EXAMINING THE EFFECT OF TEAM SPORT AND ASSOCIATED TRAINING LOADS ON CHANGES IN BODY COMPOSITION: A SYSTEMATIC REVIEW AND META-ANALYSIS

by

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Abstract

Background: The monitoring of body composition together with training load provides an informative, comprehensive assessment of training effectiveness, adaptive responses, and physiological status to strengthen athlete management and development. Currently, this relationship has yet to be fully synthesized in team sport and warrants investigation.

Objectives: The aim of this systematic review and meta-analysis was to synthesize the current literature regarding the effects of team sport and associated training loads on body composition changes.

Methods: A systematic search was completed according to PRISMA guidelines in MEDLINE, EMBASE, CINAHL, and SPORTDiscus databases to identify articles that examine the relationship between team sport, training load, and changes in body composition. A random-effects meta-analysis was performed to analyze changes in body mass (kg), body fat (%, kg), and lean body mass (kg).

Results: The database search yielded 4,594 studies, with six studies meeting all eligibility criteria for inclusion. Meta-analysis demonstrated that playing elite/professional level team sport is associated with small reductions in body fat percentage (SMD: -0.37, 95% CI [-0.74 to -0.01], $p = 0.04$). These changes appear to be associated with reductions in fat mass (SMD: -0.33, 95% CI [-0.68 to 0.02], $p = 0.07$), while body mass (SMD: -0.02 [95% CI -0.25 to 0.21], $p = 0.87$) and lean body mass (SMD: 0.02, 95% CI [-0.26 to 0.29], $p = 0.91$) tend to be maintained. Inconsistencies and diversity in training load methodologies and reporting resulted in unclear evidence depicting the moderating effect of training load; however, preliminary findings suggest that excessive volumes of high-speed running/sprinting loads may negatively impact body composition, while increasing accelerations/decelerations may provide an effective and efficient means to increase intensity, improve conditioning, and optimize adaptation.

Conclusions: Findings from this work suggest that body composition changes as an effect of the cumulative factors and stimuli of elite/professional team sport. Further research is warranted to ascertain the effect of training loads on these changes, with an aim to standardize the quantification and reporting of these loads as well as improved nutritional reporting.

Lay Summary

Body composition is an important component of athlete health and performance and is influenced by a myriad of factors. In sport, changes in body composition may reflect responses to various training factors and competitive stimuli across the training process, in addition to individual stressors and/or nutritional patterns. Currently, the relationship and complex interplay between team sport, training load, and body composition has yet to be fully synthesized. The aim of this research was therefore to summarize existing research examining the effect of team sport on body composition changes, with a secondary aim to examine the influence of quantified training loads on this relationship. Results demonstrated that body fat percentage decreases as an effect of playing team sport while lean body mass and overall body mass tend to be maintained. However, more research is needed to ascertain the effects of training loads on these changes.

Preface

This thesis project was conceptualized and designed by Jasmine Deol with assistance from Drs. Darren Warburton, Andrew Perrotta, Carolyn McEwen, and Jack Taunton. Jasmine Deol was the lead investigator in carrying out this research, with Dr. Andrew Perrotta as the co-investigator/second reviewer during the article screening process. Jasmine Deol completed all data collection, analysis, and writing of this thesis document. The protocol for this systematic review and meta-analysis was prospectively registered on PROSPERO (CRD42022296551).

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List of Abbreviations

AFL: Australian Football League

AU: Arbitrary units

BF: Body fat

BM: Body mass

CI: Confidence interval

CR: Category-ratio

FA: Fatty acids

FFA: Free fatty acids

FFM: Fat-free mass

FM: Fat mass

GPS: Global Positioning System(s)

HR: Heart rate

$HR_{exercise}$: Heart rate during exercise

$HR_{resting}$: Heart rate during rest

HR_{max}: Maximum heart rate

HSRD: High-speed running distance

LBM: Lean body mass

MFO: Maximal fat oxidation

NCAA: National Collegiate Athletic Association

NR: Not reported

RPE: Rating of perceived exertion

RT: Resistance training

SprD: Sprinting distance

SD: Standard deviation

SMD: Standardized mean difference

SSG: Small-sided games

sRPE: Session Rating of Perceived Exertion

TD: Total distance

TL: Training load

TRIMP: training impulse

UEFA: Union of European Football Associations

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Chapter 1: Introduction

1.1 Introduction/Rationale

Training at the elite or professional level of sport places considerable demand on athletes to achieve optimal performance and fitness for success within competition. Team sport athletes face the additional challenge of concomitantly training and competing throughout the duration of their competitive period, as competition periods may span more than 8 months of each annum (Gamble, 2006). As a result, they must maintain a high degree of performance and fitness throughout the competitive period, while also facing challenges associated with fatigue and non-functional overreaching (Bompa & Buzzichelli, 2019; Gamble, 2006; Smith, 2003). Training needs to be structured, prescribed, and monitored with careful and continuous scrutiny in order to optimize adaptive responses, fitness, and performance while minimizing the risk for overtraining, illness, and injury (Bompa & Buzzichelli, 2019; Bourdon et al., 2017; Halson, 2014; Smith, 2003; Soligard et al., 2016). However, training regimens are often prescribed by coaches and set for the entire team, and may not consider individual responses to an otherwise similar training load (Alexiou & Coutts, 2008; Halson, 2014; Impellizzeri, Rampinini, & Marcora, 2005; Los Arcos, Martínez-Santos, Yanci, Mendiguchia, & Méndez-Villanueva, 2015; Soligard et al., 2016). The monitoring and quantification of training load is of considerable value to address and manage these concerns (Alexiou & Coutts, 2008; Halson, 2014; Impellizzeri et al., 2005; Los Arcos et al., 2015; Soligard et al., 2016).

Body composition is one important aspect of athlete development and physical fitness that has been suggested to improve player performance and increase capacity to effectively manage the demands of the sport (Bilsborough et al., 2014, 2015; Bilsborough, Greenway, Livingston, Cordy, & Coutts, 2016; Gabbett, Jenkins, & Abernethy, 2011a, 2011b; Gabbett, Kelly, & Pezet, 2007; Johnston, Black, Harrison, Murray, & Austin, 2018; Silvestre, West, Maresh, & Kraemer, 2006; Till, Cobley, O'Hara, Chapman, & Cooke, 2010; Torres-Unda, Zarrazquin, Gil, Ruiz, Irazusta, Kortajarena et al., 2013). Team sport athletes require an optimal level of muscle mass to maximize strength and power abilities and effectively withstand mechanical stressors, while maintaining an appropriate power: weight ratio based on the demands of the sport (Bilsborough et al., 2015; Gabbett, 2005; Gabbett et al., 2011a; Johnston et al., 2018; Johnston, Gabbett, & Jenkins, 2014; Thomas, Erdman, & Burke, 2016). This often includes minimizing fat gain that impedes performance and recovery-related processes as well as that which heightens negative health risks (Gabbett, 2005; Meir, Newton, Curtis, Fardell, & Butler, 2001; Reilly, 2006; Thomas et al., 2016). An optimal body composition thereby sets the physical foundation for subsequent performance and skill development to stem from, as well as reducing the risk for injury, illness, and level of fatigue (Bompa & Buzzichelli, 2019; Lee, Myers, & Garraway, 1997; Wolfe, 2006). The appropriate accrual and maintenance of lean body mass (LBM) and reduction of excess fat mass (FM) where necessary provides athletes with an improved body composition profile in line with these objectives to optimize success and longevity within the sport (Arnason et al., 2004; Bilsborough et al., 2015; Gabbett, 2005; Gabbett et al., 2011a, 2011b; 2011c; Johnston et al., 2018; Johnston et al., 2014a; Kalapotharakos, Strimpakos, Vithoulka, & Karvounidis, 2006; Thomas et al., 2016). When specific training or nutritional interventions are set in place to achieve such goals, tracking body composition may provide an effective tool to assess the effectiveness of such interventions (Argus, Gill, Keogh, Hopkins, & Beaven, 2010; Bilsborough et al., 2014; Bilsborough et al., 2016; Morehen, Routledge, Twist, Morton, & Close, 2015; Sutton, Scott, Wallace, & Reilly, 2009). However, in addition to these direct interventions, it is also critical to consider how body composition changes indirectly as a byproduct of cumulative factors and individual responses to various loads and stimuli of the sport, particularly that of team training and competition load.

Indeed, body composition has been observed to fluctuate across various phases of the season in team sport athletes, with longitudinal changes in LBM and FM (Caldwell & Peters, 2009; Carling & Orhant, 2010; Egan, Wallace, Reilly, Chantler, & Lawlor, 2006; Harley, Hind, & O'Hara, 2011; Milanese, Cavedon, Corradini, De Vita, & Zancanaro, 2015; Ostojic, 2003; Ostojic & Zivanic, 2001). While training and competition factors have often been attributed to these changes, in addition to dietary influences, such attributions are difficult to ascertain without appropriate quantification and monitoring of training load alongside these measurements (Bilsborough et al., 2016; Egan et al., 2006). Indeed, the monitoring of training load has considerably evolved over the last several years to permit the quantification of various loads of team sport using more systematic and scientific methods, which may subsequently provide a more standardized measure of the stress incurred within team sport (Borreson & Lambert, 2009; Halson, 2014; Foster, Rodriguez-Marroyo, & de Koning, 2017; Soligard et al., 2016). The longitudinal monitoring of training load together with body composition and subsequent examination of this relationship across various periods of the training process thereby offers valuable insight into the progress, changes, and adaptations developed throughout different phases of the annual training plan and corresponding training load (Bilsborough et al., 2016; Harley et al., 2011). Through this means, body composition provides a critical link between training and performance, serving as an effective yet often overlooked tool to monitor the adaptive response of an athlete to ongoing and fluctuating training and competitive loads (Harley et al., 2011). Ultimately, this may provide a more informative, comprehensive assessment of athlete monitoring and development across the training process.

While the interaction between team sport, associated training loads, and changes in body composition implies particular value, the nature and degree of this relationship yet to be fully synthesized in the team sport athletic population, and is thus difficult to ascertain. Therefore, the aim of this study was to systematically and quantitatively synthesize and examine the current evidence from existing studies to determine the effects of intermittent team sport and specific training load variables on body composition changes using a systematic review and meta-analysis.

1.2 Aims, Research Questions, and Hypotheses

1.2.1 Specific Aims

1) To conduct a systematic review and meta-analysis of current evidence from existing longitudinal, observational studies examining changes in body composition as an effect of team sport and associated training loads in elite and professional intermittent team sport athletes. Specifically, changes in the following outcomes were assessed:
   - Body mass (BM; kg)
   - Lean body mass (kg)
   - Fat mass (kg)
   - Body fat percentage (BF; %)
2) To synthesize and examine the influence of monitored internal and external training load measures as well as sport, seasonal phase, and the duration of the monitoring period on body composition changes.

1.2.2 Research Questions

How do the cumulative loads and stimuli of intermittent team sport influence body composition in elite/professional level athletes? Secondly, how does the sport, seasonal phase, duration of the monitoring period, and/or different monitored internal and external training load metrics longitudinally predict changes in BM, LBM, FM, and BF%?

1.2.3 Hypotheses

It was hypothesized that body composition in team sport athletes would demonstrate changes across various seasonal phases and training periods due to fluctuations in sport-specific training and competition factors, among other influences such as individual stressors, lifestyle, and dietary patterns. It was anticipated that body fat would decrease during intensified periods of training and competition, whereas LBM will increase during higher loads of the preseason but decrease during higher cumulative loads of the in-season, owing to the reduced conditioning emphasis in the latter. Body mass may or may not change, depending on the extent of these relative FM/LBM changes. It was also hypothesized that certain training load metrics may be able to predict certain body composition variables with greater sensitivity than others. Specifically, markers of global workload, energy expenditure, and/or cardiorespiratory stress (i.e., oxygen consumption), such as heart rate (HR), session rating of perceived exertion (sRPE), and total distance (TD) may associate with changes in body fat, with higher loads associating with increased fat loss. Markers of high-intensity movement load (i.e., mechanical stress), such as high-speed running and sprinting distances (HSRD and SprD, respectively) as well as sport-specific movement efforts may be able to better predict changes in LBM, with excessive loads and/or fluctuations potentially reducing LBM.

Chapter 2: Literature Review

2.1 Training Load Monitoring

The development and refinement of peak athletic performance and corresponding skillsets demands an equally robust training process (Smith, 2003). Over time, the systematic repetition of exercises through training aims to generate positive effects in training outcomes, including psychophysiological fitness, competition performance, injury resistance, and improved health and wellbeing (Bompa & Buzzichelli, 2019; Impellizzeri, Marcora, & Coutts, 2019; Viru & Viru, 2000). At the same time, various stressors of both training and competition in addition to many external influences in the athlete's life collectively contribute to the development of fatigue that may negatively affect the athlete's capacity to cope (Bompa & Buzzichelli, 2019; Smith, 2003; Soligard et al., 2016). Indeed, if loads become chronically excessive in magnitude and/or frequency with little fluctuation and/or opportunity for recovery, this can subsequently lead to underperformance and non-functional overreaching, as well as predisposing the athlete to overtraining, illness, or injury (Bompa & Buzzichelli, 2019; Bourdon et al., 2017; Halson, 2014; Soligard et al., 2016). In 1975, Bannister, Calvert, Savage, and Bach proposed that these positive and negative training load-induced effects are simultaneously imparted on the athlete to influence the training-performance process (Borreson & Lambert, 2009). In this regard, performance is determined by the total positive effects (e.g., improvements in fitness) minus the total amount of residual fatigue induced by training, and forms the fitness-fatigue model (Borreson & Lambert, 2009; Bourdon et al., 2017; Bannister et al., 1975). For performance to be optimal, the progression of training-induced adaptations needs to be balanced by appropriate recovery to dissipate and minimize accumulation of fatigue (Coutts, Crowcroft, & Kempton, 2017; Matveyev, 1981). In this manner, the relationship between training and performance outcomes has been modelled as a dose-response effect, where the prescription of training "dose" (i.e., prescribed training loads) accordingly requires consideration of an athlete's performance capacity, or fitness-fatigue status (Bannister et al., 1975;

Borreson & Lambert, 2009; Ryan et al., 2020). Training load has been defined as "the cumulative amount of stress placed on an individual from a single or multiple training sessions over a [defined] period of time" (Soligard et al., 2016, p. A1). In the past, training prescription and planning was primarily based upon coaches' personal philosophy and expertise, and monitoring of athlete workload was therefore relatively subjective in nature (Borreson & Lambert, 2009; Foster et al., 2017). This creates obvious limitations surrounding the reliability of training-based decisions. As a means to more effectively assess training effectiveness and an athlete's capacity to perform, the last two decades have seen the rise and adoption of more systematic and scientific methods to permit the quantification of training loads and corresponding responses, providing evidence-based tools to help inform and guide optimal training prescription, enhance the coach-athlete interface, and improve athlete monitoring (Bourdon et al., 2017; Halson, 2014; Foster et al., 2017; McLaren et al., 2018; Wallace, Slattery, & Coutts, 2014).

