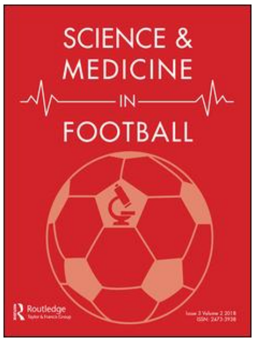

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Training monitoring in professional Australian football: theoretical basis and recommendations for coaches and scientists

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ABSTRACT
Australian football (AF) is a high-intensity field-based sport with regular collisions and intense physical demands such as jumping, tackling and jostling, resulting in neuromuscular fatigue and soreness, combined with external stressors (i.e., sponsorship, education, family). These can influence an athlete's fatigue and recovery status, requiring an individualised approach to monitoring to optimise training readiness. Optimal readiness would reflect a condition where an athlete has no impairment of physical performance, no mental fatigue or excessive psychological distress. A theoretical framework exists for athlete monitoring that includes the quantification of training load and understanding individual ability to tolerate the training demands imposed by coaches. However, while this approach is thought to ultimately determine the readiness of a player for training and competition, it has not been tested empirically. The purpose of this review is to describe the theoretical basis that underpins athlete monitoring systems, and to provide an overview of their contribution to decision-making processes in planning and delivery of training in professional AF players. This review can assist coaches and scientists to gain a better understanding of commonly used monitoring measures and how the information derived from these sources is applied in a professional AF environment.

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KEYWORDS
Australian football; monitoring; player preparation

Introduction

Australian football (AF) is a demanding, high-intensity field-based sport with regular collisions and intense activities such as jumping, tackling and jostling, resulting in neuromuscular fatigue and soreness (Johnston et al. 2018). In addition to these heavy physical demands, professional AF players also experience other performance-related psychological stress and have external demands on their time (i.e., commercial obligations, media, education, family). These stressors can impact on an athlete's fatigue and recovery status and influence their responses to the training stimulus and their readiness for competition. In the case of professional team-sport, the term of athlete readiness is often used by practitioners to describe the athlete's capacity to complete training activities and perform during competition. Optimal readiness would reflect a condition where an athlete has no impairment of physical performance, no mental fatigue or excessive psychological distress. Indeed, to enhance readiness and attempt to reduce the risk of injury and illness, training load should be adjusted on an individual level based upon training goals combined with their current fitness and fatigue status. A theoretical framework exists for athlete monitoring that includes the quantification of training load and understanding individual fitness and fatigue responses to the training dose (Impellizzeri et al. 2005). While this approach is thought to ultimately determine the readiness of a player for training and competition (Coutts et al. 2018), it has not been tested empirically.

Quantification of training load and assessments of fitness and fatigue status can be provided using athlete monitoring tools. Recent technological advancement has increased the number of tools available, such as internal and external training load measures (Impellizzeri et al. 2004; Wallace et al. 2014) in addition to training response measures including psychometric markers (Saw et al. 2015), neuromuscular fatigue assessments (Cormack et al. 2013) and fitness tests (Veugelers et al. 2016). Data obtained from these tools can support decision-making regarding the planning and delivery of training load at an individual level to optimise player readiness for training and matches. In practice, the objective information provided by these tools is often combined with expert opinion (i.e., from coaches and scientists) to make decisions about future training. Specifically, practitioners often consider information relating to previous training and match load completed and the players' response to this load (commonly assessed via short psychometric questionnaires and neuromuscular screening tests) when deciding appropriate future training activities (and load) for individual players. Alterations in individual players training load are typically achieved through manipulation of training duration, intensity and/or content. These changes are made with the intent of reducing injury risk and maximising player readiness for training and competition. However, despite the widespread use of this approach, no research has established the efficacy of this method in a professional AF environment. Therefore, the purpose of this narrative review is to describe the theoretical basis that underpins athlete monitoring systems and to provide an overview of their contribution to decision-making processes in planning and delivery of training in professional AF players. This review will assist coaches and scientists to gain a better

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understanding of the evidence supporting commonly used monitoring measures and how the information derived from these sources is applied in a professional AF environment.

