any physical training on each morning of the study period (except on match days), any time before physical training commenced. Players were able to complete their wellness in private using an online system on their own smart device/computer or a computer available upon arrival at the club. The questionnaire was customised to be short, specific to AF, and based on the components

common to existing self-report tools used to monitor training distress (Gastin, Meyer, et al., 2013; Hooper & Mackinnon, 1995; Mclean et al., 2010). The items included: sleep quality, stress, fatigue, mood, and muscle soreness. These items were rated on a seven-point Likert scale ranging from 1 ('strongly disagree') to 7 ('strongly agree') (Gastin, Meyer, et al., 2013; Mclean et al., 2010). Players were instructed to respond as how they were currently feeling. An overall daily wellness score was determined by averaging the five items. Weekly wellness was calculated as the mean of the available daily wellness scores. To minimise error due to biased data, if a player had less than 3 wellness entries in any week, weekly wellness was not calculated and this was treated as missing data.

### ***Load measurement***

Training load for each session (including matches, skills training, field-based conditioning, cross-training and strength training modes) was determined using the s-RPE method (Foster et al., 2001). Players were shown the modified category-ratio 0–10 Borg RPE scale approximately 30 min upon completing the session, and prompted with the question “How was your session?” (Foster et al., 2001). Education was provided on the RPE scale, with players encouraged to give a global rating of the entire session using any intensity cues they deemed relevant. Referencing the anchors, a rating of 0 was deemed as rest and 10 as the hardest exercise exertion ever performed. The RPE was multiplied by exercise duration defined as the sum of individual drill times, with transition time removed (Wallace et al., 2014). This commonly used method has been reported to be reliable and correlates with other measures of internal training load in a range of settings (Impellizzeri et al., 2004; T. J. Scott et al., 2013). Acute weekly load was calculated as the cumulative load from Monday to Sunday for each training modality. Chronic load was then calculated as the rolling 4-week mean. To represent the athletes physical status using training load, TSB was calculated by dividing the acute load (1-weekly total) by the chronic load (4-week mean) expressed as a percentage (Aughey et al., 2015). A TSB greater than 100% indicated the current week's acute load exceeded the mean weekly load over the



preceding 4 weeks. Alternately, a TSB less than 100% indicated the mean weekly load over the preceding 4 weeks exceeded the current week's acute load. Load from every training modality was used to calculate an overall acute load ( $acute_{all}$ ), overall chronic load ( $chronic_{all}$ ), and overall TSB ( $TSB_{all}$ ) and only outdoor skills and conditioning sessions were used to calculate a field-based acute load ( $acute_{field}$ ), a field-based chronic load ( $chronic_{field}$ ) and field-based TSB ( $TSB_{field}$ ) (Veugelers et al., 2015).

### ***Individual player performance***

Two constructs of individual player performance were examined in this study. A subjective performance measures of coaches' votes was used to represent performance in relation to an identified role in the team. In contrast, Champion Data© ranking points reflected an objective measure of skill execution and effectiveness. Coaches votes' were obtained from 5 full-time coaches who subjectively rated each player's match performance using the following categories: 1 = poor performance; 2 = moderate performance; 3 = good performance; 4 = very good performance; 5 = excellent performance. Coaches were educated to rate a player's performance based on the impact they had for the team relative to their position (e.g. a defender who has few possessions but limited his opponent's influence, might be rated highly for playing their role well). A mean score was given to each player for every match similar to a previous protocol (Mooney et al., 2012). Inter-rater reliability for this measures was as follows: ICC(3,1) = 0.65; 95% confidence interval (CI): 0.62–0.69. Objective performance was determined from the ranking points given to each player in each match by the contracted commercial statistical analytics company for the AFL (Champion Data©, South Bank, Australia). Developed in 1999, the Champion Data© player ranking system allocates a positive score for every effective skill execution and a negative rating for ineffective skill executions. Using statistical measures which are correlated to winning AF matches, the algorithm is reviewed annually and conventionally accepted as a method to rank players throughout the league (Mooney et al., 2011).

## Statistical Analysis

All statistical analysis was conducted using R (version 3.2.0, The R Foundation for Statistical Computing). Key packages included 'plyr' (version 1.8.3) and 'lme4' (version 1.1-9). Statistical significance was set at  $P < 0.05$ . Exploratory data analysis revealed that the individual mode-specific load data (matches, skills training, field-based conditioning, cross-training and strength training modes) did not approximate normal distribution and therefore were excluded from the mixed model analysis. All other variables met the assumptions of normality, linearity, and homoscedasticity.

Means  $\pm$  standard deviation (*s*) are reported for each normally distributed training load variable (*acute<sub>all</sub>*, *chronic<sub>all</sub>*, *TSB<sub>all</sub>*, *acute<sub>field</sub>*, *chronic<sub>field</sub>*, *TSB<sub>field</sub>*), wellness, and performance (coaches' votes and Champion Data© ranking points). As the mode-specific training load variables were non-normally distributed, descriptive statistics for these variables are reported as medians with the upper and lower limits of the interquartile range. Pearson's *r* values were calculated to examine bivariate associations between load and performance, and between wellness and performance. A correlation was also calculated between coaches' votes and Champion Data© ranking points to assess the relationship between the subjective and objective measures of player performance.

Generalised linear mixed models were used to investigate associations between load, wellness, and performance. The models were constructed using an iterative approach, beginning with the simplest model (intercept-only) and progressing incrementally to a full model with 3 fixed effects (2 main effects, 1 interaction effect) and 3 random effects. Player performance was the outcome variable, represented by either coaches' votes or Champion Data© ranking points. Two fixed effect parameters were examined: Load (*acute<sub>all</sub>*, *chronic<sub>all</sub>*, *TSB<sub>all</sub>*, *acute<sub>field</sub>*, *chronic<sub>field</sub>*, *TSB<sub>field</sub>*), and Wellness (weekly mean). Random effects for Participant and Round

were included to account for inter-individual variability at baseline and between match variability, respectively. Due to sample size constraints, model complexity was limited to including 3 random effects at most. The third random effect represented 1 of 4 identifiable player characteristics in relation to experience and fitness: (i) AFL experience as years played (ii) AFL experience as games played, (iii) 2-km time-trial result, and (iv) yo-yo intermittent recovery (level 2) performance (Gallo, Cormack, Gabbett, Williams, et al., 2015).  $Acute_{all}$ ,  $chronic_{all}$ ,  $acute_{field}$ , and  $chronic_{field}$ , variables were scaled so that a 1-unit change represented a 100 s-RPE load unit change.  $TSB_{field}$  and  $TSB_{all}$  values were also scaled so that 1-unit change represented a 10 percentage-point change. Model selection was conducted by comparing the Akaike weights between candidate models (Burnham & Anderson, 2002). In agreement with the principle of parsimony, if two candidate models had similar probabilities of being the optimal model, the model with fewest parameters was selected. Parameter estimates are reported with upper and lower limits of the 95% CI. If the 95% CI for the parameter estimate crossed 0 (i.e., the true effect could be either positive or negative), the effect was deemed unclear (Batterham & Hopkins, 2006).