In team sports, the quantification of training load extends itself to considerable significance at the individual level, where differences in individual characteristics in response to an otherwise collectively prescribed team training regimen will cause individuals to respond, adapt, and fatigue at different levels of training load (Alexiou & Coutts, 2008; Impellizzeri et al., 2005; Halson, 2014; Los Arcos et al., 2015; Soligard et al., 2016). Individual differences in internal response are dependent upon characteristics such as training age and history, fitness-fatigue status, genetics, nutrition, metabolism, hormones, psychological state, sleep, and environment (Borreson & Lambert, 2009; Impellizzeri et al., 2019; Soligard et al., 2016). While some of these are fixed in nature, changes in modifiable factors will subsequently alter the internal response to a given dose of exercise (Impellizzeri et al., 2019). Correspondingly, the dose-response nature of training load lends itself to being categorized as either internal or external load, where the "dose" is dictated by the external work prescribed by the coach and completed by the player, and the "response" is determined by the internal factors within the individual that govern the physiological, psychological, and biomechanical feedback to this applied stimulus (Impellizzeri et al., 2005; Impellizzeri et al., 2019; McLaren et al., 2018; Vanrenterghem, Nedergaard, Robinson, & Drust, 2017). It is this internal response that drives subsequent adaptations, and will depend upon the "nature, intensity, and duration" (Impellizzeri et al., 2019, p. 270; Viru & Viru, 2000, p. 67) of the external stimulus (Booth & Thomason, 1991).

Various markers of internal and external training load have been established, offering a combination of objective and subjective data that each provide a useful and insightful method of quantifying and monitoring load (Halson, 2014). Nevertheless, there is no one single criterion measure in the current body of research that has managed to definitively capture and validate training load (Halson, 2014 Soligard et al., 2016). Indeed, it is also necessary to consider the substantial non-training and non-sport stress encountered by the athlete in their day-to-day lives, which will impact the individual's physical, mental, and emotional status and their ability and readiness to perform (Bourdon et al., 2017; Smith, 2003; Soligard et al., 2016). As a result, literature recommends that multiple measures of training load implementing both objective and subjective tools and internal/external parameters be used, whereupon the interaction between internal and external loads be further assessed (Akubat, Barrett, & Abt, 2014; Bourdon et al., 2017; Halson, 2014; McLaren et al., 2018). Examining the relationship between internal and external loads may permit increased understanding regarding how well or poorly the athlete is managing certain training loads, with discrepancies elucidating improvements in fitness, as well as the accumulation of fatigue (Bourdon et al., 2017; Halson, 2014; McLaren et al., 2018). As a result, appropriate implementation and analysis from load monitoring can optimize the level to which this information can be effectively applied to inform training prescription and recovery as needed, significantly improving athlete management and the planning of the training process (Bourdon et al., 2017; Halson, 2014; Soligard et al., 2016; Wallace et al., 2014).

2.1.1 Internal Load

Internal load is the physiological and psychological stress experienced by an athlete in response to external loads (Impellizzeri et al., 2005, 2019; Halson, 2014; McLaren et al., 2018; Soligard et al., 2016). Unlike external load, internal load can be measured either objectively or subjectively, with each domain being of considerable importance. Objective measures quantify physiological responses and markers in relation to exercise, and include HR monitoring; oxygen uptake; blood lactate; and the monitoring of various biochemical, hormonal, hematological, and immunological markers (Halson, 2014). Subjective measures are generally self-reported, and therefore include ratings of perceived exertion (e.g., sRPE), psychological inventories, and questionnaires that assess perceived physical and psychological stress, recovery, fatigue, muscle soreness, mood, sleep, and/or wellness (Saw, Main, & Gastin, 2015; Soligard et al., 2016). Subjective measures may elucidate gaps surrounding the mental/emotional aspects of psychobiological stress as well as the individuality of internal responses that objective measures may overlook, and may thereby provide a more sensitive means to detect fluctuations in internal load (Saw et al., 2015). Both objective and subjective measures should be implemented as feasible, in addition to that which allows for consistency across the season, to allow for a comprehensive and meaningful assessment of internal load (Bourdon et al., 2017; Halson, 2014; Saw et al., 2015). Two of the most common measures of monitoring internal load are discussed below.

2.1.1.1 Heart Rate Monitoring

Heart rate monitoring is one of the most common methods to quantify internal load, providing a simple yet useful measure of training stress (Achten & Jeukendrup, 2003; Akenhead & Nassis, 2016; Borreson & Lambert, 2009). Primarily, it is used to monitor exercise intensity, based on the "linear relationship between HR and rate of oxygen consumption (VO_2) during steady state submaximal exercise" (Halson, 2014, p. S142; Hopkins, 1991). In this regard, it may often be used to estimate VO_{2max} and energy expenditure to elucidate the metabolic demands of the exercise (Achten

& Jeukendrup, 2003). Maximum HR (HR_{max}) is typically collected during a maximal graded treadmill test, match play, or sport-specific/intermittent field tests (with the latter two recommended for team sport; Alexandre et al., 2012), upon which percent maximum HR (% HR_{max}) may be subsequently used to monitor exercise intensity during regular sport training (Achten & Jeukendrup, 2003; Borreson & Lambert, 2009). These values may then be monitored to create and categorize intensity zones for each individual, based on the time spent in each HR zone (Impellizzeri, Rampinini, & Marcora, 2005). While useful, several researchers (Achten and Jeukendrup, 2003; Alexandre et al., 2012; Impellizzeri et al., 2005) have highlighted that such measures alone may not account for individual variation, owing to the differences in HR responses (e.g., HR_{max} and resting HR ($HR_{resting}$) values) between individuals. In this regard, the HR reserve method, which permits the consideration of HR_{max}, HR during exercise ($HR_{exercise}$; i.e. average HR during exercise), and $HR_{resting}$ values collectively, has been proposed as a more reliable measure of exercise intensity, where it may better reflect the unique HR responses between players (Borreson & Lambert, 2009; Alexandre et al., 2012; Impellizzeri et al., 2005; Karvonen & Vuorimaa, 1988).

In this manner, HR monitoring lends itself to many HR-based methods of quantifying internal training load, such as the training impulse (TRIMP) model, and its many derivatives (Halson, 2014). The TRIMP model, originally proposed by Bannister et al. (1975), combines average level of HR reserve with session duration and a weighting factor, taking into consideration $HR_{resting}$, $HR_{exercise}$, and maximum (HR_{max}), as well as the rate of blood lactate accumulation in response to increasing exercise intensity (Bannister, Green, McDougal, & Wenger, 1991; Borresen & Lambert, 2009; Stagno Thatcher, & Van Someren, 2007). By quantifying the impulse-response as a single "unit dose" (Borresen & Lambert, 2009, p. 784), this method provides a convenient measure of internal training load. However, Borreson & Lambert (2009) note that its accuracy may be limited by irregular rates of lactate accumulation induced by anaerobic and/or intermittent activity demands from specific modes of training, which further alludes to an important limitation of HR monitoring for capturing the frequent discrete high-intensity activities of team sport (Achten & Jeukendrup, 2003; Alexandre et al., 2012; Fox, Scanlan, & Stanton, 2017; Impellizzeri et al., 2005). Edwards' (1993) TRIMP subsequently built on this model by categorizing time spent across five predefined HR zones (50–60%, 60–70%, 70–80%, 80–90%, and 90–100% HR_{max}, respectively) with each zone assigned a corresponding coefficient, and multiplying time spent in each zone with this coefficient to produce a single summated TRIMP score (Borresen & Lambert, 2009; Halson 2014; Fox et al., 2017). Lucia's TRIMP model (Lucia, Hoyos, Santalla, Earnest, & Chicharro, 2003) builds on elements from both Banister's and Edwards' models in that it uses three HR zones, which are established according to individualized lactate and ventilatory thresholds, thus accounting for individual responses for which Banister's and Edwards' models do not (Borresen & Lambert, 2009; Halson, 2014; Impellizzeri et al., 2005; Fox et al., 2017).

While convenient and useful, HR monitoring and subsequent TRIMP models can also be a laborious process requiring a certain degree of technical proficiency to effectively collect, combine, and analyze data (Halson, 2014; Impellizzeri, Rampinini, Coutts, Sassi, & Marcora, 2004; Impellizzeri et al., 2005; Fox et al., 2017). Resources required for collecting and establishing HR_{max} and blood lactate values through maximal incremental laboratory tests are further time-consuming and demanding for both the staff and players involved (Impellizzeri et al., 2004, 2005; Fox et al., 2017). Furthermore, it is also key to acknowledge that HR is subject to day-to-day individual fluctuations, based on both physiological and psychological factors, as well as external influences such as environment, altitude, temperature, and medications (Achten & Jeukendrup, 2003). These provide important considerations when monitoring HR within team sport, where the use of additional training load measures is recommended in conjunction (Thorpe, Atkinson, Drust, & Gregson, 2017).

2.1.1.2 Session Rating of Perceived Exertion

Foster et al. (2001) proposed the sRPE method as a means to quantify intensity over the entire duration of an exercise session using a subjective and more accessible method of measuring training load (Borresen & Lambert, 2009; Haddad, Stylianides, Djaoui, Dellal, & Chamari, 2017). Implementing a version of Borg's category-ratio (CR)-10 scale (1962) adapted by Foster et al. (2001), the individual is asked 30 min after their activity session to retrospectively rate the mean intensity of their session by answering the question "How hard was your workout?" (Haddad et al., 2017). This value is then multiplied by the duration of the session (in minutes) to derive session RPE (in arbitrary units; AU; Haddad et al., 2017; Foster et al., 2001). It is a simple, quick, and convenient method of acquiring a valid measure of training load that further lends itself the versatility to quantify many modes of training, including aerobic, technical, tactical, and conditioning, as well as competition (Alexiou & Coutts, 2008; Borg, 1982; Impellizzeri et al., 2004; Haddad et al., 2017; Ryan et al., 2020). In this regard, an entire macrocycle may be monitored using sRPE-TL, increasing the comprehensiveness, consistency, and effectiveness with which training loads may be monitored and analyzed (Haddad et al., 2017).

Session RPE is also useful in that training monotony and training strain indices can be derived to provide additional information implicated by training load, specifically the risk for overtraining (Haddad et al., 2017). Training monotony is an index that reflects day-to-day variation in training stress, or lack thereof, and is calculated using the following equation: *Training monotony = weekly (i.e., average daily) mean TL divided by the standard deviation (SD)* (Foster, 1998). Training strain is the product of training load and training monotony and is calculated as follows: *Training strain = weekly mean TL multiplied by training monotony* (Foster, 1998). Despite common belief, high training loads may not necessarily be a predisposition for increasing injury risk in and of themselves (Gabbett, 2016). Indeed, literature observes sufficiently high training loads to be necessary to continue promoting optimal adaptation (Bompa & Buzzichelli, 2019; Foster et al., 1996; Foster, 1998; Gabbett, 2016). Rather, consistently high training loads coupled with little variation across week(s) (i.e., high training strain) is when loads may exceed the individual's ability to positively cope and adapt (Bompa & Buzzichelli, 2019; Foster, 1998). As such, training monotony and strain indices provide a key role in establishing the risk of overtraining syndrome (Haddad et al., 2017).

Session RPE has been demonstrated to be a valid and reliable method of monitoring internal training load with high individual consistency (Borreson & Lambert, 2009; Foster et al., 2001; Haddad et al., 2017; Herman et al., 2006). Specifically, its use in measuring the high-intensity and intermittent activity patterns associated with team sport has shown strong support in the literature, demonstrating strong correlations with more sophisticated objective measures of training load (Borreson & Lambert, 2009; Haddad et al., 2017). In example, Impellizzeri et al. (2004) monitored male soccer players for 7 weeks (training and matches), and found significant correlations of sRPE with several HR-based models of training including, including Edward's TRIMP, Banister's TRIMP, and Lucia's TRIMP. These findings were later supported by Alexiou and Coutts (2008), who monitored women's soccer players for 16 weeks across all sessions (conditioning, resistance training, matches, speed, technical). Although the use and validity of sRPE has been particularly evidenced in soccer, there is also considerable support for sRPE in other team sports to a large degree, including rugby (Clarke, Farthing, Norris, Arnold, & Lanovaz, 2013; Lovell, Sirotic, Impellizzeri, & Coutts, 2013), Australian football (Scott, Black, Quinn, & Coutts, 2013), and basketball (Manzi et al., 2010). Interestingly, while sRPE has frequently been observed to produce results that align with those derived from objective internal load measures, many more recent studies have further examined its relationship with external load markers and found equally compelling findings (Haddad et al., 2017). Indeed, large to very large correlations have been reported with sRPE and distance covered, high-speed running, and PlayerLoad™ in soccer players (Casamichana, Castellano, Calleja-Gonzalez, San Román, & Castagna, 2013), rugby players (Lovell et al., 2013), and Australian football players (Scott et al., 2013). Thus, although typically identified as a measure of internal load, sRPE may be representative of both internal and external load and therefore encompass a singular measure of global training load (Haddad et al., 2017; Impellizzeri et al., 2004).

Indeed, sRPE offers several advantages for monitoring training load supported with abundant literature advocating for its validity and reliability. At the same time, however, it is important to acknowledge the various psychophysiological internal factors as well as contextual/external factors that may interact to influence an individual's perception of exertion during any one session (Borresen & Lambert, 2009; Haddad et al., 2017). Internal characteristics, such as mood, nutrition, sleep, hormone levels, and substrate availability, as well as environmental factors such as temperature, altitude, and music are all variable factors that can consequently affect reported sRPE between sessions (Borresen & Lambert, 2009; Haddad et al., 2017). Here, the use of sRPE in supplementation with other subjective and objective measures of internal load is recommended, and may facilitate the analysis of such discrepancies to elucidate underlying stressors (Haddad et al., 2017).