Theoretical basis of athlete monitoring

Athlete monitoring is now common practice in professional team sports (Taylor et al. 2012). Monitoring systems are reliant on being able to accurately quantify the training dose completed by the athlete, and the individual athlete's response to that dose. Once this dose–response relationship is understood at the level of the individual athlete (Coutts and Cormack 2014), targeted prescription of training and recovery activities can be provided in order to optimise training outcomes. The 'fitness-fatigue' model underpins the theoretical basis of this approach, whereby performance may be modelled from the positive (i.e., fitness) and negative (i.e., fatigue) responses that arise from training load delivered to the athlete (Banister et al. 1975). Fitness was initially represented by the positive adaptations generated by training completed by an athlete over a chronic time period, with fatigue the result of an acute training dose (Coutts and Cormack 2014). Whilst the 'fitness-fatigue' model has not consistently been shown to describe or predict performance (Wallace et al. 2014; Graham et al. 2017), the theoretical and conceptual basis (balance between positive and negative training-induced effects) can be used as a generic framework to develop athlete monitoring systems.

According to the conceptual 'fitness-fatigue' model, the appropriate balance between training and recovery should be attained to maximise physical adaptations (Coutts and Cormack 2014). The balance of fitness and fatigue is achieved by careful periodisation of training to allow for higher training loads over chronic time periods to maximise fitness adaptations, but lower training loads in the days closer to competition to reduce acute residual fatigue. However, achieving an appropriate balance of fitness and recovery can be difficult in AF competition periods, as there are often relatively short periods between matches, and the training loads during these periods are typically influenced by the nature of the technical and tactical training prescribed by coaches. Moreover, training may be completed in the presence of acute fatigue to achieve physiological adaptions during preseason training periods. Indeed, training activities are derived from a combination of technical/tactical requirements determined by coaches and physical/physiological requirements determined by strength and conditioning staff, as training must be targeted to the systems that influence performance (Impellizzeri et al. 2019).

Training delivery in professional Australian football

The aim of athletic training is to provide a stimulus that improves physical performance while also attempting to protect an athlete from injury and illness during competition (Coutts et al. 2018). In professional AF, training usually includes tactical skills training designed by coaches (drills that are congruent with aspects of the team's game plan or specific technical skills that require improvement or focus), conditioning (e.g., running or cross-training) and resistance training (Ritchie et al. 2016). Recent case studies describing the training load completed by professional AF players have shown that training load (total and high-intensity running distances and session rating of perceived exertion load) is greater during the preseason period (i.e. November to February) compared to in-season (i.e. March to September), with the majority of total training load obtained from skills and conditioning sessions (Ritchie et al. 2016). During in-season, approximately half the total training load (session-RPE) is derived from matches, while the other half is typically generated from technical-tactical sessions and upper body weight sessions (Ritchie et al. 2016). The overall intensity of training is at least of moderate intensity (assessed via session-RPE), which is likely due to the nature of training being focused on tactical capabilities as opposed to physical (Moreira et al. 2015). However, whilst these studies have described the training load completed by professional AF players across typical training microcycles, they provide little insight into the methodology and decision-making process used to plan and deliver training in practice.

A contemporary approach to planning and delivering training load combines consideration of objective and subjective monitoring measures with tactical requirements of coaches. The specific nature and content of most training sessions (i.e., field-based skills sessions) in AF is typically determined by technical or tactical coaches, designed to meet specific strategies of the team and individual players. However, at an individual player level, the volume and nature of training load is often manipulated based on their readiness for training with consideration of factors such as upcoming match location, opposition strength and days between matches (Kelly and Coutts 2007; Robertson and Joyce 2018). The process of acute training load periodisation has theoretical support and is common in professional practice (Kelly and Coutts 2007; Robertson and Joyce 2018); however, there have been few reports of the specific information used to underpin decision-making regarding acute training periodisation at an individual level in professional AF.