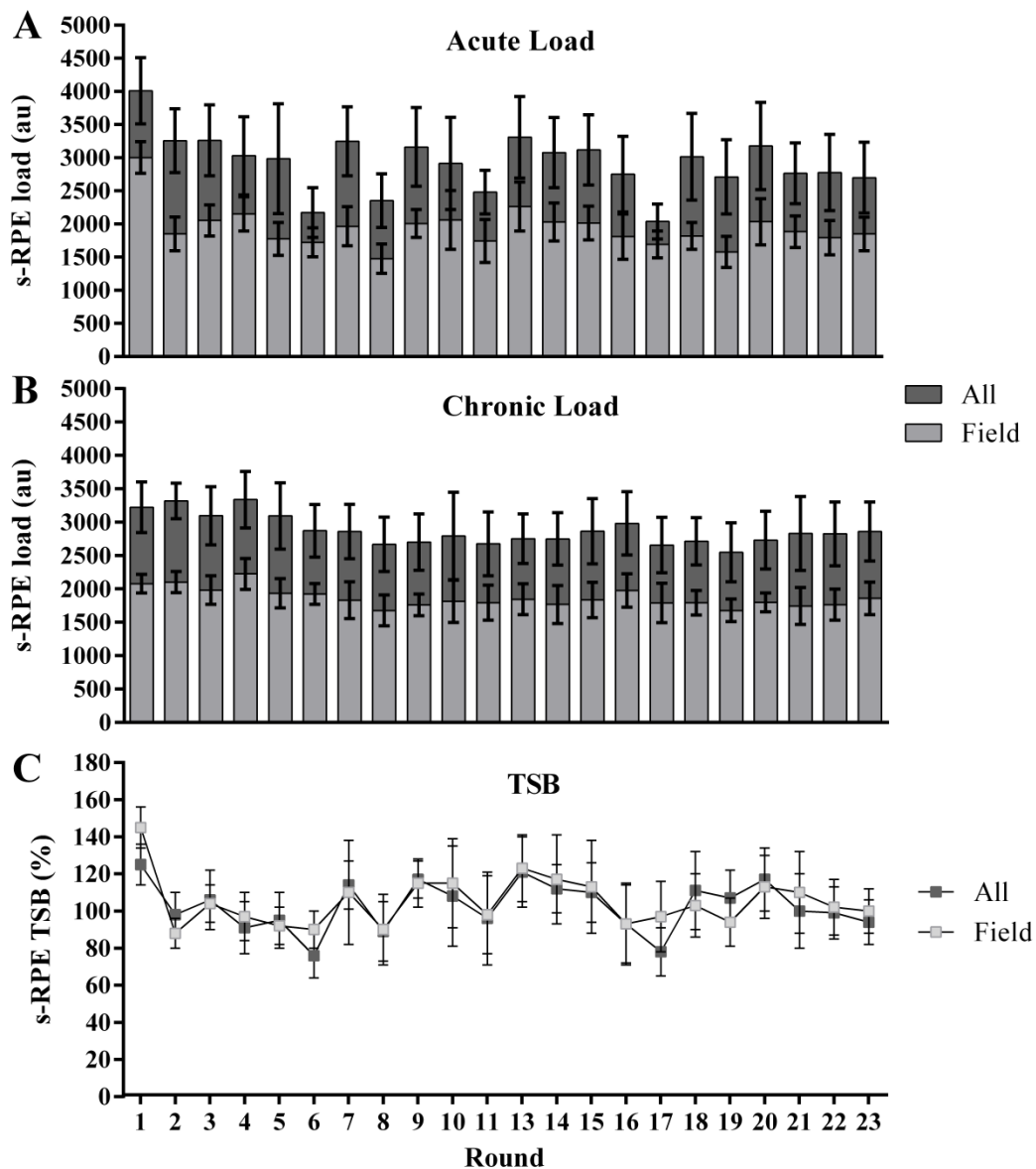
## Results

Round-by-round data for  $acute_{all}$ ,  $chronic_{all}$ ,  $TSB_{all}$ ,  $acute_{field}$ ,  $chronic_{field}$ ,  $TSB_{field}$  are presented in Figure 6-1. Coaches' votes, Champion Data© ranking points, and wellness across the season are shown in Figure 6-2. The median and interquartile range for weekly loads in specific modes were as follows: match load = 1230 au (1140–1300 au); skills load = 710 au (565–914 au), strength load = 980 au (623–1396 au). For conditioning and cross-training loads, the median and interquartile range values were 0, due to the relatively low frequency of these modes of training during the in-season training program.

## Correlations

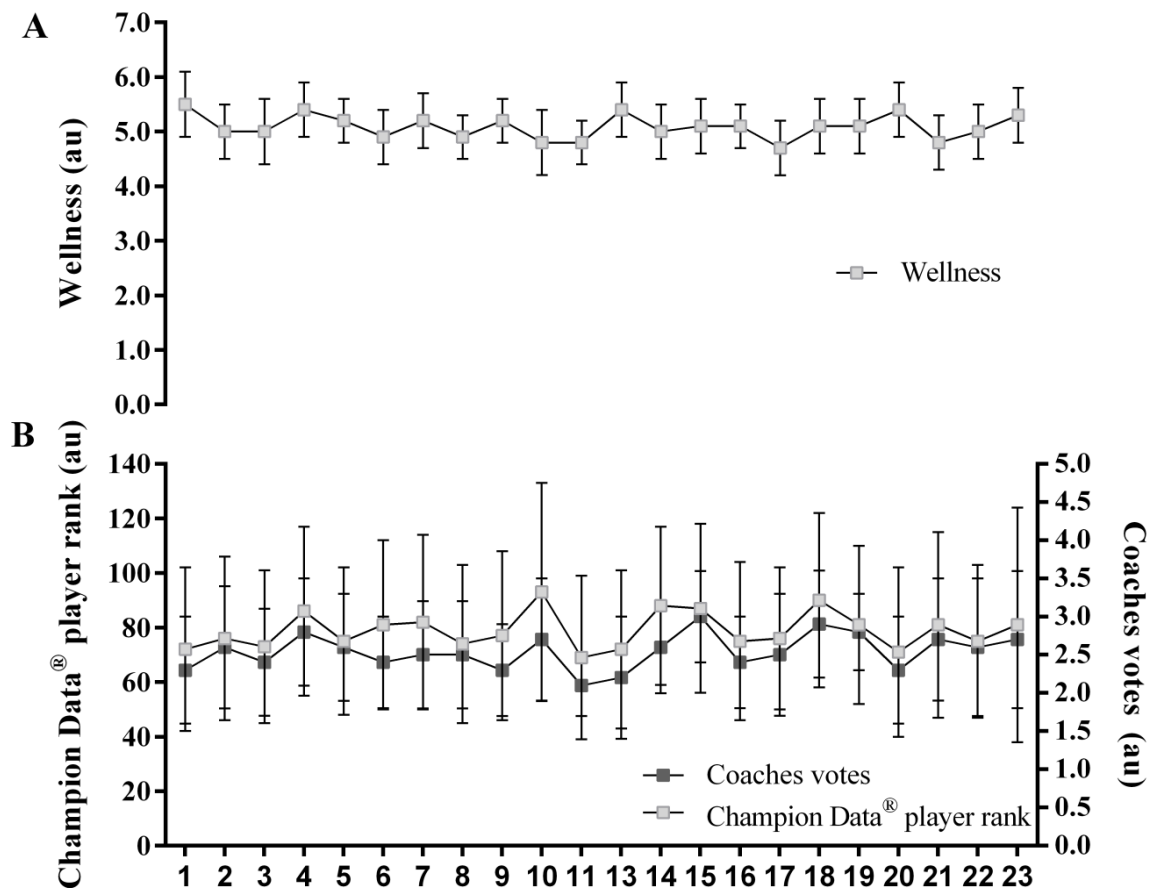
Within-individual correlations between pairs of load, wellness, and performance variables revealed large variations between participants and within participants between pairs or parameters (data presented in

APPENDIX i). The correlation ( $r$ ; 95% CI) between objective and subjective performance measures of Champion Data© ranking points and coaches' votes was 0.73 (0.69–0.77). An  $r^2$  value of 0.53, suggests that there was 53% shared variation between the two performance measures.



**Figure 6-1** Weekly in-season loads: (A)  $acute_{all}$  and  $acute_{field}$ , (B)  $chronic_{all}$  and  $chronic_{field}$ , and (C)  $TSB_{all}$  and  $TSB_{field}$  (mean  $\pm$  s).

*Notes:* a higher wellness score indicates better wellness.



**Figure 6-2** Weekly (A) wellness scores and (B) players' performance scores (Champion Data® ranking points and coaches' votes) (mean  $\pm$  s).

### Load, wellness, and objective performance

Table 6-1 shows the parameter estimates for the optimal models selected in relation to load, wellness, and objectively measured player performance. In relation to field-based loads, all optimal models included three fixed effects (Load, Wellness, and the interaction of Load  $\times$  Wellness) and three random effects (Participant, Round, and Time Trial). The parameter estimates for Load and Wellness were positive. This indicates that increases in  $acute_{field}$ ,  $chronic_{field}$ , and  $TSB_{field}$  values were associated with improvements in Champion Data® ranking points (holding wellness constant). Similarly, for a given field-based load, higher weekly wellness scores were related to improved Champion Data® ranking points. However, the Load

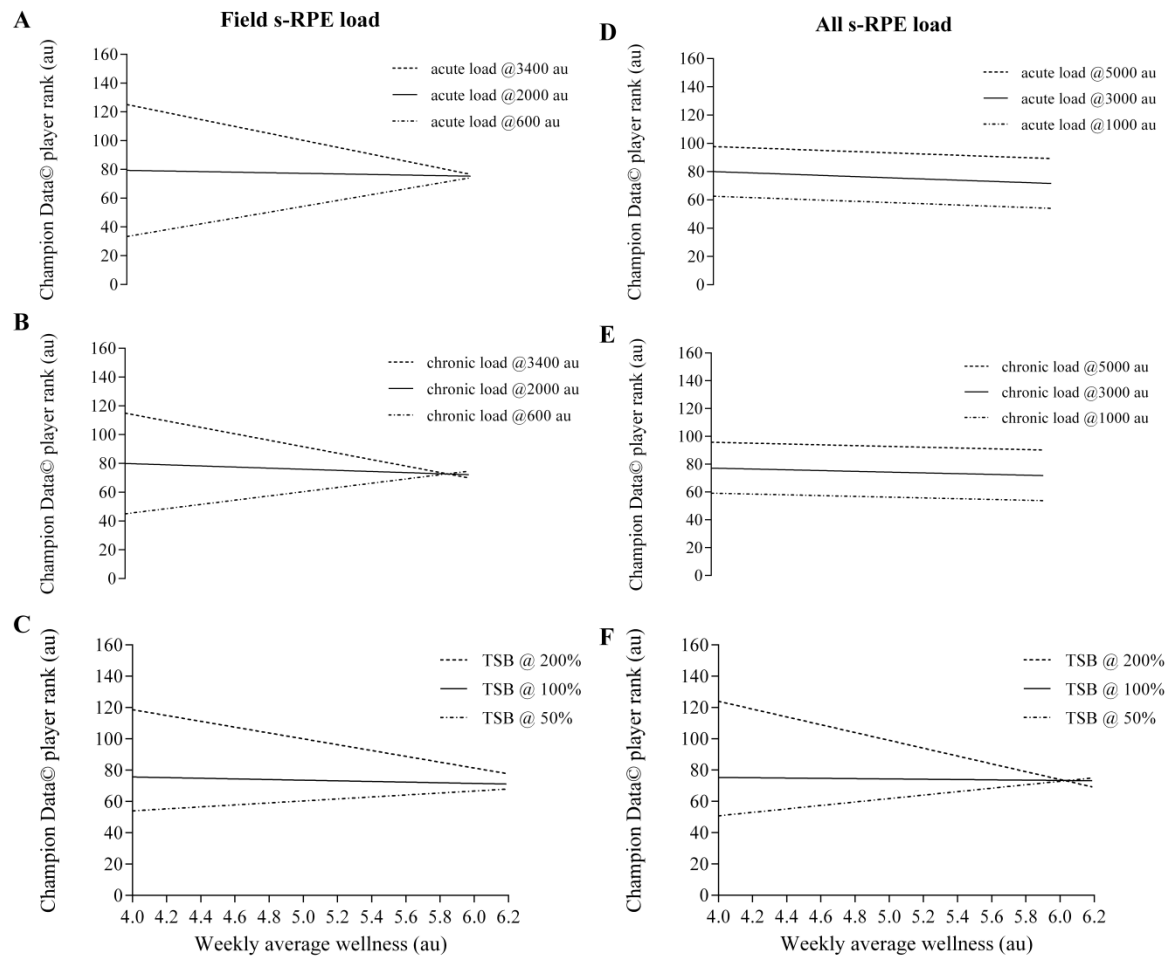
× Wellness interaction effect exhibited a negative relationship with performance. Thus, differences in weekly field-based load had a greater effect on objective performance when athletes reported low weekly wellness scores. At higher weekly wellness scores, the same changes in weekly field-based loads had less influence on Champion Data® ranking points. The same pattern was seen in the weekly total loads model of TSB<sub>all</sub>, however the acute<sub>all</sub> and chronic<sub>all</sub> models yielded slightly different results. These models included two fixed effects (Load and Wellness) and three random effects (Participant, Round, and Time Trial). The fixed effects of chronic<sub>all</sub> and acute<sub>all</sub> were positively associated with objective performance, but these effects were small ( $\beta = 0.09$ ). Negative parameter estimates for wellness indicate that, for a given overall load, higher weekly wellness scores were related to decreases in Champion Data® ranking points. Projected patterns in the load-wellness-performance relationships are graphically represented in Figure 6-3, comparing the effect of a low, moderate, and high load on performance at varying weekly wellness scores.