2.1.2 External Load

External load refers to the total amount of mechanical work and movement performed by the athlete during training and/or competition, independent of internal factors (Bourdon et al., 2017; Wallace, Slattery, Coutts, 2009). Unlike internal load, only objective measures are used to quantify external load. In their original framework, Impellizzeri et al. (2005) describe external load to be determined by the "quality, quantity, and organization of the training process" (p. 583), and is thus influenced by factors such as the frequency, duration, intensity, volume, and mode of training and/or competition (Impellizzeri et al., 2019; Fox, Stanton, Sargent, Wintour, & Scanlan, 2018). Measures of external load therefore include distance covered, speed, accelerations/decelerations, power output, movement volume, as well as the number of high-intensity actions or movement repetitions (e.g., sprints, jumps, throws, collisions, tackles; Bourdon et al., 2017; Soligard et al., 2016). While manual notation analysis formed the original method of performance analysis to quantify external work (Reilly & Thomas, 1976), the prevalence of this method has become largely eclipsed by motion analysis technologies (Carling, Williams, & Reilly, 2007; Carling et al., 2008). Indeed, technologies such as global positioning systems (GPS) and inertial sensors have become particularly prominent tools to capture measures of external work in real-time settings (Cummins, Orr, O'Connor, & West, 2013; Halson, 2014; Scott, Scott, & Kelly, 2016; Taylor et al., 2012; Wallace et al., 2014). Unlike previous methods of time-motion analysis, GPS and inertial sensors utilize an entirely automatic manner of motion analysis to collect and interpret performance data (Carling et al., 2008; Scott et al., 2016). In this regard, these technologies may permit the simultaneous tracking of multiple players at once to generate an instantaneous report of player movement patterns, providing an appreciably practical and time-efficient means to significantly enhance the quantification and monitoring of external load in team sports (Carling et al., 2008; Cummins et al., 2013; Scott et al., 2016). Moreover, the lightweight and portability of these devices further allows for ease of wear and use during activity monitoring, increasing convenience and compliance (Cummins et al., 2013; Fox et al., 2017).

Global positioning systems represent one of the most popular tools to track and analyze player movement patterns and demands (Chambers, Gabbett, Cole, & Beard, 2015; Halson, 2014; Taylor et al., 2012). This technology was first proposed for tracking human movement in 1997 (Schutz & Chambaz, 1997), and validated for team sport application in 2006 (Edgecomb & Norton, 2006). Since then, it has become widely adopted across clubs and sports of various levels as a part of regular athlete monitoring, particularly in the football codes and field-based team sports (Akenhead & Nassis, 2016; Aughey, 2011; Cummins et al., 2013; Taylor et al., 2012). Global positioning systems use satellite-based navigation to track movement data within an activity session or match, capturing raw movement data using either positional differentiation or Dopplershift to quantify measures of distance, velocity, and accelerations/decelerations (Cardinale & Varley, 2017; Malone, Lovell, Matthew Varley, & Coutts, 2017; Scott et al., 2016; Varley, Jaspers, Helsen, & Malone, 2017). Raw data is often further filtered and processed to categorize these activity demands into various intensity thresholds (e.g., speed zones), where the time spent (min.), distance covered (m), and number of "discrete efforts" (Cardinale & Varley, 2017; p. S2-58; Malone et al., 2017a, p. S2-21) within these thresholds may permit insight into the specific work-rate patterns and physiological demands of the activity being monitored (Carling et al., 2007; Cummins et al., 2013; Scott et al., 2016). In this regard, the use of speed-distance variables forms a particularly popular method of examining activity profiles in team sports, where total distance and high-speed running distances are among two of the most common external load measures used to describe volume and intensity, respectively (Akenhead & Nassis, 2016; Aughey, 2011; Cardinale & Varley, 2017; Carling et al., 2008; Cummins et al., 2013; Malone et al., 2017a). The information garnered by GPS may thereby impart coaches and sport scientist practitioners with important insight regarding match demands, training effectiveness, individual player capacity, positional differences, and fatigue identification to guide training prescription and decision-making within the training process (Bourdon et al., 2017; Cardinale & Varley, 2017; Carling et al., 2007; Cummins et al., 2013; Scott et al., 2016).

While GPS technology offers an innovative means for external load monitoring, the validity and reliability of GPS are of important concern in achieving an accurate representation of load, where validity and reliability have been observed to significantly differ based on various factors (Cardinale & Varley, 2017; Scott et al., 2016). For one, the number and quality of the satellites will affect the accuracy and the ability with which GPS may be used to capture movements (Scott et al., 2016). Consequently, the confined and indoor spaces of many court-based sports, such as basketball and handball, limit the effectiveness of GPS use without an indoor satellite system (Duffield, Reid, Baker, & Spratford, 2010; Fox et al., 2017). In general, the bulk of literature supports

GPS technology as being a valid measure of TD and relatively reliable at capturing movement data over long distances and low to medium speeds (Cummins et al., 2013; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010; Johnston et al., 2012; Scott et al., 2016). However, this accuracy is reduced during discrete bouts of high intensity work that incorporate high speeds, short distances, and/or momentary changes in velocity, and will further vary depending on the speed at which the unit is able to collect data (i.e., sampling frequency; Jennings et al., 2010; Scott et al., 2016; Varley, Fairweather, & Aughey, 2012). Sampling frequency provides an important factor in influencing the validity and reliability of GPS measures, with movement patterns quantified by higher sampling rates generally being of greater validity and reliability (Aughey, 2011; Cummins et al., 2013; Jennings et al., 2010; Johnston et al., 2012; Scott et al., 2016; Varley et al., 2012). With the widespread use and advancements in GPS technology, considerable efforts have been devoted to establishing validity and reliability of GPS measures with the existing 1, 5, 10, and 15 Hz frequencies (Aughey, 2011; Cummins et al., 2013; Jennings et al., 2010; Johnston et al., 2012, 2014b; Scott et al., 2016; Varley et al., 2012). In general, 1 Hz GPS units have been found to yield poor validity at distances of 20 m and below, regardless of the speed at which this distance is covered (i.e., walking, running, jogging) (Jennings et al., 2010; Scott et al., 2016). Additionally, several authors have cautioned the use of 1 and 5 Hz units in quantifying movement velocities greater than 5.5 m/s (20 km/h), where they have been observed to significantly heighten measurement error (Coutts & Duffield, 2010; Cummins, 2013; Johnston et al., 2012). In this regard, the influence of movement velocity on GPS accuracy has significant ramifications on the degree to which movements characterized by high rates of changes in direction/speed are reliably captured (Cummins et al., 2013; Jennings et al., 2010; Scott et al., 2016). This serves problematic owing to the recurrent change of direction, discrete accelerations/decelerations, short sprint bursts, and start-stop nature characteristic of intermittent field sports and such limitations should be acknowledged in the interpretation of data (Cummins et al., 2013; Scott et al., 2016; Varley et al., 2012). In comparison, higher frequency units have been demonstrated to capture momentary actions with greater sensitivity and precision, where 10 Hz units have been reported to be considerably more accurate and reliable in capturing instantaneous changes in velocity, particularly the occurrence of accelerations (Scott et al., 2016; Varley et al., 2012). Limited research has investigated the validity and reliability of the newer 15 Hz units (Aughey, 2011; Varley et al., 2012). Johnston et al. (2014b) compared the 10 Hz unit against the 15 Hz unit and reported both to produce valid and reliable measures of TD, in addition to demonstrating greater reliability than the 1 Hz and 5 Hz unit. However, the 10 Hz unit reported increased validity and inter-unit reliability compared to the 15 Hz in most movement demands quantified (Johnston et al., 2014b). Malone et al. (2017a) have noted that this may be attributed to the 15 Hz "interpolating" data as opposed to "true sampling" (p. S2-18). As such, literature currently suggests the 10 Hz units to be the most optimal choice in ensuring both validity and reliability at this time (Scott et al., 2016). Furthermore, intraunit reliability of GPS devices has been observed to be relatively good, and particularly superior compared to interunit reliability (Scott et al., 2016). In this regard, literature recommends that the same GPS unit be worn by each player across the duration of a season/monitoring period, where feasible (Scott et al., 2016). Ultimately, however, it is critical to consider the complexity through which GPS measurements may be compared, appraised, and utilized, where a myriad of GPS variables, differences in device characteristics (e.g., manufacturer, model, chipsets), and corresponding data filtering and processing methods are noted to considerably complicate such analyses (Cardinale & Varley, 2017; Cummins et al., 2013; Malone et al., 2017a; Scott et al., 2016; Varley et al., 2017).

The use of microsensors alongside GPS technology significantly augments the effectiveness of player monitoring, arguably providing the most comprehensive load quantification when paired with GPS, and have thus become increasingly common in contemporary load monitoring (Chambers et al., 2015). Microsensors can either be implemented alongside GPS technology, or used on their own, and may include accelerometers, gyroscopes, and/or magnetometers (Chambers et al., 2015). Microsensors generally use 100 Hz frequency, where they have been suggested to permit greater precision and sensitivity to address the limitations posed by lower frequency GPS units and more reliably capture discrete sport-specific movements (Boyd, Ball, & Aughey, 2011; Chambers et al., 2015; Malone et al., 2017a). Accelerometers are the most commonly employed, and use triaxial accelerometry to quantify instantaneous rate of change in acceleration in a 3D plane, summating accelerations in each plane of movement to produce an accelerometer load (Boyd et al., 2011; Chambers et al., 2015; Cummins et al., 2013). This sum is captured using a composite G-force (g) vector magnitude, and is often referred to as the acceleration-sum, or PlayerLoad™ (Boyd et al., 2011; Chambers et al., 2015; Cummins et al., 2013). Accelerometry may thus permit the quantification of the number, frequency, and intensity of accelerations/decelerations, changes in direction, as well as physical contacts, such as those between players, with the ground, and with the ball (Chambers et al., 2015; Cummins et al., 2013; Scott et al., 2016). In this regard, accelerometry may enable the summation of all forces sustained by the athlete, where "impact characteristics" (Cummins et al., 2013, p. 1026) from sport-specific movement repetitions such as kicks, jumps, throws, collisions, and tackles may be captured, thus yielding insight into the various acceleration/deceleration demands and patterns across team sport (Chambers et al., 2015). While the use of inertial sensors holds particular relevance for quantifying the discrete high-intensity actions and non-locomotor demands of intermittent team sport in comparison to GPS, many studies have highlighted similar issues of data filtering and processing methods to underrepresent many of the acceleration/deceleration movements that occur within team sport (Delaney, Cummins, Thornton, & Duthie, 2018; Delves, Aughey, Ball, & Duthie, 2021; Harper, Carling, & Kiely, 2019; Malone et al., 2017a; Varley et al., 2017). For instance, minimum effort duration is the minimum length of time a movement (i.e., sprint, acceleration) must be sustained (at a specific speed) in order to be detected and recorded as so (Delaney et al., 2018; Delves et al., 2021; Harper et al., 2019; Malone et al., 2017a; Varley et al., 2017). However, momentary changes in velocity may consequently disregard a movement from being recorded and quantified (Malone et al., 2017a; Varley et al., 2017). In a similar manner, a movement must cross a specific intensity threshold in order to be classified as a high-intensity, moderate-intensity, or low-intensity action (Delaney et al., 2018; Delves et al., 2021; Harper et al., 2019; Malone et al., 2017a; Varley et al., 2017). These thresholds are often predefined by the particular device, and may consequently vary between units, models, and manufacturers (Delaney et al., 2018; Delves et al., 2021; Harper et al., 2019; Malone et al., 2017a; Varley et al., 2017). In this regard, seemingly negligible differences in thresholds (e.g., 2.99 m/s^2 vs 3.01 m/s^2) between units may result in a substantial number of movements being missed or recorded at a lower intensity than they occur (Buchheit, Manouvrier, Cassirame, & Morin 2015; Delaney et al., 2018; Delves et al., 2021; Harper et al., 2019; Malone et al., 2017a; Varley et al., 2017). As such, this poses concerns with the reliability and sensitivity of these technologies to provide an accurate representation of many of the stochastic actions that occur within team sport (Delaney et al., 2018; Delves et al., 2021; Harper et al., 2019; Malone et al., 2017a; Varley et al., 2017). This warrants further research to address these limitations and improve the effectiveness and applicability with which inertial sensors may be used within team sport.

2.2 Training Periodization

Training periodization has been proposed to offer a framework to systematically structure, plan, and divide the annual training cycle of an athlete(s) into smaller phases and training periods (Bompa & Buzzichelli, 2019; Gamble, 2006; Issurin, 2010; Matveyev, 1964). These training periods are methodically organized and sequenced and can last anywhere from months (macrocycles), weeks (mesocycles), or days (microcycles) (Issurin, 2010). Based on Seyle's General Adaptation Syndrome theory (1956), the concept of periodization was first proposed by Russian scientist Leo Matveyev (1964), where the traditional periodization model has since paved the way for many different models and methodological refinements regarding the training process (Bompa & Buzzichelli, 2019; Bradley-Popovich, 2009; Fleck & Kraemer, 1987; Gamble, 2006; Issurin, 2010, 2008, 2016; Mujika, Halson, Burke, Balagué, & Farrow, 2018). The aim of periodization is to "purposefully" (Issurin, 2010, p. 190) and strategically structure the training plan to effectively prepare the athlete with the appropriate skill development for peak performance in competition, while concurrently minimizing the accumulation of fatigue and negative outcomes (Bompa & Buzzichelli, 2019; Gamble, 2006; Smith, 2003). Gamble (2006) notes that many of the traditional periodization models were developed with individual sport athletes in mind, who generally devote most of their annum preparing for select championships during the competitive phase. This will often include a tapering, or deloading, period typically lasting anywhere from 7 to 21 days prior to competition (Smith, 2003). However, Gamble (2006) explains that this practice is not feasible in many team sports, where the competition phase lasts for several months, and tapering across the entirety of this duration would produce significant losses in physical fitness, conditioning, LBM, and performance (Baker, 1998; Hoffman & Kang, 2003). Consequently, the majority of team sport training is carried out concurrently with competition, and therefore requires careful planning and variation to maintain fitness, optimize performance to align with competition, and attenuate the accumulation of fatigue to minimize underperformance and prevent overtraining and/or injury (Bompa & Buzzichelli, 2019; Gamble, 2006; Smith, 2003). An undulating, non-linear training approach is generally preferred over traditional linear models to provide athletes with variation and thus reduce monotony and staleness (Bradley-Popovich, 2009; Fleck & Kraemer, 1987; Foster, 1998; Gamble, 2006). Block periodization, as the name suggests, organizes training into specialized blocks (Bondarchuk, 1986; Issurin, 2008), and has also been suggested to be of value as it takes into consideration the interactions of various skills to minimize interference and maximize adaptations (Gamble, 2006; Hickinson, 1980; Issurin, 2008, 2016).