Monitoring player readiness in professional Australian football

Coaches and scientists obtain information from a variety of sources to inform planning and delivery of acute training stimuli at an individual level. These include internal and external training load measures (Impellizzeri et al. 2004; Wallace et al. 2014) in addition to acute and chronic responses to training load such as heart rate variability, perceptions of neuromuscular fatigue and fitness tests (Cormack et al. 2008; Buchheit et al. 2013; Saw et al. 2015; Veugelers et al. 2016). While some of these sources have established validity and reliability, practitioners must consider their association with training load, injury risk and performance and practical limitations to properly interpret the information they provide.

External training load refers to the physical work prescribed and delivered in training (Impellizzeri et al. 2019), and is often assessed using microtechnology devices which provide locomotive measures (e.g., total distance, distance covered at speed thresholds, number of accelerations and decelerations) and mechanical measures (e.g., tackles, jumps and impacts) of training demands (Johnston et al. 2014; Burgess 2017). Given the complexity of the physical requirements of AF (Coutts et al. 2010), a combination of these external load measures is required to provide a comprehensive understanding of training demands. In practice, external load is typically reported in terms of 'locomotive load' as these measures have some evidence of validity and reliability (Varley et al. 2012; Johnston et al. 2014). However, few studies have established a valid or reliable measure of other technical activities that produce substantial mechanical load such as kicking, tackling, jumping and change of direction in AF (Gastin et al. 2014; Spangler et al. 2018), possibly explaining why these measures are not widely reported. Future research may examine the validity of these measures to provide a more comprehensive understanding of AF training and match demands.

While external load variables are used to describe training and competition loads, they do not provide information on player tolerance and adaptation to this load. This necessitates the assessment of internal training load, which refers to the psychological and/or physiological responses to the external load (Impellizzeri et al. 2005, 2019). A common method of measuring internal load is the session-RPE method (Foster et al. 2001; Taylor et al. 2012), where players are shown a category-ratio RPE scale and asked to provide a number rating the overall perception of exertion relating to the whole training session (Foster et al. 2001). The figure is multiplied by the duration of the session in minutes to determine a total session training load in arbitrary units. The session-RPE method permits quantification of training load across any modality; hence, it is a practically useful method for quantifying internal load in AF (Foster et al. 2001; Fanchini et al. 2017). However, caution is needed when comparing the load measured via session-RPE generated by exercises of different nature. An additional measure of internal load is heart rate during training, extended to training impulse (TRIMP) where training intensity can be determined by calculating the average level of heart rate reserve (the difference between recorded heart rate and heart rate maximum), with a lower heart rate reserve indicative of greater training intensity and therefore greater load (Banister et al. 1999). However, heart rate monitors are not permitted to be worn by AF players during competition; therefore, session-RPE is the most practical method of measuring internal load during training and competition in these athletes (Foster et al. 2001).

Information from external load measures can provide practitioners with objective information regarding the intensity and nature of training and match-play, however, it is the internal training load that ultimately determines the training outcome, as athletes are likely to respond differently to the same external workload (Impellizzeri et al. 2019). The individual response is due to the influence of many factors that affect internal load, such as nutrition, psychological status and genetics which are not accounted for by external load measures (Impellizzeri et al. 2019). Moreover, a cohort of professional athletes may have different responses to training stimuli (Mann et al. 2014), hence monitoring training using a combination of external and internal load measures is vital for a better understanding of the dose–response relationship derived from training (Mann et al. 2014; Bartlett et al. 2017). Indeed, research in AF has reported associations between external load (total distance covered during a session) with session-RPE, suggesting that changes in external load may be indicative of training response (Bartlett et al. 2017). The relationship between external and internal load allows coaches and scientists to derive information about how an athlete is tolerating training stressors without intervention (i.e., fitness test or questionnaires) (Coutts et al. 2018).