**Table 6-1** Parameter estimates of the optimal models for s-RPE loads and objective player performance (Champion Data© ranking points).

	Acute <sub>field</sub>	Chronic <sub>field</sub>	TSB <sub>field</sub>	Acute <sub>all</sub>	Chronic <sub>all</sub>	TSB <sub>all</sub>
<i>Fixed effects: <math>\beta</math> (95% CI)</i>						
Intercept	-95.4 (-272.7–81.9)	-53.5 (-314.8–207.7)	-25.8 (-193.9–142.4)	69.6 (23.0–116.2)	60.3 (12.9–107.6)	-65.3 (-262.9–132.4)
Load	9.1 (0.7–17.5)	7.4 (-6.2–20.9)	10.9 (-3.9–25.7)	0.9 (0.2– 1.6)	0.9 (0.0–1.8)	14.5 (-3.7–32.7)
Wellness	27.3 (-7.3–61.9)	20.9 (-29.8–71.6)	14.6 (-18.1–47.2)	-4.0 (-12.2–4.3)	-2.5 (-10.9–5.9)	22.9 (-15.5– 61.4)
Load $\times$ Wellness	-1.5 (-3.1–0.2)	-1.2 (-3.9–1.4)	-1.7 (-4.5–1.2)			-2.4 (-5.9–1.1)
<i>Random effects: Variance</i>						
Champion Data© ranking points   Participant	240.7	337.5	315.3	262.6	402.1	256.7
Champion Data© ranking points   Round	164.1	1052.0	543.5	372.6	105.2	130.5
Load   Round	0.56	2.84	4.71	0.39	0.06	0.86
Champion Data© ranking points   Time Trial	1331.3	991.7	1203.8	1787.6	386.4	3581.3
Load   Time Trial	1.79	1.69	5.14	1.09	0.24	21.47
Residual	514.2	536.6	518.4	505.0	543.1	506.0

$\beta$  = parameter estimate; CI = confidence interval; Time Trial = 2-km time-trial result.





**Figure 6-3** Linear projection models illustrating the group-level associations between load variables, weekly wellness score, and objective player performance. Each panel represents a different weekly load variable, as follows: (A)  $acute_{field}$ , (B)  $chronic_{field}$ , (C)  $TSB_{field}$ , (D)  $acute_{all}$ , (E)  $chronic_{all}$ , and (F)  $TSB_{all}$ .

### Load, wellness, and subjective performance

Once inter-individual variability had been accounted for (random effects for Participant, Round, and Time Trial), few group-level associations were observed between load and wellness variables (as fixed effects) and subjective performance ratings (as the outcome variable). The fixed effects of  $chronic_{field}$  ( $\beta = 0.03$ ) and weekly wellness score ( $\beta = 0.07$ ) had very small effects on subjective performance ratings. No other group-level associations were observed between the other load variables and coaches' votes; the optimal model in these cases included

only one fixed effect for wellness ( $\beta = 0.11$ ). The optimal models for explaining variance in coaches' votes are presented in Table 6-2.

**Table 6-2** Parameter estimates of the optimal models for s-RPE loads and subjective player performance (coaches' votes).

	Wellness only	Chronic <sub>field</sub>
<i>Fixed effects: <math>\beta</math> (95% CI)</i>		
Intercept	1.91 (0.73–3.09)	1.62 (0.14–3.11)
Load		0.03 (–0.03–0.08)
Wellness	0.11 (–0.13–0.34)	0.07 (–0.14–0.28)
<i>Random effects: Variance</i>		
Coaches' votes   Participant	0.16	0.11
Coaches' votes   Round	0.32	2.30
Load   Round		0.01
Wellness   Round	0.02	
Coaches' votes   Time Trial	0.64	0.67
Load   Time Trial		0.00
Wellness   Time Trial	0.03	
Residual	0.37	0.34

$\beta$  = parameter estimate; CI = confidence interval; Time Trial = 2-km time-trial result.

## Discussion

This research was able to corroborate the use of particular s-RPE load variables and self-reported wellness, based on their relationship with individual athlete performance in AF. In this study, relationships between load, wellness, and player performance differed depending on whether the performance outcome variable were either objectively (Champion Data© ranking points) or subjectively (coaches' votes) determined. Load and wellness variables had minimal

impact on subjective performance ratings. Conversely, objective performance was positively associated with load measured via Champion Data® ranking points, although the magnitude of this effect was greater for field-based loads compared to overall loads. Similarly, wellness displayed group-level associations in each model for the objective performance outcome, although the direction of this relationship was dependent on the load parameter modelled. The presence of an interaction effect for Load  $\times$  Wellness in the field-based load models ( $acute_{field}$ ,  $chronic_{field}$  or  $TSB_{field}$ ) and the  $TSB_{all}$  demonstrated that athletes reporting low wellness with high loads, ranked better in objective performance than those reporting high wellness with high load. Alternatively, an increase in wellness was associated with better objective performance when accompanying lower loads. Wellness scores displayed a small negative association with Champion Data® ranking points when holding  $acute_{all}$ ,  $chronic_{all}$  constant. These results confirm the value of quantifying load and determining training status using self-reported measures and highlight the importance of a mixed-method approach to comprehensively assess athlete status.

### **Load, wellness, and objective performance**

The optimal models for the outcome variable of Champion Data® ranking points, included a fixed effect for load, with each load variable included independently ( $acute_{all}$ ,  $chronic_{all}$ ,  $TSB_{all}$ ,  $acute_{field}$ ,  $chronic_{field}$ ,  $TSB_{field}$ ). Parameter estimates for load in the objective performance models suggests that Champion Data® ranking points is positively associated with load. This supports previous results which found acute load was higher preceding wins when controlled for the number of days between matches (Aughey et al., 2015). It was suggested that within the context of the competition phase, because recovery between matches is of high priority, the opportunity for substantial physical load is minimal, and that the week-to-week variation in load provides mostly a tactical stimulus. This is further confirmed when examining the magnitude of the effect of various load parameters on objective performance. A 1000-unit

increase in weekly  $acute_{all}$  or  $chronic_{all}$  load was associated with a mean improvement in Champion Data© ranking points of only 9.0 au (holding wellness constant) compared to a mean improvement of 91.0 and 73.7 au, respectively, with a 1000-unit increase in weekly  $acute_{field}$  or  $chronic_{field}$  load. This suggests that higher field-based load has considerable positive effect on objective performance compared to increases in other modes of training. It is therefore possible that there is little to be gained by adding non-specific training during the competition phase as it is unlikely to have a positive effect on match performance. Whether this phenomenon is associated with psychology, training specificity, the tactical training associated with field-based modes during the competition phase, or the ability to practice for upcoming opponents is unknown (Gabbett et al., 2009; Lago, 2009).

Athlete self-reported wellness was found to have a positive (i.e. increased wellness related to improved performance) fixed effect on objective performance in each field-based load model ( $acute_{field}$ ,  $chronic_{field}$  or  $TSB_{field}$ ) and  $TSB_{all}$ , but not in  $acute_{all}$  and  $chronic_{all}$  models. Moreover, the fixed interaction of Load  $\times$  Wellness exposed that the effect of field-based load on Champion Data© ranking points was moderated by wellness score. During high field-based loads ( $acute_{field}$ ,  $chronic_{field}$  or  $TSB_{field}$ ) and/or  $TSB_{all}$ , athletes reporting low wellness scores performed better (measured via Champion Data© ranking points) than those reporting high wellness. However, with lower loads, an increase in wellness improved objective performance. Research has determined athlete self-report measures as valid assessments of training status based on their sensitivity to load and relationship with other objective markers of fatigue (Filaire et al., 2003; Mclean et al., 2010; Saw et al., 2016). With an established dose-response relationship between load and wellness, the circumstances surrounding players who report high wellness coinciding with increasing load is intriguing. Certainly, self-reported measures are global subjective assessments of wellness and a range of factors, external to training dose will contribute to this perception. However, it is unclear as to why for the same load, a high

perceived wellness would be related to a poorer performance than a low perceived wellness. It is possible that when the expected dose/response relationship between load and wellness is altered, an unidentified mechanism is associated with performance decrements.