While attractive in nature, the complexity of team sports does not always result in the adoption of the exact periodization models described above. The multifaceted nature of team sport performance and corresponding array of skills demanded further heightens the need for careful and strategic planning (Bompa & Buzzichelli, 2019; Gamble, 2006; Mujika et al., 2018; Smith, 2003). Coaches need to consider physical, technical, tactical, and mental parameters of performance and strive to develop each of these areas optimally and efficiently (Bompa & Buzzichelli, 2019; Mujika et al., 2018; Smith, 2003). Indeed, owing to the complexity of team sports, researchers have recognized there to be a paucity of empirical evidence detailing specific periodization practices and training loads actively utilized in elite sport, which has been met with increased focus over the years (Anderson et al., 2016, 2017b; Aoki et al., 2017; Fleck, 1999; Jones, Smith, Macnaughton, & French, 2016; Kelly, Strudwick, Atkinson, Drust, & Gregson, 2020; Jeong, Reilly, Morton, Bae, & Drust, 2011; Malone et al., 2015; Mara, Thompson, Pumpa, & Ball, 2015; Manzi et al., 2010; Moreira et al., 2015; Nunes et al., 2014; Plisk & Stone, 2003; Ritchie, Hopkins, Buchheit, Cordy, & Bartlett, 2016; Turner, 2011). Moreover, where much of periodization research has traditionally focused on structuring training, recent recommendations have proposed a more holistic approach to adjust non-training performance factors, including nutrition, recovery, body composition, sport-specific skills, as well as psychological skills, in line with the periodized structure, demands, and objectives of the team sport training plan (Bompa & Buzzichelli, 2019; Mujika et al., 2018; Smith, 2003). In this regard, it is important to acknowledge that athletic performance is a considerably complex concept, underpinned by the interaction of numerous dynamic factors (Bourdon et al., 2017; Smith, 2003), and training thus does not fit a "one-size fits all approach" (Mujika et al., 2018, p. 546; Soligard et al., 2016, p. 1031). Here, Mujika et al. (2018) emphasize the importance of flexibility, where the diverse spectrum of required skills, sport-specific factors, individual differences, as well as contextual considerations consequently warrant the implementation and continual modification of various periodization and planning strategies to be used to organize the training process effectively (Bompa & Buzzichelli, 2019; Gamble, 2006; Issurin, 2010 Smith, 2003).

In general, the annual training plan of team sports can be separated into the preparatory (pre-season), competitive (in-season), and transition (post-season and off-season) periods (Bompa & Buzzichelli, 2019; Gamble, 2006; Issurin, 2010; Reilly, 2006). Traditionally, the off-season has been characterized as a break following the end of the competitive period, where athletes are afforded an opportunity to physically and psychologically rest (Bompa & Buzzichelli, 2019; Silva, Brito, Akenhead, & Nassis, 2016). With the culmination of competitions, sport-related training is generally discontinued in order to dissipate fatigue and facilitate physiological regeneration and rehabilitation within the body prior to the start of the next competitive cycle (Bompa & Buzzichelli, 2019). In most professional sports, the transition period may last between from 4-6 weeks; however, this may vary considerably according to sport, playing level, league, and additional sport commitments (e.g., international, university, or school-level representation; Reilly, 2006; Silva, Brito, Akenhead, & Nassis, 2016). In the absence of a structured sport-specific training regimen during this time, a considerable decline in performance and fitness is generally expected. However, as the length and severity of training reduction increases, this period may observe significant decrements in training adaptations, described as detraining (Bompa & Buzzichelli, 2019; Mujika & Padilla, 2000a, 2000b; Silva et al., 2016). Indeed, literature has observed that long term (> 4 weeks) detraining may produce reductions in aerobic fitness (Reilly & Williams, 2003; Silva et al., 2016), sprint performance (Amigo, Cadefau, Ferrer, Tarrados, & Cusso, 1998; Caldwell & Peters, 2009; Ross & Leveritt, 2001; Silva et al., 2016), anaerobic power (Ross & Leveritt, 2001; Silva et al., 2016), agility (Caldwell & Peters, 2009; Helgerud, Engen, Wisløff, & Hoff, 2001), and flexibility (Caldwell & Peters, 2009), underpinned by various metabolic, hormonal, muscular, neural, and morphological changes (Mujika & Padilla, 2000a, 2000b). The significant reduction in training load, coupled with any changes in nutrition, may also observe negative alterations in body composition, including losses in LBM and gains in FM, BF%, and/or BM, depending on the extent of detraining and change in energy expenditure (Caldwell & Peters, 2009; Mujika et al., 2018; Ostojic, 2003; Reilly, 2006; Silva et al., 2016). Such detraining effects may consequently predispose athletes to exacerbated levels of fatigue and heightened risk of overtraining and/or injury upon return to the pre-season, owing to the abrupt demand and accelerated loading placed on the body to regain fitness in a confined period of time (Caldwell & Peters, 2009; Kraemer et al., 2004; Silva et al., 2016). In consideration of the negative implications of offseason detraining, recent literature has suggested reframing this period into an opportunity to regenerate the body from the ground up in between the structured phases of the team sport cycle (Bompa & Buzzichelli, 2019; Silva et al., 2016). In addition to engaging in alternative modes of recreational activity, such as cross-training, a general physical conditioning program desgined to maintain fitness and body composition is recommended (Bompa & Buzzichelli, 2019; Gamble, 2006; Mujika & Padilla, 2000a, 2000b; Mujika et al., 2018; Reilly, 2006). While specific training characteristics have not been definitively prescribed in the literature, Silva et al. (2016) suggest these programs to be individual-specific, considering training history, fitness-fatigue status, personal preferences, and commitments influencing the nature and/or duration of the offseason, and focus on high-intensity, low-volume training inclusive of strength/power training 2-3 times per week. Ultimately, this may support an increased psychophysiological readiness to effectively adapt to the rigorous demands of the ensuing preseason (Bompa & Buzzichelli, 2019; Mujika et al., 2018; Silva et al., 2016). Overall, research examining the offseason is quite limited, and warrants further research in consideration of these implications.

As players gradually return to the sport, training is increased as the pre-season begins. The pre-season will initially focus on reversing the detraining that has occurred in the off-season, and regaining previous training state (Mujika et al., 2018; Silva et al., 2016). A battery of physical fitness, performance, and anthropometric tests and measures at the start of the pre-season allows coaching staff to establish a baseline for the upcoming season, assess the degree of deconditioning that has occurred, and prescribe and monitor training accordingly (Bompa & Buzzichelli, 2019; Reilly, 2006). Coaches strive to achieve peak physical and physiological fitness and conditioning in their players throughout this period in order to optimize performance capacity and load tolerance in time for the competitive season (Bompa & Buzzichelli, 2019). In many sports, the pre-season period can be quite extensive, with multiple phases and modes of training devoted to developing specific facets of performance (Dobbin et al., 2018; Moreira et al., 2015). When comparing this period with the in-season, Jeong et al. (2011) reported a total of 34 sub-components in pre-season, as opposed to only 18 in the in-season period. The number and specificity of such sub-components, as well as the general length of the preparatory period, will significantly depend on the demands of the sport. Studies in team sports have reported anywhere from 2 weeks to 4-5 months for the preparatory period, ranging from intense short training camps to months-long competition preparation that may consist of several periodized phases (Buchheit et al., 2013; Dobbin et al., 2018; Holway & Spriet, 2011; Reilly, 2006). Resistance training comprises a considerable component of collision-based sports such as Australian football and rugby, where this component is generally afforded less focus in soccer in favour of metabolic conditioning and an emphasis on technical and tactical training (Jones et al., 2016; Moreira et al., 2015; Ritchie et al., 2016; Wrigley et al., 2012). An all-round conditioning and fitness regimen in the preseason focuses on both aerobic and anaerobic conditioning; strength, power, flexibility, coordination, and hypertrophy-based muscle training; as well as sport-specific skill training and tactical competence (Bangsbo, Mohr, Poulsen, Perez-Gomez, & Krustrup, 2006; Bompa & Buzzichelli, 2019; Gamble, 2006). Training volume and often intensity is kept high during the early general conditioning period, with the aim of optimizing physical capacity and developing a strong base for the upcoming season (Bompa & Buzzichelli, 2019; Matveyev, 1964, 1981; Mujika et al., 2018; Reilly, 2006). Here, the strategic implementation, or lack thereof, of recovery may further promote increased adaptation (Mujika et al., 2018). High training volumes in the preparatory period correspondingly produced higher daily and weekly sRPE-TL values in basketball and soccer players in the literature, accumulating 4343 ± 329 (Borg scale · min) reported in the pre-season compared to 1703 + 173 (Borg scale · min) in the in-season (Aoki et al., 2017; Jeong et al., 2011). In addition, greater TRIMP scores and HR responses have also been observed during this period, including higher average HR, $\%HR_{max}$, and time spent at higher intensity HR zones (i.e., 80-90% and 90-100% of HR_{max}) for a session (Aoki et al., 2017; Bangsbo et al., 2006b; Jeong et al., 2011; Nunes et al., 2014). In this regard, an attenuation of internal responses has been observed after a preseason deloading phase, emphasizing the significance of training volume during the preparatory period (Bansgbo et al., 2006b; Nunes et al., 2014). Additionally, Moreira et al. (2015) observed higher training loads in the pre-season to be a product of both increased session duration and intensity of sessions across an Australian football pre-season when compared to the in-season, noting the exception of games and recovery-based training modes. Owing to the standard objectives stipulated in pre-season, the prescription of high training loads, and the synergistic effects of aerobic, anaerobic, and strength-based training, this period generally observes the gain of LBM and loss of FM across sports (Argus et al., 2010; Caldwell & Peters, 2009; Mercer, Gleeson, & Mitchell, 1997; Milanese et al., 2015; Ostojic, 2003). Optimizing the full spectrum of physical fitness and conditioning components during this period is paramount to establish the foundation from which sport-specific skill and competition performance can develop and be sustained throughout the in-season (when conditioning is not afforded focus) (Bompa & Buzzichelli, 2019; Reilly, 2006). As athletes develop fitness for the upcoming season, general preparatory work gradually transitions toward sport-specific training and preparation to improve physical conditioning under technical and tactical focus and optimize transfer unto the sport (Bompa & Buzzichelli, 2019; Mujika et al., 2018). Training volume is steadily reduced as training intensity increases to effectively prepare athletes for the high-intensity demands of the competitive period (Bompa & Buzzichelli, 2019; Matveyev et al., 1981; Mujika et al., 2018).

The competitive season constitutes the largest and central focus of the annual training plan. Regular match schedules necessitate dedicated periods of recovery and rest as well as effective match preparation (Bompa & Buzzichelli, 2019; Reilly, 2006). Training volume is significantly lower during this period and focuses on specialized, sport-specific tactical-technical and high-intensity training, while maintaining physical fitness adaptations acquired in the pre-season (Bompa & Buzzichelli, 2019; Mujika et al., 2018; Reilly, 2006). Training organization and planning tends to revolve around matches, as proposed by Reilly's ergonomics model (2005), in which the intensities and cumulative stress of competition comprise the bulk of high training loads accumulated during the in-season (Alexiou & Coutts, 2008; Anderson et al., 2016; Impellizzeri et al., 2004). However, competition schedules may not always be consistent, where the weekly microcycle is often adjusted based on match frequency, perceived match importance, as well as the resultant level of post-match stress (Anderson et al., 2016; Cross, Siegler, Marshall, & Lovell, 2019; Gamble, 2006; Martín-García, Díaz, Bradley, Morera, & Casamichana, 2018). In this regard, strategic periodization using the "match difficulty index" has been proposed to organize training and recovery according to the quality of the opponents, the time available between matches, as well as match location (as travel is noted to pose additional stress to the athlete) (Kelly & Coutts, 2007; Mujika et al., 2018; Robertson & Joyce, 2015, 2018). While such factors may vary week to week, deloads in the day(s) before and after a match constitute a consistent pattern of loading observed across the in-season in the literature (Anderson et al., 2016; Malone et al., 2015; Martín-García et al. 2018; Moreira et al., 2015; Reilly, 2006). Indeed, such a deload is imperative to reduce catabolic stress, promote regeneration, and optimize physical function and player freshness for the game. Slattery, Wallace, Bentley, & Coutts (2012) observed significant reductions in match performance, including decreased sprint ability as well as TD covered, when preceded by four days of high training loads compared to low training loads. Serum creatine kinase levels were also reported higher for the "High TL" group, and were observed to be a result of the high residual muscle damage and inflammatory processes following high loads (Slattery et al., 2012). In addition to reducing contractile function, high levels of creatine kinase and muscle damage are also observed to impede glycogen transport and resynthesis rates for up to 48h post-exercise, which constitue considerable barriers to optimizing fuel stores and substrate utilization for match performance (Slattery et al., 2012; Tee, Bosch, & Lambert, 2007). Opportunity to allow muscle damage and fatigue to effectively dissipate prior to a match is thus key for maximizing performance capacity. For similar reasons, appropriate recovery and reduced load is also crucial in the day(s) following a match, where the effects of post-match fatigue may persist for more than 72 h (Nédélec et al., 2012). As a means to facilitate recovery in the body and reduce loading, strategies such as hydrotherapy, massages, compression garments, yoga/stretching, electrical stimulation, and proprioception are often implemented (Moreira et al., 2017; Nédélec et al., 2013). During periods of frequent and congested competition load, attenuating fatigue becomes exceptionally critical, yet also complex. Limited variation in load, increased travel, poor sleep quality and duration, alterations in dietary patterns, and insufficient recovery between matches may all exacerbate the accumulation of fatigue and induce negative consequences, including underperformance, illness and/or injury, owing to exhaustion (Ekstrand, Waldén, & Hägglund, 2004; Meeusen et al., 2013; Soligard et al., 2016). Thus, the need for optimal and precise load monitoring and management serves paramount to keep players healthy, strong, and injury-free.

2.3 Body Composition

2.3.1 Body Composition in Team Sport

Body composition is a key aspect of physical fitness and conditioning with strong potential to both influence and inform an athlete's development and performance. It has been defined as "a health-related component of physical fitness that relates to the relative amounts of muscle, fat, bone, and other vital parts of the body" (Caspersen, Powell, & Christenson, 1985, p. 129). Where BM may oversimpliyfy body morphology (Nuttall, 2015, Prentice & Jebb, 2001), Prado & Heymsfield (2014) assert that body composition looks beyond BM to differentiate and consider the relative proportions of heavier, more metabolic fat-free soft tissue, and lighter adipose tissue. The precise analysis of these specific components and the manner in which they influence both performance and health may thereby provide a more well-informed basis for talent identification, selection, and athlete management (Ackland et al., 2012; Collins et al., 2021; Gabbett et al., 2011b; Morehen et al., 2015; Thomas et al., 2016; Till et al., 2010).

While technical and tactical sport-specific skills often form the central components of sport performance, achieving and maintaining an ideal body composition can provide the foundation for optimizing the development of subsequent functional and sport-specific adaptations (Bompa & Buzzichelli, 2019). Fitness adaptations from appropriate training and physical conditioning, as well as proper diet and nutrition, cultivate changes in body composition changes, such as the gain of LBM and reduction in FM, to collectively influence subsequent levels of fitness, fatigue, and injury, from both a health and performance standpoint (Bompa & Buzzichelli, 2019; Burke, Loucks & Broad, 2006; Collins et al., 2021; Hawley, Burke, Phillips, & Spriet, 2011; Thomas et al., 2016).