External and internal load measures both provide useful information on the demands of training and matches, however, meaningful relationships between these measures and match performance in professional AF are not well-established. Research has shown running performance during simulated team-sport match activity (i.e., sprint velocity and total distance covered) to decrease following high acute training loads (Slattery et al. 2012), while acute running distances in training have demonstrated small effects (effect size: 0.13) on subsequent match running performance in professional AF players (Ryan et al. 2018). Additional research has shown that both running distances and session-RPE load during training are associated ($r = 0.76$ and 0.73, respectively) with changes in relative running distances during matches (Graham et al. 2017). However, this study found trivial relationships between training load and an objective measure of overall football match performance derived from match statistics (Player Rank, Champion Data) (Graham et al. 2017). Similarly, investigations into the relationship between training load and AF performance measures have reported small effects of weekly total and high-speed running volumes on objective and subjective ratings of performance (Gastin et al. 2013a, Ryan et al. 2018). Collectively, this research indicates that training load may influence subsequent match running performance in AF players; however, this relationship is likely influenced by other elements of a player's preparation for competition (Ryan et al. 2018). Moreover, training load appears to only associate with a relative running performance during matches, and these measures have been found to relate poorly with coach ratings of performance and statistical performance measures (Sullivan et al. 2014). Longitudinal investigations of large cohorts (using multiple teams) are required to establish associations between aspects of in-season training load (locomotive load, resistance training load and measures of training completion) and measures of football performance in professional AF players.

Measuring training response in professional Australian football

It is important that athletes are monitored for their response to training, as individual athletes may respond to the same training dose differently (Saw et al. 2016a). One way to assess training response is through player perceptual wellness, which is typically measured by short psychometric questionnaires (Taylor et al. 2012). In practice, assessments of wellness are usually collected several times during a training week, with players providing a subjective rating of their muscle soreness, fatigue, stress and sleep quality (Saw et al. 2016b). These responses are often compared to an individual's normal response (z-score) and can be viewed in the form of a 'traffic light system' to alert practitioners to a meaningful change (i.e., a change that exceeds the typical variation) in a player's perceived wellness) (Robertson et al.

2016). For this reason (i.e., simplicity), these self-reports are quite common in research and practice. However, evidence of validity for most of these questionnaires is lacking and they have not been developed using valid and well-established psychometric methods. Indeed, the concept of wellness has not been defined and it is prone to various interpretations, and the use of single items is theoretically limited to unidimensional constructs and not complex constructs such as stress and motivation (Sloan et al. 2002). Future work is required to develop appropriately-validated short questionnaires that can be applied in professional AF and athletes in general. However, despite these limitations this measure of training response is considered by practitioners to be a useful and inexpensive method of determining an athlete's perception of their training readiness, provided the aforementioned limitations of these instruments are considered.

Although a precise and shared definition of wellness is not available, research in professional AF has shown perceived wellness responses to be associated with changes in training load, with poorer perceptions of wellness associated with higher training load (Gastin et al. 2013b). However, a study investigating player wellness during an AF competition season found no significant relationship between match load and subsequent wellness (Gallo et al. 2016), indicating that commonly used measures of wellness may only provide an acute assessment of training readiness and limited insight into a player's readiness to perform in a match. Few studies have examined associations between wellness elements and football performance measures, however, research has shown perceived muscle soreness 48 h prior to a game to have a small, positive effect on a statistical indicator of match performance (Player Rating, Champion Data) (Ryan et al. 2018). These findings suggest that wellness responses may provide some insight into a player's capacity for subsequent match performance (Ryan et al. 2018), however, until studies examine the validity of these instruments, their utility and sensitivity is difficult to ascertain. Therefore, caution is need in their interpretation while it is acknowledged that practitioners find information derived from these measures as useful.

Neuromuscular screening and fitness tests

Individual monitoring of training response and injury risk is often achieved by neuromuscular screening and fitness tests. These include but are not limited to adductor strength tests, eccentric hamstring strength tests, countermovement jump tests, mid-thigh pull tests and submaximal heart rate tests (Cormack et al. 2008; Opar et al. 2013; Veugelers et al. 2016; Ryan et al. 2018; Norris et al. 2019).