This interaction also suggests that if athletes are reporting high wellness, field-based load has little effect on objective performance, while during low wellness periods, high field-based loads are associated with better Champion Data® ranking points. Initially it may appear counter-intuitive that high  $acute_{field}$ ,  $chronic_{field}$ , and/or  $TSB_{field}$  together with low wellness is linked to improved objective performance. The explanation might exist in the underlying direction of the relationship that cannot be determined in correlational (rather than causal) study designs. Research would suggest that if a player has poor wellness and is continually exposed to high loads, there is likely to be a decrement in performance (Coutts & Reaburn, 2008; Saw et al., 2016). Although, the time frame for this relationship is conceivably longer (i.e. delayed) than the weekly responses assessed in this study (Meeusen et al., 2006). As such, it is more likely that a player with high  $acute_{field}$ ,  $chronic_{field}$ , and/or  $TSB_{field}$ , might respond with acute reductions in wellness, but the positive effect (technical, tactical, psychological, and physiological) of the field-based training supersedes the diminished perceived wellness and leads to enhanced objective performance. On the other hand, reporting a negative training state without the positive stimulus of field-based training results in reduced performance. A circumstance of reduced wellness without a high field-based training load might suggest peripheral factors (other than the 4 weeks of field-based load quantified) are impacting training state, leading to objective performance decrements.

The optimal model for  $TSB_{all}$  for the objective performance outcome was similar to that described above for field-based load models. However, the  $acute_{all}$  and  $chronic_{all}$  load had different model structures than the  $acute_{field}$  and  $chronic_{field}$  loads. As well as a smaller

magnitude effect of load on objective performance, negative parameter estimates for wellness were revealed, with no interaction of Load  $\times$  Wellness. This indicates that for a given *acute<sub>all</sub>* or *chronic<sub>all</sub>* load, higher weekly wellness scores were related to decreases in Champion Data© ranking points. Again, the magnitude of the effect was relatively small, with a 1 unit increase in wellness score associated with a mean decrease in Champion Data© ranking points of  $-4.0$  and  $-2.5$  for the *acute<sub>all</sub>* or *chronic<sub>all</sub>* models, respectively. Therefore, the practical importance of this finding is somewhat unclear.

### **Load, wellness, and subjective performance**

For the outcome variable of subjective performance, the *chronic<sub>field</sub>* parameter was the only load variable to demonstrate a fixed effect on subjective performance. The other load parameters (*acute<sub>all</sub>*, *chronic<sub>all</sub>*, *TSB<sub>all</sub>*, *acute<sub>field</sub>*, *TSB<sub>field</sub>*) did not demonstrate group-level associations with coaches' votes, although wellness was positively related to subjective performance (i.e. as wellness scores improved, coaches' votes increased). However, it is important to note that these fixed effects - *chronic<sub>field</sub>* load and weekly wellness score in relation to subjective player performance - were very small in magnitude and potentially negligible. For example, a 1000-unit increase in weekly *chronic<sub>field</sub>* load resulted in an improvement of 0.3 au coaches' votes. Similarly, an increase in weekly wellness score by 1 unit was linked to a mean increase in coaches' votes of 0.07 au. The low resolution of the 5-point scale used in this study may have limited the sensitivity of the coaches' votes measure for distinguishing performance differences between players and over time. This may explain the small or possibly negligible effects of load and/or wellness on subjective player performance.

Differences in structure between the optimal models for the two outcome variables might be explained by the different constructs of performance each measure represents. One key feature of subjective performance measures is that coaches can rate player performance in relation to that player's identified role in the team. In contrast, objective measures that reflect skill

execution and effectiveness do not explicitly assess whether an athlete has successfully fulfilled their roles and responsibilities within the team plan. For example, a player may be assigned the role of minimising the impact that an opposition player has on a match. This player may perform this role at or above expectations, while registering few instances of skill executions (e.g. kicks, handballs). In this scenario, the player would achieve a low Champion Data© ranking points value but would likely receive high votes from the coaches. Nevertheless, objective methods remain important for accurately assessing performance. The Champion Data© ranking points provides an objective quantification of a players involvement in the game, unaffected by the human biases that can influence subjective ratings of performance (Hoyt, 2000). Furthermore, the Champion Data© ranking points evaluates players at a given point in time (game day) irrespective of preconceived opinions based on expectations, player prestige or the quality of training performed over a period of time (i.e. chronic field load) that might influence how a coach subjectively rates a player on game day. These critical differences are evidenced by the correlation observed between objective and subjective performance parameters ( $r = 0.73$ ;  $r^2 = 0.53$ ). Thus, almost half of the variation between measures was unique, which suggests that both objective and subjective methods should be used as part of a comprehensive strategy for player performance assessment in Australian football.

Although in the current study increases in TSB were seen to improve objective performance, evidence currently exists suggesting that spikes in acute workload are related to increased injury risk (Hulin et al., 2014; Hulin et al., 2015). Due to the method of calculating chronic load there will always be a smaller variation in the chronic load over time compared to acute load because the 4-week rolling mean will smooth out peaks and troughs in the acute load. A TSB calculated with a varying acute load divided by a relatively unchanging chronic load, will therefore have a very strong association with acute load. Given that acute load had a positive impact on performance, it is unsurprising that a higher TSB was also related to performance

improvements. Indeed, the calculation of TSB is ecologically valid to represent the ratio of acute load to chronic load at a given point in time. This ratio however, may add minimal information when used in linear modelling techniques because of its high correlation with acute load. Moreover, the previous research examining TSB is predominated by injury and illness dose-response models (Hulin et al., 2014; Hulin et al., 2015). While reducing/minimising TSB may be important to decrease injury and illness risk, the same relationship may not exist with performance during the competition phase of a team sport. It may be that the concepts surrounding the optimal load and TSB for minimising injury are unique from those for enhancing performance. Moreover, each of the acute, chronic and TSB measures may be associated with improved performance potentially as a function of excessively low chronic load. A positive TSB might represent reaching a threshold level of skill/tactical training (even physiological) that translates to improved performance (Aughey et al., 2015).

As well as fixed effects, random effects were included to account for inter-individual variability at baseline and between match variability. Further, a third random effect of player characteristic was included to determine if experience (years played or games played) or fitness (2-km time-trial result or yo-yo IR level 2 performance) explained some of the variation in the models. Player id and round were indeed important components of each model structure, suggesting variability between players and between matches irrespective of any fixed effect. The random effect of 2-km time-trial also appeared to explain some of the variability in the models, suggesting there is difference in how load and wellness relates to performance based on fitness.

As with most applied research designs, there were limitations with this study. Firstly, research in professional soccer has reported that individual indices of athlete self-report measures may be more sensitive to load demonstrating a significant correlations between self-reported fatigue and total high-speed running distance, while no significant relationship was evident with sleep



quality, and muscle soreness (Thorpe et al., 2015). Therefore, it is possible that in this study, using the mean of five indices and an overall marker of wellness may have confounded the relationship observed between wellness, load and performance. Also, using a linear mixed-models approach may be too simplistic, as linear models are unlikely to accurately reflect relationships between load, wellness and performance which may be non-linear or do not exhibit dose-response relationships (Busso, 2003; Gabbett et al., 2014). Research using advanced modelling techniques to explore the relationship between match performance and a mixed-methods approach of contemporary monitoring practices would be worthwhile.

The results of this study were able to demonstrate that common parameters of contemporary monitoring systems impact on match performance in AF. Load and wellness variables were less influential on subjective ratings of performance than objective performance measures. The substantial distinction in structures between the Champion Data© ranking points and coaches' votes models emphasises the varying constructs being measured in the objective versus subjective parameters. Furthermore, overall load had a considerably smaller positive effect on objective performance than field-based loads for acute and chronic calculations. Field-based loads were positively associated with Champion Data© ranking points, particularly when combined with reduced wellness scores. However, high load combined with high wellness score seemed to be detrimental to performance and determining if this phenomenon exists in another sample of athletes would be valuable. Acute load, chronic load and TSB all displayed the same relationship for field-based loads, suggesting that the variability in the parameters during the competition phase may be minimal.

## **Practical Applications**

- The dissimilar model structures between objective and subjective performance outcomes indicates that Champion Data© ranking points and coaches' vote are highly

distinct constructs and both should be used to comprehensively quantify match performance.

- It appears that non-specific training during the competition phase is unlikely to have a positive effect on match performance and as such practitioners ought to focus on field-based training modalities to improve match performance.
- Field-based loads were positively associated with objective match performance, particularly when combined with reduced wellness scores. This may suggest that increased loads are beneficial for performance, although caution should be employed if increasing training load with consideration of other factors such as injury risk and illness.
- Limited variation in week-to-week load during the competition phase of the season sees acute load, chronic load and TSB all displaying similar relationships to performance. This suggests that this technique of quantifying TSB may be mostly valuable for injury and illness detection and less effective in performance prediction.

## **Chapter 7. General Discussion and Conclusions**

### **Major Findings**

This body of research investigated contemporary athlete monitoring practices in professional Australian football (AF). Although individual components of monitoring athlete preparedness have been broadly explored, there is a lack of evidence-based research on how to apply and interpret the complex interactions between various components of a monitoring system. It is currently accepted that both external and internal load quantifications are valuable and that the relationship between the two is modulated by a range of factors (Halson, 2014; Impellizzeri et al., 2004; Lambert & Borresen, 2010; Manzi et al., 2010). However, characteristics which are easily identifiable in professional sport settings, such as playing position and fitness; have not been directly researched in AF. Additionally, athlete self-report measures have emerged as feasible and valid instruments for assessing training status, with further insight into their response to match and training load, in the context of the competitive season, required (Saw et al., 2016). A common application of these instruments is to identify how an athlete is coping with the current training doses and implement modifications to prescribed loads if required. Interestingly though, the association between changes in pre-training self-reported wellness and subsequent exercise output has not been considered. Undoubtedly, the purpose of monitoring preparedness in professional sport is to contribute to the goal of improving performance, and hence competition wins. Evidence of the contribution of contemporary monitoring practices to this goal, by examining their direct effect on individual match performance in AF, has not been reported (Aughey et al., 2015).