For the purposes of this study, LBM was defined according to previous work by Wang, Pierson, and Heymsfield (1992) and Heydenreich, Kayser, Schutz, & Melzer (2017) to encompass both lean soft tissue and bone mineral content, and thus may be used synonymously with fat-free mass (FFM). Composing the central framework of the body, the musculoskeletal system is at the essence of body movement and force production, through which LBM lays the foundation of the performance profile (Bompa & Buzzichelli, 2019; Frontera & Ochala, 2015; Reilly, 2006). Strength, power, quickness, control, and agility are all key components of team sports, and these attributes rely on an optimal level of muscle mass for effective force output and explosive power transfer during key moments of the game (Gabbett et al., 2005; Gray & Jenkins, 2010; Stølen, Chamari, Castagna, & Wisløff, 2005). High-intensity efforts such as sprinting, jumping, cutting, kicking, tackling, and physical impacts demand a significant level of force within a given period of time, requiring players to maximize both the magnitude and rate of force production during contests with the opposition (Stølen et al., 2005; Suchomel, Nimphius, & Stone, 2016). Muscle mass provides athletes with a larger force reserve to tap into, where Cormie, McGuigan, & Newton (2011) demonstrate muscle fiber size to directly correlate with the maximum force and contractile power produced by that fiber. In a review of the literature, Suchomel et al. (2016) found that contractile power has been related to both playing level and starting status (Baker, 2001; Fry & Kraemer, 1991; Hansen, Cronin, Pickering, & Douglas, 2011; Gabbett, Kelly, Ralph, & Driscoll, 2009; Young et al., 2005). In addition, improved performance in 10 and 30 m sprint speed as well vertical jump height has been consistently reported in stronger athletes (Cronin & Hansen, 2005; Wisløff, Castagna, Helgerud, Jones, & Hoff, 2004) across a range of team sports, including young elite soccer players (Comfort, Stewart, Bloom, & Clarkson, 2014), Champion League players (Helgerud, Kemi, & Hoff (2002), as well as football (McBride et al., 2009) and rugby players (Comfort, Haigh, & Mattews, 2012). By optimizing both the morphological and neuromuscular adaptations through which force production largely occurs, a competent muscular base can thereby enhance the efficiency and potential with which sport-specific skills can develop (Bompa & Buzzichelli, 2019; Cormie et al., 2011; Folland & Williams, 2007; Reilly et al., 2006; Suchomel et al., 2016). The dynamic and adaptive response of musculoskeletal tissue is of particular amenability and significance for positive training and performance adaptations (Frontera & Ochala, 2015; Hawley et al., 2011).

Other than governing movement and force, the muscles are also involved in many critical processes and form a reservoir of key nutrients. Muscle tissue is highly metabolic, with higher muscle mass correlating with increased basal metabolic rate (Zurlo, Larson, Bogardus, & Ravussin, 1990). The ability of skeletal muscle to contract further facilitates the regulation body temperature through the production and dissipation of heat (Frontera & Ochala, 2015). Skeletal muscle also provides the body's secondary, albeit largest glucose reservoir, through which it enables the regulation of blood glucose levels (Frontera & Ochala, 2015). In addition, it holds 50-75% of the body's protein supply which regulate the synthesis, repair, regeneration, maintenance, and optimal functioning of muscular tissue as well as numerous tissues, structures, and non-muscle proteins within the body, constituting a fundamental role in many critical physiological and cellular processes (Frontera & Ochala, 2015; Wolfe, 2006). Owing to the immune supporting function of many of these proteins, the loss of LBM can thereby be implicated in increased susceptibility for illness, infection, and injury (Wolfe, 2006). Thus, the maintenance of optimal levels of LBM can be a key yet sometimes overlooked indicator for health.

In addition to its effect on health and performance, a strengthened coordinated musculoskeletal foundation is a key component in reducing the incidence, severity, and recovery rate of injury among athletes (Bennell, Matheson, Meeuwisse, & Brukner, 1999; Croisier, Ganteaume, & Ferret, 2005; Lehance, Binet, Bury, & Croisier, 2009; Suchomel et al., 2016). High levels of eccentric activity and impact forces within the sport are inevitable, such as abrupt changes in direction and speed as well as physical contact with opposing players, which collectively place considerable stress on the body, particularly on the joints and involved musculoskeletal and connective tissue (Clarkson & Hubal, 2002; McBurnie, Harper, Jones, & Dos Santos, 2022; Vanrenterghem et al., 2017; Young, Hepner, & Robbins, 2012). Vanrenterghem et al. (2017) and McBurnie et al. (2022) explain how muscles, along with tendons, ligaments, and cartilage, play a key role in the effective absorption ("braking") and production ("propulsion") of these forces and may thus help to impart a vital protective factor to the athlete (Harper et al., 2019; Harper & Kiely, 2018), further supporting and stabilizing joints in proper alignment (Fleck & Falkel, 1986). In this regard, a balanced strength profile, efficient neural coordination, and sufficient mass distribution may enhance musculoskeletal resiliency and functional integrity to better withstand the mechanical impact imparted by the sport, effectively dissipate external forces, and reduce the magnitude of damage inflicted by these forces (Bennell et al., 1999; Fleck & Falkel, 1986; Harper et al., 2019; Harper & Kiely, 2018; McBurnie et al., 2022). This constitution may allow the athlete to effectively transpose this mechanical loading during forceful contractions to create powerful movements as well as further stimulate positive tissue remodelling in turn (Chilibeck, Sale, & Webber, 1995; Goodman, Hornberger, & Robling, 2015; McBurnie et al., 2020; Vanrenterghem et al., 2017). However, excessive loads in the absence of adequate LBM integrity predisposes the athlete to ineffectively absorb and dissipate such mechanical stress, leading to increased risk of injury (Croisier et al., 2005; Harper et al., 2019; Lehance et al., 2009; McBurnie et al., 2022; Vanrenterghem et al., 2017). Unfortunately, while leaner athletes have been observed to demonstrate reduced susceptibility to injury (Lee et al., 1997), Vanrenterghem et al. (2017) highlight that the precise mechanisms by which musculoskeletal tissue adapts biomechanically requires greater consideration.

In contrast, excess adipose tissue largely serves as a detriment to both performance and health, acting as deadweight by increasing BM through non-productive tissue and impeding both aerobic and anaerobic fitness (Meir et al., 2001; Reilly, 2006). While team sport athletes generally carry greater FM than most endurance athletes (Oliveira et al., 2017), it is that in excess to one's respective sport that has widely been observed to hinder multiple aspects of team sport performance. Higher adiposity has been observed to negatively affect performance metrics, such as vertical jump height ($r=-0.55$), 30 m sprint time ($r= 0.417$), 505 agility time ($r = 0.391$), aerobic capacity ($r=-0.65$), and even playing time (Gabbett et al., 2011b; Johnston et al., 2014a; Silvestre et al., 2006; Till et al., 2010). Meir et al. (2001) highlight that power production is affected through a reduced power: weight ratio, thereby decreasing capacity for high-intensity performance and acceleration ability (Gabbett, 2005). In sports that emphasize speed, performance is significantly compromised with excess FM as the individual must overcome a greater initial inertia as well as propel this increased mass though space (Meir et al., 2001). Owing to the greater physiological strain placed on the working muscles as a consequence, Meir et al. (2001) also note excess FM to increase the metabolic cost of exercise, leading to a reduced work rate and fatiguing the individual quicker than their leaner counterparts (Reilly, 2006). In addition to lowering aerobic capacity, this can also increase recovery time needed owing to poor metabolic efficiency and adaptive responses (Norton & Olds, 1996). This excess energy is subsequently ineffectively dissipated due to the poor thermal conductivity of adipose tissue, and further exacerbated with a reduced body surface area: BM ratio, interfering with thermoregulation in the already exerted athlete (Meir et al., 2001; Norton & Olds, 1996).

The optimal levels of LBM, FM, and the ratio of these tissue components to overall BM and corresponding power: mass ratios will be specific to the activity profile and demands of the sport. Many team sports are characterized by an intermittent activity profile with recurring high-intensity actions interspersed with repeated bouts of running and lower-intensity activity (Gray & Jenkins, 2010; Gabbett, 2005; Johnston et al., 2014a, 2018; Stojanović et al., 2018; Stølen et al., 2005). Sports such as soccer, basketball, rugby, and Australian football require high levels of both aerobic and anaerobic fitness, owing to the intertwined components of endurance, speed, power, and agility involved (Gray & Jenkins, 2010; Gabbett, 2005; Johnston et al., 2014a, 2018; Stojanović et al., 2018; Stølen et al., 2005). The multifaceted nature of these sports will thereby demand a specific body morphology and ideal composition for each sport.

2.3.1.1 Sport-Specific Activity Demands

Soccer is widely recognized for the high degree of aerobic capacity it stipulates, with players regularly covering around 10-12 km over the duration of the game (Stølen et al., 2005). While a large portion of this distance is spent at lower speeds, players also require speed and strong anaerobic fitness, with sprinting constituting 1-11% of the TD covered, a high-intensity running bout occurring every 70 seconds, and average intensity often reaching the anerobic threshold at 80-90% HR_{max} (Stølen et al., 2005). In efforts to maintain intensity, govern energy provision, and minimize the accumulation of fatigue over the course of the two 45-minute halves, utilizing an effective pacing strategy is often a crucial element to the game (Varley, Gabbett, & Aughey, 2014). Basketball, in comparison, is often observed as a more anaerobic-dominated intermittent sport owing to the start-stop nature of the game, requiring considerably greater agility to swiftly move between offensive and defensive plays in a much more confined court space that is characterized by a change in movement patterns every 1-3 seconds (McInnes, Carlson, Jones, & McKenna, 1995; Stojanović et al., 2018). However, basketball players also need to possess a strong level of endurance, running more than 5-6 km during the course of a 40-minute game (McInnes et al., 1995; Stojanović et al., 2018). Indeed, a higher level of aerobic fitness has been observed to further facilitate quicker recovery between anaerobic bouts to maintain high-intensity performance, where pacing may similarly constitute key tactical component of the game (Castagna et al., 2008; Köklü, Alemdaroğlu, Koçak, Erol, & Findikoğlu, 2011; Tomlin & Wenger, 2001). In both soccer and basketball, preserving a fine balance between LBM and BM to maintain a high power: weight ratio has been noted to be particularly key in optimizing performance (Hoff & Helgerud, 2004; Oliveira et al., 2017). However, in basketball, height and a lean long-limbed profile further form particularly valuable assets, from which many of the decisive high-intensity movements, such as shooting, blocking, and capitalizing on rebounds benefit (Ostojic et al., 2006). In contrast to soccer and basketball, there are also team sports which emphasize BM and size to a greater degree. Rugby is an intermittent collision-based sport and requires players to be heavier than in most team sports, where players must possess a considerable level of both mass and strength to effectively tackle, scrum, and endure intense physical impacts (Gabbett et al., 2011a, 2011c; Johnston et al., 2014a). At the same time, players must possess speed, reactive agility, and proficient acceleration ability to evade tackles and maintain possession of the ball (Johnston et al., 2014a). However, owing to the start-stop style of play and the backward passing of the ball, players are often confined to smaller field space in completing these movements, with roughly only a third of these accelerations crossing the high-velocity threshold, and a TD of 6.3 km covered during a game (Varley et al., 2014). Specific body composition profiles will further vary between rugby union and rugby league, as well as between forwards and backs, owing to considerable differences in activity demands. These differences will be discussed later in this section. Australian rules football, or Australian football, is a collision-based, albeit highly fast-paced team sport and combines many elements of the various football codes, while imparting an entirely unique nature. Australian footballers complete a number of repeated high-intensity actions, such as running, handballing, kicking, tackling, and marking (Johnston et al., 2018). Sustaining 32% and 42% fewer heavy and total collisions per minute, respectively, compared to rugby, and an average 11-12 km distance covered during a game, it may be considered more or less demanding than rugby or soccer (Varley et al., 2014). However, in comparison, Bilsborough et al. (2015) highlight that distance and collisions in Australian football are completed at significantly greater speeds, with over a third of both activities occurring at high-intensities (Coutts et al., 2015; Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Gastin, McLean, Spittle, Breed, 2013). Owing to the unlimited number of substitutions permitted within a game, players are enabled more frequent opportunities for recovery, at an average rotation of 13.5 min (Aughey et al., 2010; Varley et al., 2014). As a result, the reduced need for pacing allows these players to maintain a greater level of high-intensity work and a TD of 10-18 km over the course of a game (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004; Varley et al., 2014). With these dynamic demands, Australian footballers are considerably lighter and leaner than rugby or American football players but often heavier than soccer or basketball players, and thus require a rather intermediate body composition profile to effectively balance the specific combination of speed, strength, power, endurance, and agility components necessitated in the sport (Bilsborough et al., 2015).

2.3.1.2 Positional Role

In addition to sport-specific factors, body composition may also demonstrate within-sport differences based on the specific activity profiles and physiological demands across distinct positional roles, where players of certain body morphology may further be better suited for particular positions. In soccer, the largest body composition differences within a team and corresponding playing position are generally observed between goalkeepers and outfield players, with goalkeepers being significantly taller and heavier than forwards and midfielders at 1.9 ± 0.03 m and 91.2 ± 4.6 kg, respectively (Milsom et al., 2015; Sutton et al., 2009). In this regard, they tend to carry more FM and less muscle and bone mass than outfield players at a BF% of 12.9 ± 2.0 (Arnason et al., 2004; Matković et al., 2003; Sutton et al., 2009). Body composition differences between outfield positions have been reported to be relatively small within the literature, demonstrating non-significant differences in LBM, body fat, and bone mineral density among forwards, midfielders, and defenders (Arnason et al., 2004; Matković et al., 2003; Milsom et al., 2015; Sutton et al., 2009). In English Premier League players, BF% values of 9.7-10.6% have consistently been observed across these outfield positions (Milsom et al., 2015; Sutton et al., 2009). On average, midfielders tend to be both the lightest and shortest on the team at 1.78 ± 0.05 m and 78.0 ± 5.8 kg, respectively, with significant differences reported in comparison to defenders (Sutton et al., 2009).

Limited research has investigated positional differences in anthropometric and body composition variables in Australian football. In general, players can similarly be grouped into these three general positions; however, unlike soccer, there exists a greater level of variation between the 11 players as well as within the respective forward, midfield, and defender groupings (Pyne, Gardner, Sheehan, & Hopkins, 2006). As such, anthropometric profiles are more often grouped according to specific size tendencies of players (Pyne et al., 2006). Ruckmen, tall forwards, tall defenders tend to be the tallest and heaviest on the team (all exceeding the team average for height

(187.0 ± 6.6 cm) and BM (81.0 ± 7.6 kg)), followed by medium forwards, medium defenders, and medium midfielders, with small midfielders consistently observed to be the shortest and lightest in line with their roving role on the team (Pyne et al., 2006). Moderate to large differences have been reported in both height and weight between small and medium size players (Height: *d*= 1.41–1.61; Mass: *d*= 0.77–0.94) and between medium and tall players (Height: *d*= 1.58–1.81; Mass: *d*= 0.83–1.10), with ruckmen demonstrating further large differences in height than even the tall sized players (*d*= 1.33–1.34) (Pyne et al., 2006). However, with specific activity demands being governed by positional role, body composition has been observed to fall in accordance with forward, defender, and midfielder classifications. Midfielders report a significantly lower sum of skinfolds than forwards and have been observed to possess greater levels of endurance, speed, and agility, whereas forwards have reported a greater running jump height albeit poorer aerobic fitness (Pyne et al., 2006; Young et al., 2005). With midfielders reporting a greater number of high-intensity efforts and covering greatest TD in the game, lower subcutaneous fat values have been suggested to optimize such fitness profiles described (Dawson et al., 2004; Young et al., 2005). As positional demands significantly vary between each of the tall and medium sized players (Dawson et al., 2004), further research is warranted to explore the corresponding body composition profiles between ruckmen, forwards, and defenders.