Adductor strength assessment

Adductor strength of professional AF players is typically assessed via isometric adductor muscle contractions with the aim of detecting pain and decrements or limb imbalances in force output following training and matches (Ryan et al. 2019). A study of professional AF players found adductor strength assessed two to three days post-match were not sensitive to internal training load (session-RPE), indicating it to be a poor indicator of training responsiveness (Esmaeili et al. 2018). Nonetheless, a recent study examining the reliability of an adductor strength assessment system in professional AF players reported a very likely moderate negative effect of reported adductor pain on adductor strength (Ryan et al. 2018), indicating that this measure is useful in detecting groin pain and can prompt further investigation to establish a player's readiness for training. Collectively, adductor strength tests appear to be a suitable indicator of adductor pain and rate of lower limb recovery, but with poor sensitivity to training load. Future work is required to assess associations between changes in adductor strength during in-season periods and match performance to enhance the utility of this test.

Eccentric hamstring strength assessment

Eccentric hamstring strength is commonly assessed using the Nordic hamstring exercise to evaluate limb force reductions or imbalances (Opar et al. 2013). The Nordic hamstring test has been shown to be a reliable measure of eccentric hamstring strength, and can also discriminate between previously injured and uninjured athletes (Opar et al. 2013). However, few studies have examined the association between eccentric hamstring strength and training readiness in professional AF players. A recent study in professional AF that examined the influence of session-RPE training load on hamstring flexibility found higher training loads to have a trivial association with lower hamstring flexibility (Esmaeili et al. 2018), indicating that a change in this measure is not sensitive to changes in training load. However, while the diagnostic accuracy of this test in detecting injury has not been demonstrated, research has shown that relatively low levels of eccentric hamstring strength measured during a preseason training period are associated with an increased risk of hamstring strain injury in a subsequent competition season (Opar et al. 2015). Collectively, eccentric hamstring strength appears to have limited utility in assessing a player's readiness to train (over acute timeframes), however, it may provide practitioners with useful information regarding future injury risk during a competition season. Future research examining associations between acute changes in eccentric hamstring strength and both mechanical load (i.e., acceleration, deceleration, change of direction during training) and injury risk is warranted.

Countermovement jump performance and mid-thigh pull

Countermovement jump (CMJ) performance has been shown to be responsive to match load, with substantial reductions in CMJ flight time following AF competition matches (Cormack et al. 2008), while decreases in CMJ performance have also been related to increases in low-speed movement and reduced accelerations during competition matches (Cormack et al. 2013). These findings support the use of CMJ tests as an indicator of post-match recovery in AF players and suggest it to be a useful test to prompt altered training loads during a 96-h period following competition. Additionally, mid-thigh pull (MTP) has been proposed as an isometric alternative to CMJ for assessing neuromuscular fatigue in professional AF (Norris et al. 2019). Previous research has established MTP to be a valid, reliable and practical method of assessing lower limb neuromuscular fatigue in team sport athletes (Comfort et al. 2014; James et al. 2015); however, no research has examined relationships between CMJ or MTP and match performance in professional AF.

Submaximal heart rate measures

Research has established associations between heart rate measures to changes in training status in endurance athletes (Aubry et al. 2015) which have subsequently been applied to cohorts of AF athletes (Veugelers et al. 2016). Heart rate is typically expressed by heart rate during exercise (HRex), with lower values indicative of greater cardiac efficiency (Aubry et al. 2015) and heart rate recovery (HRR) with faster return to pre-exercise heart rate indicative of better aerobic fitness (Aubry et al. 2015). Previous research in professional AF has reported a submaximal heart rate recovery test to be a valid and reliable measure of training status (Veugelers et al. 2016). Additionally, research investigating training response during a preseason training camp in AF reported lower HRex following intense periods of training, indicating it provides a useful index of aerobic fitness in AF players over short timeframes (Buchheit et al. 2013). However, future work is required to establish meaningful changes in HRex and HRR in order to enhance interpretation of these measures when assessing training readiness in AF players.