### **STUDY 1: Characteristics impacting on session rating of perceived exertion training load in Australian footballers**

With an objective to enhance the understanding of external and internal load, the relationship between external load and the commonly used session rating of perceived exertion (s-RPE)

method of quantifying internal load was examined. A principle component analysis approach was taken, where five external load parameters (distance, average speed, high-speed running distance, PL and PL<sub>slow</sub>) were reduced to one component, which accounted for most of the variation within the variables (Hair et al., 1998). The single external load component was then held constant to determine the impact of suspected characteristics on s-RPE load. Playing experience, position, and time-trial performance were all found to influence s-RPE load, when controlled for the variance explained by the external training load component. The 4- to 5-year players had higher s-RPE training loads for the same external load than the 0- to 1-year or 2- to 3-year players. The ruckmen also had higher s-RPE compared to key position, midfield or nomadic players. Lastly, the worse a player performed on the 2-km time-trial, the higher their s-RPE was for a constant external load. The finding that the 4- to 5-year players had higher s-RPE might be initially counter-intuitive when less experienced (first-years) and more senior players (7<sup>+</sup>-years) have been shown to perform the smallest load (Rogalski et al., 2013). However, it is likely that the greater overall training loads achieved by the 4- to 5-year players throughout the week influences their training state and potentially s-RPE for a given external output. The effect of position on s-RPE coincided with previous reports that the movement profile of ruckmen was substantially different from other positions (Boyd et al., 2013). This concept is supported by the current work, suggesting a particular external load may elicit different internal loads in ruckmen compared to players in other positions. The impact of time-trial performance on s-RPE was also not surprising as previous research has reported fitness as a factor impacting s-RPE (Garcin et al., 2004; Milanez et al., 2011). A critical finding from this current work is that consideration should be given to playing experience, position and time-trial performance when interpreting athletes internal load. The results of this study support the use of s-RPE training load to quantify and monitor global internal training load but also highlight the constraints of a subjective parameter and cautions against using s-RPE training load to plan training.

## **STUDY 2: Self-reported wellness profiles of Australian footballers during the competition phase of the season**

In order to satisfy the aim of providing insight on the response of athlete self-report measures in the context of the competitive phase, wellness weekly profiles were determined relative to match load, the length of the match-to-match micro-cycle and stage of the season. In supporting previous research, days-post-match was the best predictor of wellness Z-score (Gastin, Meyer, et al., 2013). The interaction of days-post-match and match-to-match micro-cycle length, which had not previously been reported in AF, was established (McClean et al., 2010). The reduced wellness on 1 d post match for the 8-day cycle compared to the 6- and 7-day cycle, without a presence of a match load effect, highlighted a potential delayed recovery during the longer micro-cycle. Further, the absence of an effect of internal match load on self-reported wellness may highlight a lack of sensitivity of s-RPE to detect subtle differences in match load, despite between match variability of external load being reported (McLaren et al., 2016). In contrast to previous work, the latter half of the season (post bye) was found to have a lower weekly wellness than the first half of the season, suggesting a reduced perception of training status as the season progresses (Gastin, Meyer, et al., 2013). When considering the days-post-match, micro-cycle and stage of the season, additional training load had no further effect on wellness profile. This adds verification to existing work which also found minimal to no influence of training load on athlete self-report measures during the competition phase (Montgomery & Hopkins, 2013). Such conclusions can be attributed to the pronounced focus on recovery during the competition phase. The highest load of the week undoubtedly comes from the match itself and it is therefore likely that the restricted opportunity for substantial training load in a congested competition schedule limits the influence of training load on markers of training status (Cormack, Newton, McGuigan, et al., 2008; Moreira et al., 2015).

### **STUDY 3: Pre-training self-reported wellness impacts training output in Australian footballers**

To examine the use of athlete self-report measures to adjust subsequent training doses, the association between pre-training self-reported wellness and activity profile during skill-based training sessions was examined. Five individual athlete self-reported indices for a given day were averaged to provide a quantitative score of overall pre-training wellness for each player. The main finding was that reductions in pre-training wellness Z-score was associated with reductions in the external (microtechnology-derived) load parameters of PL and PL<sub>slow</sub>. Moreover, lower wellness was associated with a reduced PL<sub>slow</sub>: RPE ratio, while the mean speed: RPE ratio was seen to increase with lower wellness. The fact that the two accelerometer variables were modified, while running variables maintained, might be related to previous research which demonstrated that fatigue alters the way PL is accumulated in AF matches (Cormack et al., 2012; Mooney et al., 2011). It appears that athletes may modify their movement strategy to maintain running output and RPE. This study employed magnitude-based inferences to interpret the practical size of the associations found. The magnitude-based inferences suggested that a large change in wellness Z-score would need to exist for confidence that the effect it has on PL or the mean speed: RPE and PL<sub>slow</sub>: RPE ratios were meaningful. Nonetheless, these findings are the first to provide evidence that activity profile in skill-based trainings sessions is indeed related to changes in self-reported wellness and supports the practice of adjusting subsequent training load based on athlete self-report measures.

### **STUDY 4: Effects of internal load measures and athlete self-reported wellness on match performance in Australian football**

Finally, the objective of this final study was to corroborate the use of various athlete monitoring variables (load and wellness) based on their relationship to individual athlete performance. Overall acute (acute<sub>all</sub>) and chronic (chronic<sub>all</sub>) load, as well as training-stress balance (TSB<sub>all</sub>)

were calculated from every training modality, whereas only outdoor skills and conditioning sessions were used to calculate a field-based acute ( $acute_{field}$ ) and chronic ( $chronic_{field}$ ) load and field-based training-stress balance ( $TSB_{field}$ ) (Veugelers et al., 2015). An iterative linear mixed modelling approach demonstrated that s-RPE loads parameters and self-reported wellness indeed impact match performance in AF. Two constructs of individual player performance were examined with load and wellness variables having minimal influential on subjective ratings of performance (coaches' votes) compared to the objective performance measure (Champion Data© ranking points). Objective performance was positively associated with load, although the magnitude of this effect was greater for field-based loads. There was a positive association between field-based loads and objective performance suggesting that as field-based load increased, so too did Champion Data© ranking points. The presence of an interaction effect for Load  $\times$  Wellness in the field-based load models ( $acute_{field}$ ,  $chronic_{field}$  or  $TSB_{field}$ ) and the  $TSB_{all}$  demonstrated that athletes reporting low wellness with high loads ranked better in objective performance than those reporting high wellness with high load. Alternatively, an increase in wellness was associated with better objective performance when accompanying lower loads. Acute load, chronic load and TSB all displayed similar model structures, suggesting that the variability in the parameters during the competition phase may be minimal.

## **Practical Applications**

The results from study 1 highlight that prescribing training based on absolute external load measures will result in dissimilar internal responses between players of different positions, with varying levels of experience and time-trial performance. Since internal load is the stimulus that leads to adaptation, these variations may leave some athletes at risk of overtraining and others failing to reach a sufficient training stimulus. Although prescribing training using internal load derived from physiological measures, such as heart rate may not be feasible in skill-based training sessions, the RPE method may also be inappropriate. Players will adjust their exercise

intensity based on a complex interaction of psychobiological characteristics resulting in varied activity profiles between and within players in the training program. This method neglects the absolute capacity the athlete requires for success. It is therefore suggested that to increase the chance of achieving the desired training effect, loads should be systematically prescribed using external parameters with consideration of psychobiological characteristics. Moreover, an assessment of the internal load (in the form of s-RPE) that the external load elicits should be included in a successful contemporary athlete monitoring system.

In conjunction with a systematically prescribed external load training regime and well-monitored internal load influencing adjustments, athlete self-report measures are also valuable tools in contemporary monitoring practice. Profiling weekly wellness in the context of the competitive phase of the season revealed that the length of the match-to-match micro-cycle and stage of the season affected self-reported wellness in response to matches. This research also exposed a potentially blunted recovery process during the longer micro-cycle, possibly due to complacency with recovery practices or players regulating their perception of recovery according to days-to-match. Using irregularities in athlete wellness profiles as a warning sign, often labelled as 'red flags', is a common application of self-report measures. It would be reasonable to consider that with the differences seen in wellness profiles based on micro-cycle length and stage of the season, evaluation of 'red flags' should be made to a comparative context in order to determine an athlete's status relative to their typical weekly profile. The revelation that the second half of the season had lower overall perceived wellness may also provide reason to adjust training load and increase opportunities for recovery later in the season.

Further developing the application of athlete self-report measures in AF, it was found that subsequent exercise intensity was related to pre-training self-reported wellness. This suggests that monitoring self-reported wellness prior to a training session, offers an indication on the



activity profile that might be produced. Coaches and sport scientists can use this information to make adjustments to training if warranted. For example, a reduced wellness Z-score might direct practitioners to adjust the volume of the session to encourage intended exercise intensity. Furthermore, attention might be given to the content of the planned session to provide a metabolic exercise stimulus without peripherally demanding activities (e.g. high-speed accelerations, grappling, contact) that may be linked to the PL and PL<sub>slow</sub> variable (Buchheit & Laursen, 2013b; Cormack et al., 2012; Johnston et al., 2012a). Although the decision on how to intervene when an individual player or a large proportion of the team have reduced wellness Z-scores will be influenced by other factors (e.g. match-to-match micro cycle, skill and tactical position and coaching philosophy), the adjustment of training volume and/or intensity based on perceived wellness is supported.