In basketball, consistent trends have been observed across the literature with respect to height and weight, in particular, with significant differences reported between guards and centres (Bradic, Bradic, Pasalic, Markovic, 2009; Nikolaidis, Calleja-Gonzalez, & Padulo, 2014; Ostojic et al., 2006; Sallet, Perrier, Ferret, Vitelli, & Baverel, 2005). Height and weight ranges from 180.3-220.5 cm and 75.6-121.2 kg, respectively, with guards on the lower end, centres on the taller and heavier end, and forwards possessing more intermediate profiles averaging at 200.2 ± 3.4 cm and 95.7 ± 7.1 kg (Ostojic et al., 2006). In addition, height and weight both demonstrate very large correlations with BF% ($r= 0.85$, $p < 0.01$ and $r = 0.92$, $p < 0.01$, respectively) (Ostojic et al., 2006), with similar significant differences between centres and guards (Bradic et al., 2009; Ostojic et al., 2006; Sallet et al., 2005). Guards require effective ball-handling and tactical awareness to strategically set up attacks and capitalize on mid-range and 3-point shots, and therefore tend be lighter and quicker to cover greater distance at higher speeds, while centres require considerably more size and strength to maintain possession and pressure near the basket, capitalizing on offensive and defensive rebounds (Abdelkrim, El Fazaa, & El Ati, 2007; Hůlka, Cuberek, & Bělka, 2013; McInnes et al., 1995; Ostojic et al., 2006; Scanlan, Dascombe, & Reaburn, 2011; Scanlan, Dascombe, Kidcaff, Peucker, & Dalbo, 2015). Owing to these specific positional demands, body composition has also been observed to have strong relationships with physical fitness, with taller and heavier players reporting lower aerobic fitness and vertical jump height (Boone & Bourgois, 2013; Koklu et al., 2011; Ostojic et al., 2006; Sallet et al., 2005; Tsitskaris, Theoharopoulos, & Garefis, 2003).

In rugby, playing position as well as rugby code principally dictate body composition profiles, with characteristics demonstrating a generic divide between forwards and backs, owing to their distinct roles and corresponding physiological demands and activity profile. Forwards require greater BM at over 95 kg in rugby league and over 105 kg observed in rugby union, compared to backs, due to the intense physical nature and effective scrummaging and tackling ability demanded by their positions as a means to acquire possession and field space (Morehen et al., 2015). Backs, in comparison, are roughly 10 kg smaller and quicker in both union and league, possessing a great deal of speed, agility, and proficient kicking and ball-handling skills to run and kick long distances across the field with the ball (Morehen et al., 2015). However, this difference is much more pronounced in rugby union, owing to the frequency and intensity of scrums, rucks, mauls, and physical contact, while rugby league often observes a greater level of homogeneity between players owing to the quicker paced nature and lower physicality of the game (Duthie, Pyne, & Hooper, 2003; Johnston et al., 2014a).

2.3.1.3 Playing Level

Body composition standards among team sport athletes will also vary with age and playing level. In particular, body fat percentage has been observed to possess a negative association with playing standard across many team sports, and has further been reported as a key indicator of team success within a league, even at the highest levels (Arnason et al., 2004; Duthie et al., 2003; Kalapotharakos et al., 2006). Milsom et al. (2015) observed three tiers of professional soccer players from an English Premier League club (first team, U21, and U18) and found significant differences in body fat percentage across squads, with BF% decreasing as playing standard increased. Upon further examination, many studies revealed that these BF% differences across playing standards, which are observed in soccer, basketball, as well as Australian Football, are in fact attributable to greater levels of LBM in higher tier players, rather than lower levels of FM (Bilsborough et al., 2015; Milsom et al., 2015). In particular, there appears to be a trend in the literature reported for increased LBM and muscularity at higher playing levels across team sports. Milsom et al. (2015) highlight that this may warrant the redirection of efforts in improving body composition goals towards an increase in LBM, rather than an emphasis on losing fat, particularly in those sports that emphasize a leaner profile. In the study by Milsom et al. (2015), U21 and first team soccer players reported 4 to 6 kg greater whole-body LBM in comparison to U18 players, respectively. Recent literature has also been consistent in reporting that professional senior Australian Football League (AFL) players are significantly taller and heavier than sub-elite, rookie, and junior level players (Bilsborough et al., 2015; Robertson, Woods, & Gastin, 2014; Veale, Pearce, Buttifant, & Carlson, 2010; Woods et al., 2015). Interestingly, in both the soccer study by Milsom et al. (2015) and the Australian football study by Bilsborough et al. (2015), FM showed no significant differences across the varying levels, further emphasizing the previous point, while LBM showed a greater regional increase in both the upper and lower limbs in addition to the trunk. In a similar manner, Bilsborough et al. (2015) found that a lower BF% (7.8 ± 1.5%) in spite of a greater BM in professional senior level players was attributed to a greater total FFM when compared to elite junior and sub-elite senior groups (8.3 ± 2.7 % BF and 8.5 ± 2.8% BF, respectively). These authors further note the greater overall lower body power observed amongst the professional senior group in an accordant manner (Bilsborough et al., 2015).

Owing to the greater activity intensity observed at higher levels, it would seem logical for body composition requirements and profiles in basketball to correspondingly support these findings, however, this has not been extensively investigated in the literature. Research in high level and professional basketball players is relatively limited compared to the football codes, and thus restricts comparisons across levels. Despite representing the highest level of basketball competition in the world, there is a particular dearth of research in today's NBA players, with existing studies being significantly older (Bale, 1991; Latin, Berg, & Baechle, 1994; Hoffman, Tenenbaum, Maresh, & Kraemer, 1996; Parr, Hoover, Wilmore, Bachman, & Kerlan, 1978), whose findings do not accurately reflect today's different game and anthropometric profiles (Abdelkrim, Castagna, El Fazaa, & El Ati, 2010). Height and weight have been observed to be the most significant and consistently observed differences across levels, increasing with level (Masanovic, Popovic, & Bjelica, 2019; Scanlan et al., 2011; Torres-Unda et al., 2013). Elite Spanish junior players were reported to be significantly taller, heavier, possess longer limbs and hands, as well as a higher percentage of total muscle mass in comparison to their non-elite junior counterparts, while also tending to have lower BF% (Torres-Unda et al., 2013). These findings were later replicated in adult Serbian premier league players by Masanovic et al. (2019), whom reported significant differences between elite (1st division) and sub-elite (5th division) players in height, weight, LBM (%), BF%, and bone mineral content. However, without quantification of relative LBM (kg) and FM (kg), the degree to which elite players derive a lower BF% from increased LBM is not evident, highlighting the need for further research. Of significance in the junior group of athletes (Torres-Unda et al., 2013), point average demonstrated significant positive correlations with many anthropometric characteristics, including height, weight, arm span, leg length, and hand length ($P < 0.005$), as well as body composition, specifically positive associations with LBM (%) and negative associations with BF% ($P < 0.05$), suggesting key anthropometric and morphological influences on performance in younger players.

In line with the literature observed in these sports, rugby follows a similar trend, where the frequency and intensity of collisions warrant BM as a substantial asset for performance, with the composition of this mass setting apart selected elite level players from non-selected, sub-elite, or junior players in the game (Gabbett, 2000; Gabbett et al., 2009, 2011a, 2011c). Meir et al. (2001) observe that it is often believed in many collision sports that FM may help to exert a certain protective factor and increased resistance of the player against tackles and physical impacts, possibly owing to the greater inertia provided by a greater BM, as well as an improved absorption of impact. However, in contradiction, Gabbett et al. (2011a) observed skinfold thickness and adiposity to in fact negatively correlate with tackling proficiency, where this may illustrate a preference for LBM in collision-based play. Indeed, skinfold thickness is one of most significant predictors for selection in professional and elite rugby teams, with amateur players further reporting a 31% poorer BF% compared to senior professional players (Gabbett, 2000, 2002a; Gabbett et al., 2009, 2011c; Johnston et al., 2014a). Higher playing standards thus observe BM to be predominately acquired through the accrual of LBM, compared to non-productive FM (Duthie et al., 2003; Johnston et al., 2014). Thus, in conjunction with team sports requiring a lighter and leaner body composition, maintaining a high power: weight ratio is additionally key in rugby. Tracking body composition across the season therefore ensures players are acquiring mass from the appropriate LBM increase, while minimizing fat gain, in order to achieve optimal playing and selection success (Gabbett et al., 2007, 2009, 2011a, 2011b, 2011c; Johnston et al., 2014).

Many authors observe that propensity and selection for increased LBM across many of these team sports is indeed influenced by both biological and training age, but more notably a requisite of the increased intensity, strength, and power demands at the higher level, with particular emphasis on building upper body size and strength in collision-based sports such as Australian football and rugby in response to the greater physicality of the game (Bilsborough et al., 2015; Caia et al., 2013; Young et al., 2005). The development and accrual of LBM is thus valuable for high levels of performance, and should be equally distributed in order to optimize strength and power characteristics through the entire body. However, Bilsborough et al. (2015) note that while age, growth and maturation, and training history undeniably influence the potential to accrue greater levels of LBM in senior professional players in comparison to their younger, lower tier counterparts, these very factors may also enable these former individuals to more effectively tolerate greater levels of both LBM and BM. As such, in sports where both lightness and leanness is emphasized, monitoring body composition allows for appropriate attention to be given to maintaining an optimal power to LBM ratio, building and maximizing strength whilst accruing LBM progressively and where needed, so as to maintain optimal levels of performance throughout. Strength and conditioning training is often customized for these requirements accordingly, with emphasis on neuromuscular adaptations and power development and incorporating hypertrophy where needed (Bangsbo et al., 2006b; Hoff & Helgerud, 2004).

Clearly, the wide range of morphological standards across team sports lends itself to precise differences in body composition profiles. While specific body composition requirements and ideals are evidently influenced by the sport, with further specifications and variation between positions and across playing levels, it is ultimately crucial to acknowledge that even within a team, individual differences will apply (Harley et al., 2011; Sundgot-Borgen et al., 2013; Thomas et al., 2016). Body composition is a complex phenomenon, and is influenced by a myriad of factors, including but not limited to age, sex, growth and maturation, genetics, race/ethnicity, and nutrition. As a result, while players may conform to a general ideal morphological standard within a sport, Thomas et al. (2016) have emphasized that there are indeed no definitive values that must or should be acquired (Collins et al., 2021; Oliveira et al., 2017; Sundgot-Borgen et al., 2013). Rather, several researchers suggest that an optimal range of body composition values be established through individual profiles, in which an athlete is at their healthiest to optimize performance (Harley et al., 2011; Oliveira et al., 2017; Thomas et al., 2016. p. 547). Monitoring body composition changes within these individualized profiles and comparing intra-individual variation across the season in conjunction with variations in team training load would therefore create the most effective approach to utilizing body composition tracking as a tool in team sport (Harley et al., 2011; Thomas et al., 2016). With routine testing, coaching staff and team sport scientists can thereby monitor the physical development and adaptive response of each athlete against these optimal reference ranges, prescribing and adjusting training and nutritional programs as needed to align with individualized goals (Harley et al., 2011; Thomas et al., 2016). Suboptimal changes may reveal insight into non-training related information, such as nutrition patterns and health parameters, as well as fatigue and overtraining- related symptoms seen with lack of progression or maladaptations (Harley et al., 2011). Taken together, this information can facilitate the optimization of adaptations, performance, and recovery; improve health and wellness; and minimize risk of injury, ultimately enabling long-term career progression, success, and well-being (Harley et al., 2011; Thomas et al., 2016). Through this practice, tracking body composition provides an effective tool to further inform decisions regarding athlete management and training load monitoring, assessment and prescription.

Chapter 3: Methodology

Prior to commencing this study, a search was conducted in relevant databases (including PROSPERO) to verify that no systematic review of this subject currently existed or was in progress. This systematic review and meta-analysis protocol was registered in the PROSPERO database (CRD42022296551) and completed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and Cochrane Collaboration guidelines (Higgins et al., 2021; Moher et al., 2015; Page et al., 2020). The research questions, aims, and eligibility criteria were established a priori; however secondary aims required modification owing to the limited number of studies gathered, extensive methodological diversity, and inconsistent reporting. As a result, the relationship between prospectively outlined covariates, including sport, seasonal phase, duration of monitoring period, and monitored training load and body composition could not be quantitatively synthesized, and were instead transitioned into a more qualitative examination.

3.1 Eligibility Criteria

To address and answer the research aims and objectives, a rigorous selection criteria was defined according to the PICOS approach (Page et al., 2020; Moher et al., 2020) to seek articles that examined the effect of team sport (intervention) and associated training loads (comparators) on body composition changes (outcome) in elite/professional athletes (population). These criteria are outlined in detail below.

3.1.1 Population

Studies were only included if they involved healthy, able-bodied (i.e., nondisabled) intermittent team sport athletes playing at the elite/professional level, the criteria for which was refined based on previous work in the field (Harper et al., 2019; Hughes & Bartlett, 2002; McLaren et al., 2018; Swann, Moran, & Piggott, 2015). For the purposes of this study, team sports were defined as intermittent, invasion/territorial, land-based ball sports, and included field and court-based sports (Holway & Spriet, 2011; Hughes & Bartlett, 2002; Renard et al., 2021; Spittle, 2013; Young, Dawson, & Henry, 2015). Elite athletes were defined using criteria previously outlined by Swann et al. (2015; based on performance standard, success and experience at the highest level, as well as the competitiveness of the sport both nationally and worldwide), and included “semi-elite, competitive elite, successful elite, and world-class elite” (p. 11). Healthy able-bodied athletes were defined as those free from illness, injury, and/or physical/mental impairment/disability (McLaren et al., 2018). Studies were excluded if they examined “striking/fielding games [or] net/wall games” (Harper et al., 2019, Table 2, p. 1927; Hughes & Bartlett, 2002); “[individual or] non-team sports; racquet or bat sports; combat sports; or ice-, sand-, or water-based team sports” (McLaren et al., 2018, Table 2, p. 645). Studies with “recreational athletes, match officials, special populations (e.g., clinical, patients, [chronically ill]), athletes with a physical or mental disability, athletes considered to be injured or returning[/recovering] from injury, and non-athletic populations” (McLaren et al., 2018, Table 2, p. 645) were also excluded. No restrictions were placed on age or sex.