Current evidence shows that neuromuscular screening tests provide practitioners with limited information to predict the training readiness and injury risk status of their athletes in isolation, hence we suggest caution when interpreting results from these tests. While adductor strength and CMJ performance are reduced following competition matches, their sensitivity to changes in training load are unknown, hence they should be used in conjunction with other measures when assessing a player's readiness to train. In contrast, eccentric hamstring strength measures can provide practitioners with insight into subsequent risk of hamstring injury during a competition season, however the responsiveness of this measure to alterations in acute training load remains unclear. A heart rate recovery test can provide an index of aerobic fitness during preseason and competition periods, however, further research is needed to establish meaningful changes in this measure to enhance interpretability for practitioners. Nonetheless, in practice, changes in these and similar measures administered regularly (i.e., each week between matches) can prompt further examination of other monitoring data when assessing an individual player's readiness to train, hence these tests of fitness and fatigue can be used in conjunction with other monitoring measures in AF. However, research establishing relationships between these tests and both alterations in training load and injury risk is required to enhance the interpretability of test results for coaches and scientists.

Acute training periodisation and delivery in professional Australian football

The theoretical model of athlete monitoring presented in this review indicates that preparing an athlete for competition is multi-factorial, and to do so effectively requires inputs of information from a range of objective and subjective sources. There are a range of factors that influence an athlete's readiness to train demanding individual monitoring and alteration of acute training load. In practice, coaches design training based on tactical and strategic requirements to best equip players with the knowledge and capabilities to perform against a given opposition team each week during a competition season. Subsequently, coaches and scientists consider information relating to previous training and match load completed and response to this load to deliver appropriate training load to individual players. Acute training load alterations are typically achieved through manipulation of running volume at different speed thresholds, instances of maximum speed exposure, and volume of mechanical load, among others. The aim of this approach is to minimise risk of injury and enhance individual player readiness for training competition; however, no research has established the efficacy of this approach in a professional AF environment. Moreover, the utility of many of the monitoring measures described in this review in detecting meaningful changes in injury risk and match performance remains unknown. Therefore, accurate training load delivery continues to be reliant on the collaboration of coaches and scientists, supported by objective monitoring measures of player readiness.

Practical applications

- Coaches and scientists should use locomotive and mechanical external load, and session-RPE load when assessing individual player readiness for training based on load completed.
- Perceptual wellness responses are widely used in professional AF club settings to prompt further investigation of player readiness for training; however, further work is required using established psychometric methods to determine their validity.
- Adductor strength and countermovement jump performance are useful neuromuscular fatigue measures following AF matches and should be administered to guide acute delivery of training load during between-match microcycles.
- Submaximal heart rate measures (HRex and HRR) are unobtrusive and non-fatiguing methods of assessing training response and aerobic fitness over short periods in AF players.
- External and internal training load measures show strong associations with subsequent running performance but not football performance measures in competition matches.
- Measurement characteristics (validity and reliability) of monitoring measures specific to the protocols used in AF clubs should be established to provide practitioners with the most interpretable information when assessing a player's training readiness.

Conclusions

Monitoring measures used to inform decisions about future training load delivery should be based on a proof of concept and strong theoretical support. These elements can be derived from high-quality research that establishes the validity and reliability of monitoring measures to allow proper interpretation of data collected. Only measures that can provide meaningful information (i.e., a meaningful change in a measure) on how the athletes tolerate training demands (i.e., fitness and fatigue status) should be considered when assessing player readiness for training and competition. Optimal readiness would reflect a condition where an athlete has no impairment of physical performance, no mental fatigue or excessive psychological distress. Additionally, collection of monitoring information needs to be cost-efficient and parsimonious for practitioners to allow timely feedback to coaches on the training readiness of their player. The feedback should be integrated with the expert knowledge and experience of coaches and scientists to allow holistic assessments of a player's readiness to train and compete.

Disclosure statement

No potential conflict of interest was reported by the authors.

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