The value of using contemporary monitoring systems to complement training prescription is evident in this research. Load and wellness variables were substantially less influential on the coaches' vote's measure of performance than Champion Data© ranking points, emphasising the highly distinct constructs being measured in the objective and subjective performance parameters and both should be used to comprehensively quantify match performance. The finding that overall load has a considerably smaller positive effect on objective performance than field-based loads might lead coaches and sport-scientist to use specific field-based training modes during the competition phase of the season. Furthermore, the positive association between field-based loads and objective match performance suggests higher loads improved performance, particularly when combined with reduced wellness scores, however caution should be employed if increasing training load with consideration of other factors such as injury risk and illness. The similar model structures between acute load, chronic load and TSB calculations during the competition phase of the season suggests that this technique of quantifying TSB may be mostly valuable for injury and illness detection and less effective in

performance prediction. Overall, these results highlight the importance of a mixed-method approach to comprehensively assess athlete status.

## **Limitations**

Across the four studies, there are some limitations associated with research in an applied professional sport setting. Whilst applied research provides strong ecological validity, it also creates challenges that need to be recognised. For example, relative to studies 1 and 4, the use of a direct fitness measure such as a laboratory-based  $\text{VO}_{2\text{max}}$  test or validated field test such as the Yo-Yo IR level 2 would have been ideal. Since the research was constrained to pre-existing testing protocols within the club, the lack of construct validity of 2-km time-trials for determining fitness in AF is recognised as a potential limitation. Similarly, the timing of the testing procedures in studies 1 and 3 may be problematic as the last testing time point in pre-season may not be representative of fitness by the last week of the season. Also restricted by the club procedure, the protocol used to determine individualised high-speed running threshold was each player's mean 2-km time-trial speed. Although no uniform recommendations exist, it is acknowledged that using the speed at which the second ventilatory threshold is reached recommended by Abt and Lovell (2009) may have resulted in different outcomes. Although unavoidable, a further considerable limitation of researching the relationship between monitoring parameters is the continual manipulation of training load and recovery doses in response to a judgement of athlete status. The interventions that take place on a daily basis in a professional sport setting may impact the findings of this work, particularly relevant to the model parameters presented in study 4.

In study 2, internal match load was found to have no effect on wellness. The between-match variability of s-RPE has been reported to be lower than other external load measures, such as high-intensity running distance (McLaren et al., 2016). Using a RPE scale of 0–10 (CR-10)

restricts the range of responses allowed, creating a clustering of data and limiting its sensitivity to detect subtle variations in match load. Moreover, recent research demonstrated that differential ratings of perceived exertion have improved precision to reflect central, local and technical internal load, compared to overall RPE (Weston et al., 2015). As such, it is possible that a lack of sensitivity of the RPE method impacted these findings. The complex interaction of psychobiological contributors to RPE is a valuable characteristic of a global measure to assess the magnitude of training load experienced by the athlete but is a trade-off with the sensitivity of the measure. Similarly, individual items of self-reported wellness (e.g. fatigue) have demonstrated superior sensitivity to load (Thorpe et al., 2015). As such, using the mean of all of the five items may have restricted the ability to identify particular relationships between individual wellness components and different load and performance variables (Thorpe et al., 2015). Alternatively to using individual items, a weighting system may have also enhanced the significance of the overall wellness score.

Furthermore, using athlete-self report measures (studies 2, 3 and 4) undoubtedly relies on accurate and honest self-reporting by players. The applied setting of this research has the potential to heighten this risk, as players might be cautious of 'providing the right answer' or not wanting/wanting to have their loads adjusted. On the other hand, the education provided to these professional athletes and years of experience of being exposed to these protocols is likely to reduce the risk of such an outcome. Finally, it is accepted that the relationship between load, wellness and performance may be non-linear and therefore, linear modelling techniques may provide too simplistic, or inaccurate representations of such relationships (Gabbett et al., 2014).

## **Future Research**

The concept of contemporary athlete monitoring in professional sport settings is developing and more research in the field is imperative. Establishing evidence-based applications of

parameters for monitoring preparedness will enhance the outcome of a training program. In particular, the gap in the current body of work seems to be in interpreting the interaction among a variety of monitoring parameters. For example, evidence is mounting for the existence of a modified movement profile under fatigue/during a reduced training state. If deviations from the typical movement pattern can indeed be detected, and accurately represent a negative training state, practitioners can use this marker as an early warning sign to intervene.

## **Conclusions**

The following conclusions were determined from the independent but related studies that comprised this thesis:

- (1) In a high-intensity, intermittent collision sport, s-RPE has a strong relationship with measures of external load, which is moderated by playing position, experience and time-trial performance in Australian footballers.
- (2) While s-RPE appears to be a valid measure of the magnitude of load experienced by an athlete, using s-RPE to prescribe training has important limitations.
- (3) The weekly profile of self-reported wellness in response to matches is impacted by match-to-match micro-cycle and stage of the season in AF. However, when factoring in these conditions, training load does little to further influence wellness profile.
- (4) Determination of 'red flags' in self-reported measures should be made against comparative weeks.
- (5) Pre-training self-reported wellness impacts accelerometer-derived external load measures suggesting altered movement patterns during diminished training states. Understanding the changes in external load that might be produced relative to the pre-training self-reported wellness provides coaches with an opportunity to adjust prescription if warranted.

- (6) Relationships between load, wellness, and player performance differ depending on whether the performance outcome variable is either objectively (Champion Data© ranking points) or subjectively (coaches' votes) determined.
- (7) Non-specific training during the competition phase is unlikely to have a positive effect on match performance.
- (8) Field-based loads are positively associated with objective match performance, particularly when combined with reduced wellness scores, indicating that increased field-based load is associated with improved Champion Data© ranking points.

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## Appendices

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**APPENDIX i Table of within-individual correlations between pairs of load, wellness,  
and performance variables from Chapter 6**



**Table i** Within individual correlations ( $r$ ) between s-RPE load and performance, and wellness and performance parameters.

#	Champion Data© ranking points							Coaches' votes						
	Acute <sub>field</sub>	Chronic <sub>field</sub>	TSB <sub>field</sub>	Acute <sub>all</sub>	Chronic <sub>all</sub>	TSB <sub>all</sub>	Wellness	Acute <sub>field</sub>	Chronic <sub>field</sub>	TSB <sub>field</sub>	Acute <sub>all</sub>	Chronic <sub>all</sub>	TSB <sub>all</sub>	Wellness
1	0.02	0.06	0.01	-0.21	-0.01	-0.20	0.38	0.23	0.22	0.18	-0.21	0.11	-0.24	0.39
2	0.00	0.40	0.05	0.62	0.43	0.59	-0.49	0.20	0.60	0.15	0.84	0.99	0.21	0.56
3	0.12	0.06	-0.14	0.05	-0.08	0.09	-0.36	-0.06	-0.25	-0.06	0.10	-0.06	0.16	0.20
4	0.12	0.14	0.06	0.01	-0.14	0.17	0.13	0.05	0.18	-0.06	0.08	0.12	0.05	0.55
5	-0.17	-0.04	-0.06	-0.19	0.26	-0.29	0.20	-0.30	0.15	-0.41	-0.37	0.25	-0.47	-0.03
6	0.11	-0.15	0.19	0.05	-0.10	0.12	-0.05	-0.08	0.06	-0.11	-0.03	0.12	-0.22	0.08
7	0.26	-0.26	0.23	0.77	-0.08	0.75	-0.51	0.32	0.46	0.22	0.86	0.17	0.74	-0.38
8	-0.70	-0.10	-0.30	-0.96	-0.22	-0.92	-0.50	-0.90	-0.70	-0.60	-0.64	0.47	-0.72	-0.64
10	0.13	0.15	0.09	-0.37	-0.45	-0.15	0.13	-0.23	0.25	-0.43	-0.47	-0.21	-0.39	0.17
11	1.00	-1.00	1.00	1.00	-1.00	1.00	1.00	1.00	-1.00	1.00	1.00	-1.00	1.00	1.00
12	0.20	-0.12	0.23	0.20	0.08	0.22	-0.02	-0.02	-0.03	-0.04	-0.08	-0.04	-0.04	-0.01
13	0.16	-0.03	0.26	0.16	0.09	0.14	0.29	0.14	0.02	0.11	0.27	0.12	0.27	0.27
14	0.03	0.14	0.14	0.12	0.19	0.05	-0.24	0.60	0.26	0.49	0.55	0.28	0.54	-0.13
15	0.22	-0.02	0.00	0.54	0.10	0.32	0.08	-0.05	0.24	-0.35	0.08	0.28	-0.24	0.35
16	0.26	-0.07	0.32	0.38	-0.19	0.44	0.50	-0.06	-0.19	0.12	0.04	-0.18	0.16	0.17
17	0.50	-0.50	0.50	0.54	-0.41	0.66	0.46	0.00	-0.87	0.00	-0.16	-0.92	-0.01	0.94
18	-0.30	-0.15	0.03	-0.23	-0.31	0.01	0.09	-0.13	-0.02	-0.11	-0.16	-0.22	0.01	0.12
19	0.54	0.03	0.20	0.47	0.56	-0.25	0.37	0.62	0.09	0.35	0.31	0.30	-0.08	0.45
20	0.68	-0.32	0.68	0.37	-0.51	0.73	-0.07	-0.11	-0.76	-0.11	-0.43	-0.71	-0.01	-0.14
21	0.20	0.05	0.17	0.25	0.26	0.12	-0.10	0.03	0.00	-0.06	0.40	0.31	0.26	0.22
22	0.88	0.44	0.94	0.59	0.16	0.53	-0.52	0.43	0.14	0.52	0.35	-0.23	0.40	-0.20
23	0.62	0.31	0.05	0.59	0.42	0.55	-0.18	0.38	0.22	0.04	0.37	0.23	0.35	-0.22
24	0.45	0.04	0.29	0.53	0.36	0.35	0.22	0.47	0.17	0.26	0.29	0.24	0.18	0.54
25	-0.27	-0.09	-0.29	-0.36	-0.16	-0.28	-0.34	-0.35	0.14	-0.42	-0.47	0.08	-0.50	-0.35
26	0.68	0.79	0.57	0.90	0.62	0.92	-0.09	0.25	0.13	0.26	0.55	0.21	0.63	0.19
27	0.23	0.31	0.20	0.36	0.40	0.22	0.02	0.26	0.36	0.10	0.25	0.38	0.08	0.27