3.1.2 Intervention and Comparators

Included studies were required to encompass “[regular] team sport training and/or [competition]” (McLaren et al., 2018, p. 645; intervention), as well as clearly quantify and report training load (i.e., at least one measure of internal or external training load, either subjective or objective; comparators) accumulated over a minimum study-defined monitoring period of 6 weeks. This timeframe was designed to align with the minimum length of time required for muscle fiber growth (Phillips, 2000). According to previous work by McLaren et al. (2018), studies that did not adhere to “[regular] team sport training, [where] training [involved] an experimental intervention (e.g., recovery [or rehabilitation] interventions, manipulation [of] nutrition [including supplementation and/or] ergogenic aids [and/or] environment [e.g., heat, altitude, hypoxia]” (Table 2, p. 645) were excluded. Studies that solely reported training load as duration, exposure, training/match frequency, and/or type(s) of training (i.e. training modes) were also excluded, as these variables alone do not provide sufficient information regarding the demands or intensity of the activities (Fox et al., 2018; Soligard et al., 2016).

3.1.3 Outcome

Studies were required to monitor and report changes in at least one measure of body composition as one of the outcomes. Changes in the following outcome variable(s) were sought from each study where reported: BM (kg), FM (kg), LBM (kg), and BF%. Lean body mass was defined as comprising both lean soft tissue and bone mineral content, and was thus used synonymously with fat-free mass, in accordance with past consensus from Wang et al. (1992) and previous work by Heydenreich et al. (2017). Studies were excluded if body composition values were only given at one point in time (i.e. baseline values, descriptive data, or cross-sectional data). Studies were also excluded if measurements employed the use of skinfolds/calipers, as the precision and reliability of skinfolds is heavily dependent on the skill and expertise of the examiner (Aragon et al., 2017; Heydenreich et al., 2017; Hume & Marfell-Jones, 2008). Moreover, previous literature observes skinfolds to further be subject to increased error and inconsistency when body composition variables are derived through the use of regression equations, in which the selection from over 100 existing equations will significantly vary and influence results (Ackland et al., 2012; Heydenreich et al., 2017; Reilly, Wilson, & Durnin, 1995).

3.1.4 Study Type/Publication Status

Studies were required to be original peer-reviewed research. Reviews, editorials, commentaries, case studies, books, conference proceedings, and abstracts were excluded.

3.1.5 Language

Studies were restricted to those with full text available in English.

3.1.6 Other

Studies were restricted to those involving human participants.

3.2 Literature Search Strategy

A total of four electronic databases (MEDLINE (via Ovid), EMBASE (via Ovid), CINAHL (via EBSCOHost), SPORTDiscus (via EBSCOHost)) were systematically searched to identify relevant articles for the review from the earliest available records to the date of the search. A comprehensive and iterative search strategy was devised a priori and adapted for each database according to its controlled vocabulary (i.e., MESH terms). Search terms were determined through a scoping search and involved controlled vocabulary where possible, in addition to standardized keywords, synonyms, and truncations pertaining to team sport, training load, and body composition. Search terms within an independent concept were combined with the Boolean operator 'OR'. The search string for all three concepts were then combined using the Boolean 'AND' to form the complete search strategy. The full search strategy is available in Appendix A.

3.3 Data Management

All search records identified through the systematic search were exported and collected in RefWorks citation management software (Bethesda, Maryland, USA) and also saved as .ris files on an encrypted computer. Records were organized in folders pertaining to their respective database.

Deduplication of references was completed using a combination of Refworks, Covidence, and manual deduplication to ensure accuracy and thoroughness (Kwon, Lemieux, McTavish, & Wathen, 2015). Deduplication was completed prior to the screening process. Once duplicates were removed, the remaining references were imported into Covidence software (www.covidence.org); an online systematic review tool recommended by the Cochrane Collaboration (Higgins et al., 2021).

3.4 Selection Process

Covidence software was used to streamline the screening process. Two reviewers (JD and AP) independently screened the titles and abstracts against the selection criteria, excluding those that did not meet these criteria. Those that were considered relevant were moved forward to the full-text screening stage. Full texts of these articles were retrieved and the two reviewers independently read and thoroughly assessed the studies against the same selection criteria to determine final inclusion-exclusion status for the review. Studies excluded during screening and reason(s) for exclusion were noted. Any conflicts were resolved by consensus decision.

3.5 Data Extraction

A standard data extraction template was used based on the Cochrane Data Extraction and Assessment Form template and pilot tested with a small subset of included studies and adapted as needed for this study. Data extraction was completed by the lead author (JD) and verified by a second reviewer (AP). Study authors were contacted for any missing or additional information and/or to seek clarification as needed. The following data and details were extracted from each study where reported: study information (sport, sample size, duration, and seasonal phase(s) of monitoring period), participants' demographics (age, height, sex, playing standard), training characteristics (training mode(s), number of sessions/matches, structure and frequency of sessions/matches), training load and body composition variables monitored, methodologies and instruments employed for quantifying training load and measuring body composition, nutritional details, and study findings.

The primary outcome examined was changes in body composition. Changes in the following outcome variable(s) were sought from each study where reported: BM (kg), FM (kg), LBM (kg), BF%. If data was reported in different units (i.e. LBM % instead of kg), the data was converted to the necessary units to permit the pooling and synthesis of data (Heydenreich et al., 2017). If a study had multiple time points where body composition outcome data was collected, only the pretest and posttest outcomes were retrieved in order "to facilitate data entry" (Heydenreich et al., 2017, p. 4).

Training load was the secondary outcome and main covariate to be examined and analyzed for its relationship with body composition changes. The training load metric, internal/external dimension of the measure(s), instrument details and model specifications pertaining to the quantification of measure(s), and training load results reported in each of the included studies were extracted, where possible.

If any necessary data was missing, ambiguous, or incomplete from the included studies, the author(s) of the respective study were contacted by email to request the relevant information and/or seek clarification where needed. Data not disclosed in either the publication or in the follow up with the authors was denoted as “not reported”.

3.6 Methodological Quality Assessment

Full methodological quality assessment of the included studies was completed by the lead author (JD) and verified by a second reviewer (AP) using a modified version of Downs and Black (D&B) checklist for randomized and nonrandomized healthcare interventions (Downs & Black, 1998). As many studies in this review were observational and longitudinal in design, this tool was selected a priori as most appropriate, according to recommendations by the Cochrane Collaboration (Higgins et al., 2021). The D&B checklist is one of two most cited tools in evaluating non-randomized interventions (Higgins et al., 2021), with the second being the Newcastle-Ottawa Scale (NOS), where the D&B was selected over the latter owing to its greater inter-rater reliability (ICC = 0.73; CI = 0.47–0.88) and study-specific customization (Hootman et al., 2011). Based on previous systematic reviews (Fox, Bonacci, McLean, Spittle, & Saunders, 2014; Fox et al., 2018; Gorber, Tremblay, Moher, & Gorber, 2007; Heydenreich et al., 2017; Prince et al., 2008), the most relevant items that could be applied to all studies in the review were selected from the original 27-point checklist. This resulted in a total of 11 items in the final modified Downs & Black checklist used, established according to previous work by Fox et al. (2018) and Heydenreich et al. (2017). Higher points reflect a stronger methodological quality, with a maximum of 11 points possible. Any disagreements in critical appraisal were discussed and resolved by consensus.

3.7 Data Synthesis and Analysis

To determine the effects of intermittent team sport on body composition, a meta-analysis was performed to synthesize and examine changes in each body composition outcome (changes in BM, FM, LBM, BF%). Effect size was calculated from means and standard deviations (SD) for each outcome using standardized mean difference (SMD) alongside 95% confidence intervals (CI). To adjust for small sample sizes, Hedge's g was selected as a measure of effect size to minimize bias by using a sample size weighted SD (Hedges, 2014). Effect sizes were interpreted using the thresholds outlined by Hopkins et al. 2009: <0.2=trivial; 0.2–0.6=small; 0.6–1.2=moderate; 1.2–2.0=large; 2.0–4.0=very large; and>4.0=extremely large (Hopkins et al, 2009).

Data was uploaded and combined in RevMan where all analyses were performed (Review Manager (RevMan) [Computer program]. Version 5.4, The Cochrane Collaboration, 2020). A random effects meta-analytic model was employed as it accommodates for the heterogeneity between studies, such as differences in interventions and variability between teams (Higgins, Thompson, & Spiegelhalter, 2009). The level of between-study variability that was due to heterogeneity as opposed to random error, such as sampling error, was assessed with a chi-squared statistic (Cochran's Q; Higgins, Thompson, Deeks, & Altman, 2003). To estimate the total heterogeneity as a percentage (%), the I^2 statistic was calculated, where an $I^2 < 25\%$ was interpreted as low heterogeneity, $25 < I^2 < 75$ was moderate, and an $I^2 > 75$ was considered high heterogeneity (Higgins et al., 2003). Publication bias and small sample size bias was assessed through visual inspection of funnel plots for signs of asymmetric scatter (Hopkins et al., 2009; Egger, Smith, Schneider, & Minder, 1997), and quantitatively assessed using Egger's regression test (Egger, Davey-Smith, & Altman, 2008). Sensitivity analyses were performed to examine the degree to which effects may be dependent on a specific study, or group of studies. Metaregression and subgroup analyses were originally planned to explore specific source(s) of heterogeneity, including training load, seasonal phase, sport, and duration of monitoring period; however, this was ultimately deemed inappropriate due to the limited number of included studies, extensive methodological diversity, and inconsistent reporting across the included studies (Thompson & Higgins, 2002). Thus, pooling of training load and covariate results for quantitative synthesis examining its relationship with body composition changes was not possible, where these relationships were instead transitioned into a more qualitative examination.

Chapter 4: Results

4.1 Literature Search Results

The database search strategy yielded a total of 4594 studies across four separate databases (MEDLINE = 765; EMBASE: 1292; CINAHL = 1252; SPORTDiscus = 1285). Following the removal of duplicates (n = 1683), 2911 remained for screening. The titles and abstracts of these studies were then screened against the predefined eligibility criteria, excluding 2858 studies at this stage. The full-text articles of the remaining 53 studies were then examined thoroughly against the same criteria, which resulted in six studies that met all eligibility criteria for inclusion in the final systematic review and meta-analysis. The full details of the search are presented in Figure 4.1.

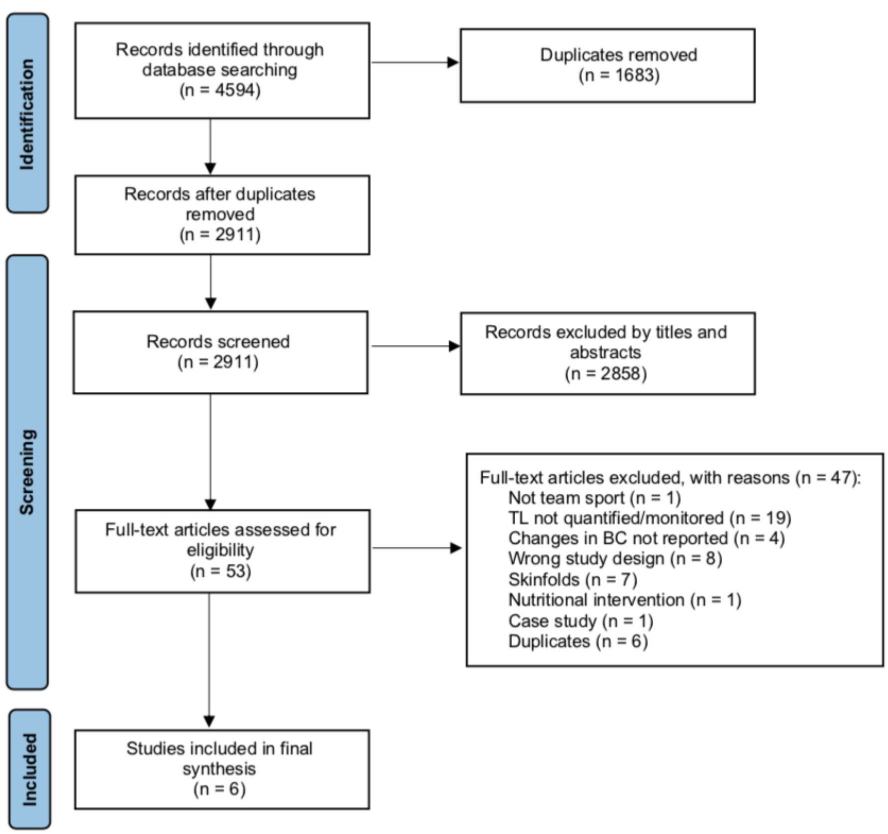


Figure 4.1 Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) flow diagram of the systematic search, identification, screening, and selection process throughout each stage of the review

TL: training load, *BC*: body composition.

4.2 Study Characteristics

The characteristics of the six included studies are presented in Table 4.1. Team sports included four of the six studies examining soccer (Clemente, Nikolaidis, Rosemann, & Knechtle, 2019; Mara et al., 2015; McEwan et al., 2020; Walker et al., 2019), one examining field hockey (Kapteijns, Caen, Lievens, Bourgois, & Boone, 2021), and one examining Australian football players (Bilsborough et al., 2016), the latter of which gave way to two independent sample groups. Bilsborough et al. (2016) reported separate findings for experienced (>4 y) and inexperienced (<4 y) AFL players, whom completed different training programs, and samples were appropriately treated as independent for the purposes of the meta-analysis, as denoted by (a) experienced and (b) inexperienced. Sample sizes of the individual studies ranged from 17-45 players, comprising a total of 150 athletes (62 female, 3 studies; 88 male, 3 studies) included in the meta-analysis. The mean age of participants ranged from 20.0 - 25.1 y, with one study not reporting age (Mara et al., 2015). The competitive level of participants was reported as professional; first league club (Bilsborough et al., 2016; McEwan et al., 2020), professional; second league club (Clemente et al, 2019a), national (Kapteijns et al., 2021; Mara et al., 2015), and collegiate; NCAA Division 1 (Walker et al., 2019).

Training load and body composition were monitored across the preseason phase (McEwan et al. 2020), both the preseason and early season phases (Clemente et al. 2019a; Kapteijns et al. 2021), as well as the full competitive season (i.e., including both preseason and the full in-season) (Bilsborough et al., 2016; Mara et al. 2015; Walker et al. 2019). Changes in BM (kg) and BF% were measured in all six studies. Lean body mass (kg) and/or FM (kg) required conversion from % to kg in three of the studies (Clemente et al., 2019a; Mara et al., 2015; Walker et al., 2019). The majority of studies utilized dual energy x-ray absorptiometry to measure body composition, with two studies using pencil-beam (Bilsborough et al., 2016; Kapteijns et al. 2021), one study using fan-beam technology (McEwan et al., 2020), and one with model details unspecified (Mara et al., 2015).