28	0.44	-0.07	0.58	0.52	-0.11	0.64	0.17	0.07	0.08	0.25	0.18	-0.16	0.30	-0.19
29	0.19	0.29	-0.04	-0.08	0.12	-0.16	-0.11	0.10	0.34	0.03	-0.11	0.05	-0.20	-0.27
30	-0.27	-0.04	-0.36	-0.20	0.32	-0.40	0.16	-0.23	-0.01	-0.44	0.07	0.52	-0.19	0.29
31	0.04	0.21	-0.09	0.12	0.03	0.15	0.14	0.11	0.17	-0.06	0.02	-0.25	0.24	0.01
32	0.20	-0.04	0.13	-0.22	-0.32	0.01	0.22	-0.09	-0.40	-0.01	-0.34	-0.47	-0.06	0.37
33	-0.17	-0.14	-0.09	-0.47	-0.36	-0.31	0.21	-0.30	-0.18	0.00	-0.09	-0.28	0.10	0.07
Mean	0.20	0.01	0.17	0.18	0.00	0.18	0.04	0.07	0.00	0.03	0.10	0.02	0.07	0.14
± SD	± 0.36	± 0.31	± 0.32	± 0.44	± 0.35	± 0.43	± 0.33	± 0.35	± 0.38	± 0.32	± 0.40	± 0.41	± 0.37	± 0.36
Rang e	-0.70– 1.00	-1.00–0.79	-0.36– 1.00	-0.96– 1.00	-1.00– 0.62	-0.92– 1.00	-0.52– 1.00	-0.90– 1.00	-1.00–0.60	-0.60– 1.00	-0.64– 1.00	-1.00– 0.99	-0.72– 1.00	-0.64– 1.00

## **APPENDIX ii Research portfolio**

## STUDY 1

Gallo, T., Cormack, S. J., Gabbett, T. J., Williams, M. D., & Lorenzen, C. (2015). Characteristics impacting on session rating of perceived exertion training load in Australian footballers. *Journal of Sports Sciences*, 33(5), 467-475. doi: 10.1080/02640414.2014.947311 (PUBLISHED).

*Contribution statement:* **TG (70%)** was primarily responsible for the study design, gaining ethics approval, data collection, data handling, statistical analysis, interpreting the results, drafting the manuscript, submitting the manuscript, responding to reviewer feedback, and approving the final proof. **SC (10%)** contributed to the study design, interpreting the results, conception of the discussion, proof reading the manuscript, and responding to reviewer feedback. **TGabbett (5%)** contributed to the study design, interpreting the results, proof reading the manuscript, and responding to reviewer feedback. **MW (5%)** contributed to the statistical analysis and interpreting the results. **CL (10%)** contributed to the study design, interpreting the results, conception of the discussion, proof reading the manuscript, and responding to reviewer feedback.

I acknowledge that my contribution to the above paper is 70%.



**Tania Gallo**

As principal supervisor, I certify that the above contributions are true and correct.

A handwritten signature in black ink, appearing to read 'C. Lorenzen'.

**Christian Lorenzen (10%)**

A handwritten signature in black ink, appearing to read 'Stuart Cormack'.

**Stuart Cormack (10%)**

A handwritten signature in black ink, appearing to read 'Tim Gabbett'.

**Tim Gabbett (5%)**

A handwritten signature in black ink, appearing to read 'Morgan Williams'.

**Morgan Williams (5%)**



## STUDY 2

Gallo, T., Cormack, S. J., Gabbett, T. J., & Lorenzen, C. Self-reported wellness profiles of Australian footballers during the competition phase of the season. *Journal of Strength and Conditioning Research* (AMENDMENTS SUBMITTED).

*Contribution statement:* **TG (75%)** was primarily responsible for the study design, gaining ethics approval, data collection, data handling, statistical analysis, interpreting the results, drafting the manuscript, submitting the manuscript, responding to reviewer feedback, and approving the final proof. **SC (10%)** contributed to the study design, interpreting the results, conception of the discussion, proof reading the manuscript, and responding to reviewer feedback. **TGabbett (5%)** contributed to the study design, interpreting the results, and proof reading the manuscript. **CL (10%)** contributed to the study design, interpreting the results, conception of the discussion, proof reading the manuscript, and responding to reviewer feedback.

I acknowledge that my contribution to the above paper is 75%.



**Tania Gallo**

As principal supervisor, I certify that the above contributions are true and correct.



**Christian Lorenzen (10%)**

A handwritten signature in cursive script, reading "Stuart Cormack". The letters are fluid and connected, with a prominent 'S' and 'C'.

**Stuart Cormack (10%)**

A handwritten signature in cursive script, reading "Tim Gabbett". The signature is more compact and stylized than the one to its left, with a clear 'T' and 'G'.

**Tim Gabbett (5%)**

### STUDY 3

Gallo, T., Cormack, S. J., Gabbett, T. J., & Lorenzen, C. (2015). Pre-training self-reported wellness impacts training output in Australian footballers. *Journal of Sports Sciences*. doi: 10.1080/02640414.2015.1119295 (IN PRESS).

*Contribution statement:* **TG (75%)** was primarily responsible for the study design, gaining ethics approval, data collection, data handling, statistical analysis, interpreting the results, drafting the manuscript, submitting the manuscript, responding to reviewer feedback, and approving the final proof. **SC (10%)** contributed to the study design, interpreting the results, conception of the discussion, proof reading the manuscript, and responding to reviewer feedback. **TGabbett (5%)** contributed to the study design, interpreting the results, and proof reading the manuscript. **CL (10%)** contributed to the study design, interpreting the results, conception of the discussion, proof reading the manuscript, and responding to reviewer feedback.

I acknowledge that my contribution to the above paper is 75%.



**Tania Gallo**

As principal supervisor, I certify that the above contributions are true and correct.



**Christian Lorenzen (10%)**

A handwritten signature in cursive script, reading "Stuart Cormack". The letters are fluid and connected, with a prominent 'S' at the beginning and a long, sweeping 'C' at the end.

**Stuart Cormack (10%)**

A handwritten signature in cursive script, reading "Tim Gabbett". The signature is more compact and stylized than the one to its left, with a clear 'T' and 'G'.

**Tim Gabbett (5%)**

## STUDY 4

Gallo, T., Cormack, S. J., Gabbett, T. J., Tran, J. & Lorenzen, C. (2015). Effects of internal load measures and athlete self-reported wellness on match performance in Australian football (IN PREPARATION).

*Contribution statement:* **TG (62%)** was primarily responsible for the study design, gaining ethics approval, data collection, data handling, statistical analysis, interpreting the results, drafting the manuscript, and is responsible for submitting the manuscript, responding to reviewer feedback, and approving the final proof. **SC (8%)** contributed to the study design, interpreting the results, conception of the discussion, proof reading the manuscript, and will contribute to responding to reviewer feedback. **TGabbett (4%)** contributed to the study design, interpreting the results, and proof reading the manuscript. **JT (18%)** contributed to the study design, data handling, statistical analysis, interpreting the results, conception of the discussion, proof reading the manuscript, and will contribute to responding to reviewer feedback. **CL (8%)** contributed to the study design, interpreting the results, conception of the discussion and proof reading the manuscript, and will contribute to responding to reviewer feedback.

I acknowledge that my contribution to the above paper is 62%.



**Tania Gallo**

As principal supervisor, I certify that the above contributions are true and correct.

A handwritten signature in black ink, appearing to read 'C. Lorenzen'.

**Christian Lorenzen (8%)**

A handwritten signature in black ink, appearing to read 'Stuart Cormack'.

**Stuart Cormack (8%)**

A handwritten signature in black ink, appearing to read 'Tim Gabbett'.

**Tim Gabbett (4%)**

A handwritten signature in black ink, appearing to read 'Jacqueline Tran'.

**Jacqueline Tran (18%)**

## **APPENDIX iii Ethics documents**



## INFORMATION LETTER TO PARTICIPANTS

**TITLE OF PROJECT:** The relationship between external training load and internal training load in elite Australian Football players.

**PRINCIPAL SUPERVISOR:** Dr. Christian Lorenzen

**STUDENT RESEARCHER:** Tania Gallo

**PROGRAMME IN WHICH ENROLLED:** Doctor of Philosophy

You are invited to participate in a study investigating the relationship between external training load (determined from GPS derived variables) and internal training load (determined using the session-RPE method) in elite Australian football players. The study will examine this relationship and explore the impact that aerobic fitness level and playing experience has on the relationship. The knowledge gained from this study will help fitness staff understand and monitor training loads in an attempt to optimize training prescription.

This project is being conducted by Tania Gallo and will form part of the research for a Doctorate of Philosophy at Australian Catholic University under the supervision of Dr. Christian Lorenzen. Your club has provided support for this research.

You will not be required to do anything for the research as the data required has already been collected by your club, we are simply seeking your permission to use the data collected from pre-season in our analysis. Hence, there are no foreseeable risks, inconvenience and/or discomfort to you.

The findings of this research will help your coaches improve training practices and preparation for the following season(s). The results will potentially allow them to better understand the individual response to external training load use this to monitor training load in the aim of preventing overtraining.

Be advised, participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences up until the data has been deidentified and aggregated. Withdrawal from the research study will not impact upon your employment or team selection.

It is our intention to present the findings of the group data in the form of a journal publication. This means other athletes within the community will be able to benefit from the knowledge gained from this study. Please note that you will not be named within this report and no one outside your club staff and the team of researchers will be able to identify your results at any time during or following the testing. An identification number will be assigned to your data, known to only the researchers.

On completion of the study, we would be delighted to discuss with you the findings of the study, and your individual results. Furthermore, a copy of the publication will be pinned to the notice board at your football club for you to read at your convenience.



Should you have any questions regarding this project, please contact the Principal Supervisor and/or the Student Researcher:

Dr Christian Lorenzen  
(03) 9953 3849  
School of Exercise Science  
ACU National, St Patrick's Campus,  
115 Victoria Parade, Fitzroy, VIC 3065

Tania Gallo  
(03) 9320 2407  
School of Exercise Science  
ACU National, St Patrick's Campus,  
115 Victoria Parade, Fitzroy, VIC 3065

The study has been approved by the Human Research Ethics Committee at Australian Catholic University (approval number 2012 238V). If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Chair, HREC  
c/o Office of the Deputy Vice Chancellor (Research)  
Australian Catholic University  
Melbourne Campus  
Locked Bag 4115, FITZROY, VIC, 3065  
Ph: 03 9953 3150 Fax: 03 9953 3315  
Email: [res.ethics@acu.edu.au](mailto:res.ethics@acu.edu.au)

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

If you agree to participate in this project, you should sign both copies of the Consent Form. If you do not wish to participate, do not sign the consent form. Please retain one copy for your records and return the other copy to the Principal Supervisor or Student Researcher.

Yours sincerely,



Dr Christian Lorenzen  
Principal Investigator



Tania Gallo  
Student Researcher



## CONSENT FORM

*Copy for Researcher/Participant*

**TITLE OF PROJECT:** The relationship between external training load and internal training load in elite Australian Football players.

**PRINCIPAL SUPERVISOR:** Dr. Christian Lorenzen

**STUDENT RESEARCHER:** Tania Gallo

I ..... *(the participant)* have read *(or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study, which involves the researchers having access to my training data over the last season.

I realise that I can withdraw my consent up until the point that the researchers have deidentified and aggregated the data, without comment or penalty or affect upon my future relationship with researchers or the club. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: .....

SIGNATURE: .....

DATE:.....

SIGNATURE OF PRINCIPAL SUPERVISOR: .....

DATE:.....

SIGNATURE OF RESEACHER: .....

DATE:.....



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kangaroos.com.au

28/08/2012



To whom it may concern,

As Director of Sports Science and Rehabilitation of the North Melbourne Football Club, I completely support the research led by Dr. Christian Lorenzen, entitled "*The relationship between external and internal training loads in elite Australian Football players*", to be conducted at ACU. I give permission for the researchers to seek consent from the players and access the relevant data. The club is aware of the voluntary nature of participation and need for consent from individual participants.

Regards,

A handwritten signature in black ink, appearing to read "Peter Mulkearns", written over a horizontal line.

Peter Mulkearns

Director of Sports Science and Rehabilitation



## **PARTICIPANT INFORMATION LETTER**

**PROJECT TITLE:** External and internal training loads over a full season of Australian Football.

**PRINCIPAL INVESTIGATOR:** Dr. Christian Lorenzen

**STUDENT RESEARCHER:** Tania Gallo

**STUDENT'S DEGREE:** Doctor of Philosophy

Dear Participant,

You are invited to participate in the research project described below.

### ***What is the project about?***

The research project investigates the relationship between external training load (determined from GPS derived variables) and internal training load (determined using the session-RPE method) in elite Australian football players. The study will examine this relationship and explore the impact that self-reported wellness scores, counter-movement jump data and performance measures such as coach's ratings and game statistics has on the relationship. The knowledge gained from this study will help fitness staff understand and monitor training loads in an attempt to optimize training prescription.

### ***Who is undertaking the project?***

This project is being conducted by Tania Gallo and will form part of the research for a Doctorate of Philosophy at Australian Catholic University under the supervision of Dr. Christian Lorenzen. Your club has provided support for this research.

### ***What will I be asked to do? Are there any risks associated with participating in this project?***

You will not be required to do anything for the research as the data required has already been collected by your club, we are simply seeking your permission to use the data collected in our analysis. Hence, there are no foreseeable risks, inconvenience and/or discomfort to you.

### ***What are the benefits of the research project?***

The findings of this research will help your coaches improve training practices and preparation for the following season(s). The results will potentially allow them to better understand the individual response to external training load and use this to monitor training load in the aim of preventing overtraining. There are no immediate benefits to the participant.

### ***Can I withdraw from the study?***

Participation in this study is completely voluntary. You are not under any obligation to participate. If you agree to participate, you can withdraw from the study at any time without adverse consequences up until the data has been de-identified and aggregated. Non-participation or withdrawal from the research study will not impact upon your employment or team selection.

### ***Will anyone else know the results of the project?***

It is our intention to present the findings of the group data in the form of a journal publication. This means other athletes within the community will be able to benefit from the knowledge gained from this



study. Please note that your club will be identified but you will not be named within this report and no one outside your club staff and the team of researchers will be able to identify your results at any time during or following the testing. Data will be stored on password locked computers and deleted after 5 years. An identification number will be assigned to your data, known to only the researchers.

***Will I be able to find out the results of the project?***

On completion of the study, we would be delighted to discuss with you the findings of the study. Furthermore, a copy of the publication and a lay summary will be pinned to the notice board at your football club for you to read at your convenience.

***Who do I contact if I have questions about the project?***

Should you have any questions regarding this project, please contact the Principal Supervisor and/or the Student Researcher:

Dr Christian Lorenzen  
School of Exercise Science  
Australian Catholic University  
Melbourne Campus  
Locked Bag 4115, Fitzroy, VIC 3065  
(03) 9953 3849

Tania Gallo  
School of Exercise Science  
Australian Catholic University  
Melbourne Campus  
Locked Bag 4115, Fitzroy, VIC 3065  
Ph. (03) 9320 2407 Mob. 0410 509 213

***What if I have a complaint or any concerns?***

The study has been approved by the Human Research Ethics Committee at Australian Catholic University (approval number 2013 50V). If you have any complaints or concerns about the conduct of the project, you may write to the Chair of the Human Research Ethics Committee care of the Office of the Deputy Vice Chancellor (Research).

Chair, HREC  
c/o Office of the Deputy Vice Chancellor (Research)  
Australian Catholic University  
Melbourne Campus  
Locked Bag 4115, FITZROY, VIC, 3065  
Ph: 03 9953 3150 Fax: 03 9953 3315  
Email: [res.ethics@acu.edu.au](mailto:res.ethics@acu.edu.au)

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

***I want to participate! How do I sign up?***

If you agree to participate in this project, you should sign both copies of the Consent Form. If you do not wish to participate, do not sign the consent form. Please retain one copy for your records and return the other copy to the Principal Supervisor or Student Researcher.

Yours sincerely,



Dr Christian Lorenzen  
Principal Investigator



Tania Gallo  
Student Researcher



## CONSENT FORM

*Copy for Researcher/Participant*

**TITLE OF PROJECT:** External and internal training loads over a full season of Australian Football.

**PRINCIPAL SUPERVISOR:** Dr. Christian Lorenzen

**STUDENT RESEARCHER:** Tania Gallo

I ..... *(the participant)* have read *(or, where appropriate, have had read to me)* and understood the information provided in the Letter to Participants. Any questions I have asked have been answered to my satisfaction. I agree to participate in this study, which involves the researchers having access to my training data (load, GPS, self-reported wellness, counter-movement jump data, and performance measures such as coach's ratings and game statistics) from the 2013 season.

I realise that I can withdraw my consent up until the point that the researchers have de-identified and aggregated the data, without comment or penalty or affect upon my future relationship with researchers or the club. I agree that research data collected for the study may be published or may be provided to other researchers in a form that does not identify me in any way.

NAME OF PARTICIPANT: .....

SIGNATURE: .....

DATE:.....

SIGNATURE OF PRINCIPAL SUPERVISOR: .....

DATE:.....

SIGNATURE OF RESEACHER: .....

DATE:.....



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ABN: 21 006 468 962

[kangaroos.com.au](http://kangaroos.com.au)



27/3/2014

To whom it may concern,

As Director of Sport Science and Medical Services of the North Melbourne Football Club, I completely support the research led by Dr. Christian Lorenzen, entitled "External and internal training loads over a full season of Australian Football", to be conducted at ACU. I give permission for the researchers to seek consent from the players and access the relevant data (load, GPS, self-reported wellness, counter-movement jump data, and performance measures such as coach's ratings and game statistics). The club is aware of the voluntary nature of participation and the need for consent from the individual participants.

Regards,

A handwritten signature in blue ink, appearing to read "Steve Saunders", with a long horizontal flourish extending to the right.

Dr. Steve Saunders  
High Performance Manager/Director of Sports Science and Training Services



**END OF DOCUMENT**