Table 4.1 Characteristics of the included studies

Study	Participants (n, Sex, Sport)	Competition Level and/or League	Age (y)	Height (cm)	Monitoring Period and Seasonal Phase(s)	Training Sessions and/or Match Monitoring	Training Details	Internal TL	External TL	TL Instrument	Body Composition Assessment Method	Nutrition
Bilsborough et al., 2016	n= 45 Male, Australian Football 2 subgroup samples: a) n =23 Experienced (>4 y experience) b) n = 22 Inexperienced (<4 y experience)	Professional, Australian Football League (Carlton Football Club)	22.8 ± 3.0	188 ± 7.0	1 competitive season; Preseason to end season	All training sessions	Modes: RT, skill-based, cross-training, recovery, injury prevention (jump and land training, water mobility, Pilates, proprioceptive training). Preseason (Weeks 1-23; 3 training phases): ~ 2 to 4 RT, 2 to 4 skill-based, and 2 or 3 cross-training sessions per week; In-season (Weeks 24-44; 2 training phases): One competitive match plus ~ 1 or 2 recovery, 2 or 3 RT, 2 or 3 skill-based, and 1 or 2 cross-training sessions each week; Full-season (52 weeks): 2-3 injury prevention each week.	Session RPE (Overall and RT; A.U.)	Summation of RT load for each exercise of each RT session (mass × repetitions × sets; kg)	Borg sRPE CR-10	DXA (Pencil beam; Lunar DPX-IQ, General Electric, Lunar Corp, USA)	Nutrient intake assessed using 24-hour recall 5 times throughout study. Nutrition education program implemented by club. Post-training meals common.

Study	Participants (n, Sex, Sport)	Competition Level and/or League	Age (y)	Height (cm)	Monitoring Period and Seasonal Phase(s)	Training Sessions and/or Match Monitoring	Training Details	Internal TL	External TL	TL Instrument	Body Composition Assessment Method	Nutrition
Clemente et al., 2019a	n=23 Male, Soccer	Professional, Second league of Portugal	24.7 ± 2.8	179.2 ± 6.3	10 weeks total; 4 weeks pre-season, 6 weeks early season	Training sessions and match play (47 sessions and 12 matches)	Players trained 4–8 times a week during the pre-season and 3–5 times a week during the early season.	NR	Duration of training sessions (min.), Total distance covered (m), Sprinting distance covered (m) at >20.0 km·h^{-1}, Acceleration sum - load (A.U.)	10 Hz GPS with accelerometer, gyroscope, and magnetometer [100 Hz, 3 axes,16 g] (JOHAN Sports®, Noordwijk, Netherlands)	BIA (SECA, mBCA 515, Hamburg, Germany)	NR
Kapteijns et al., 2021	n=20, Female, Field hockey	Elite, National, Field Hockey Pro League	23 ± 4.0	168.6 ± 5.1	Preseason to midseason (# of weeks NR)	Competitive match play (26 games)	Focus on strength (including plyometrics), speed, agility.	NR	Playing time (min.), Distance (m): Total, Zone 1: 0–0.6 km·h^{-1}, Zone 2: 0.7–6 km·h^{-1}, Zone 3: 6.1–11 km·h^{-1}, Zone 4: 11.1–15 km·h^{-1}, Zone 5: 15.1–19 km·h^{-1}, Zone 6: ≥19.1 km·h^{-1}, Number of accelerations (≥ 3 m·s^{-2}), Number of decelerations (≥ 3 m·s^{-2}), Number of sprints (≥ 19.1 km·h^{-1}; ≥1 s), Work rate	10 Hz GPS (APEX; STATSports®, County Down, Northern Ireland)	DXA (Stratos DR; DMS Imaging, Gallargues-le-Montueux, France)	NR

Study	Participants (n, Sex, Sport)	Competition Level and/or League	Age (y)	Height (cm)	Monitoring Period and Seasonal Phase(s)	Training Sessions and/or Match Monitoring	Training Details	Internal TL	External TL	TL Instrument	Body Composition Assessment Method	Nutrition
									($m \cdot min^{-1}$), High metabolic load distance (Z5 Distance + Z6 Distance + Distance of accelerations and decelerations (≥2 $m \cdot s^{-2}$) completed above 25.5 $W \cdot kg{-1}$)			
Mara et al., 2015	n=17, Female, Soccer	Elite, National	NR	172.9 ± 5.5	1 national-league season; Preseason to end season (18 weeks)	Training sessions (90 sessions)	Season divided into 3 training phases: preseason, early season, late season (6 weeks each). Skill, conditioning, tactical, recovery training. Matches (not monitored): 5 friendlies during the preseason phase and 11 matches (10 round games and a semi-final game) in the competitive season. Typical weekly in-season training structure: 1 game followed by 2 recovery days and then	Perceived fatigue and muscle soreness scores (Borg CR-10; A.U.), Number of hours of sleep (n)	Total distance (m), High speed distance (>3.4 m/s), Number of sprints (>5.4 m/s), Number of high-intensity accelerations (>2 m/s^{-2}), Number of high-intensity decelerations (< 2 m/s^{-2})	Internal TL: Player Wellbeing Questionnaire External TL: 15 Hz GPS (SPI HPU, GPSports® Systems, Canberra, Australia)	DXA (Details unspecified)	NR

Study	Participants (n, Sex, Sport)	Competition Level and/or League	Age (y)	Height (cm)	Monitoring Period and Seasonal Phase(s)	Training Sessions and/or Match Monitoring	Training Details	Internal TL	External TL	TL Instrument	Body Composition Assessment Method	Nutrition
							1 conditioning, 1 skill, and 2 tactical sessions.					
McEwan et al., 2020	n=20 Male, Soccer	Professional, La Liga (FC Barcelona)	25.1 ± 4.1	177.0 ± 6.9	Pre-season; 38 ± 10 days (~ 6 weeks)	On-field training sessions (21 ± 10* sessions) *Variation due to different player circumstances (date of return to pre-season following international competition, injury, fatigue management, etc.).	Physical, technical, tactical	Total energy cost (kJ·kg^{-1}), Energy Expenditure (kcal)	Total distance (m), High-speed running distance (m; 19.8–25.09 km·h^{-1}), Sprinting distance (m; ≥ 25.1 km·h^{-1}), Number of accelerations (>3 m/s^{-2}), Number of decelerations (<3 m/s^{-2}), Average metabolic power (W·kg^{-1})	10 Hz GPS (Viper Pod, Statsports®, Northern Ireland)	DXA (GE Healthcare Lunar, Madison, WI)	Nutritional practices informed by club's nutritional adviser and included individualised nutritional goals and guidelines. Meals and snacks provided by club.
Walker et al., 2019	n = 25 Female, Soccer	Collegiate, NCAA Division 1	20 ± 1.1	NR	1 competitive season; Preseason, regular season, and tournaments	All training sessions and match play, including tournaments (57 training sessions, 24 competitive games)	Season divided into 4-week training blocks: T1–T2 (2 weeks preseason; 2 weeks early in-season): 18 practices (6 double sessions and 2 exhibition matches) and 4 games, T2–T3 (early in-season to mid in-season): 15	Individual workload (A.U.), Time spent at percentages of HR_{max} (% HR_{max}): (55–65, 66–75, 76–85, 86–95, and 96–100), Energy expenditure (kcal), Biomarkers: Free and total cortisol, prolactin,		Polar® S610 heart rate monitor, Polar Team[2] system (Polar Electro Co., Woodbury, NY, USA)	ADP (BOD POD®; COSMED, Concord, CA, USA)	NR

Study	Participants (n, Sex, Sport)	Competition Level and/or League	Age (y)	Height (cm)	Monitoring Period and Seasonal Phase(s)	Training Sessions and/or Match Monitoring	Training Details	Internal TL	External TL	TL Instrument	Body Composition Assessment Method	Nutrition
							practices and 6 games, T3–T4 (mid in-season to late in-season):13 practices and 7 games, T4–T5 (late in-season to in postseason): 11 practices and 7 games (including the first 3 rounds of the NCAA tournament).	triiodothyronine (T3), interleukin-6, creatine kinase, sex-hormone binding globulin, omega-3, vitamin-D, iron, hematocrit, ferritin, percent saturation, and total iron-binding capacity.				

Data are presented as mean ± SD, unless denoted otherwise.

ADP: air displacement plethysmography, *AU*: arbitrary units, *BC*: body composition, *BIA*: bioelectrical impedance analysis, *BF*: body fat, *CR*: category-ratio, *DXA*: dual x-ray absorptiometry, *FM*: fat mass, *FFSTM*: fat-free soft tissue mass, *FFM*: fat-free mass, *GPS*: global positioning system, HR_{max}: maximum heart rate, *LBM*: lean body mass, *NCAA*: National Collegiate Athletic Association, *NR*: not reported, *RPE*: rating of perceived exertion, *RT*: resistance training, *SD*: standard deviation, *TL*: training load

Other methods of measuring body composition included one study utilizing air displacement plethysmography (BOD POD®; Walker et al., 2019), and one using bioelectrical impedance analysis (8-electrodes; Clemente et al., 2019a). Details of standardization for body composition measurements were provided in all but one study (Kapteijns et al., 2021).

4.3 Meta-Analysis: Changes in Body Composition

4.3.1 Body Mass (kg)

All six studies, consisting of a total of 150 participants, reported changes in BM, and showed an overall non-significant effect when summarized (SMD: -0.02 [95% CI -0.25 to 0.21], p = 0.87; Figure 4.2). Results were associated with minimal between-study heterogeneity (I^2 = 0%), with no significant effect observed in any of the individual studies (ranging from small to trivial). Visual inspection of funnel plots showed no evidence of publication bias (Figure 4.6a), further confirmed by Egger's regression test (z = 0.6453, p = 0.519).

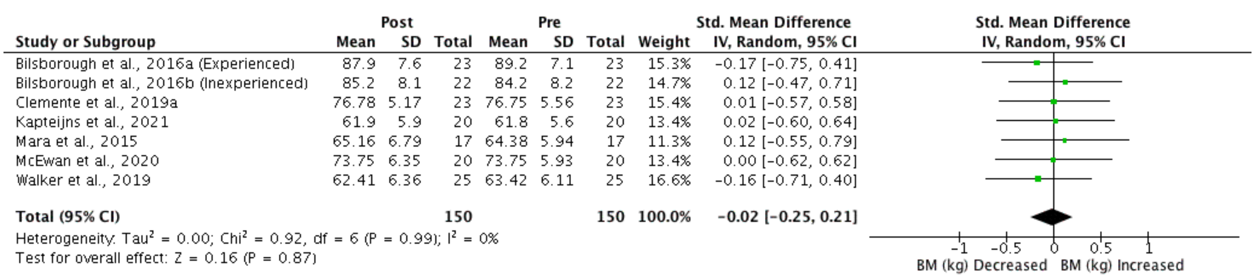


Figure 4.2 Forest plot of standardized mean difference and 95% confidence intervals in body mass (kg) between pretest and posttest

Green square: Individual study group effect. Black diamond: Overall effect.
BM: body mass.

4.3.2 Body Fat Percentage (%)

All six studies, consisting of a total of 150 participants, reported changes in BF%, and showed an overall small reduction when summarized (SMD: -0.37, 95% CI [-0.74 to -0.01], p = 0.04; Figure 4.3). Moderate heterogeneity (I^2 = 59%) was observed between studies, with individual

Study or Subgroup	Post Mean	Post SD	Post Total	Pre Mean	Pre SD	Pre Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bilsborough et al., 2016a (Experienced)	7.9	1.8	23	10.5	2.7	23	14.1%	−1.11 [−1.74, −0.49]
Bilsborough et al., 2016b (Inexperienced)	8.4	1.9	22	9.8	2.7	22	14.5%	−0.59 [−1.19, 0.02]
Clemente et al., 2019a	14.45	1.27	23	14.04	1.12	23	14.9%	0.34 [−0.25, 0.92]
Kapteijns et al., 2021	22.3	4.2	20	23.7	4.6	20	14.1%	−0.31 [−0.94, 0.31]
Mara et al., 2015	22.36	6.37	17	21.45	6.03	17	13.2%	0.14 [−0.53, 0.82]
McEwan et al., 2020	12.9	2	20	14.4	2.3	20	13.8%	−0.68 [−1.32, −0.04]
Walker et al., 2019	20.43	3.76	25	22.07	4.17	25	15.3%	−0.41 [−0.97, 0.15]
Total (95% CI)			**150**			**150**	**100.0%**	**−0.37 [−0.74, −0.01]**

Heterogeneity: $Tau^2 = 0.14$; $Chi^2 = 14.79$, $df = 6$ ($P = 0.02$); $I^2 = 59\%$
Test for overall effect: $Z = 2.01$ ($P = 0.04$)

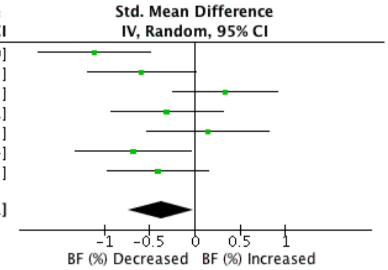


Figure 4.3 Forest plot of standardized mean difference and 95% confidence intervals in body fat percentage (%) between pretest and posttest

Green square: Individual study group effect. Black diamond: Overall effect.
BF: body fat.

study effects ranging from large reductions (Bilsborough et al., 2016a) to small increases (Clemente et al., 2019a). Four of the studies showed a negative effect, of which two were significant moderate-to-large reductions (Bilsborough et al. 2016a; McEwan et al., 2020); and two were small-to-moderate yet nonsignificant (Bilsborough et al., 2016b, Walker et al., 2019). Two of the studies showed a positive effect, both of which were nonsignificant and ranged from trivial to small (Clemente et al., 2019a, Mara et al., 2015). Visual inspection of funnel plots showed no evidence of publication bias (Figure 4.6b), further confirmed by Egger's regression test (z = −0.1178; p = 0.906).

4.3.3 Lean Body Mass (kg)

Four studies reported changes in LBM (kg), whereas two studies reported LBM as a percentage (%; Clemente et al., 2019a; Mara et al., 2015) only. Findings from Clemente et al. (2019a) and Mara et al. (2015) were correspondingly converted to kg values. All six studies, consisting of a total of 150 participants showed an overall nonsignificant effect in LBM when summarized (SMD: 0.02, 95% CI [-0.26 to 0.29], p = 0.91; Figure 4.4). Low to moderate heterogeneity (I^2 = 29%) was observed between studies, with a significant reduction observed in one of the individual studies (SMD: -0.77; 95% CI [-1.38 to -0.17]; Clemente et al., 2019a), while the

Study or Subgroup	Post Mean	Post SD	Post Total	Pre Mean	Pre SD	Pre Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bilsborough et al., 2016a (Experienced)	75.828	6.526	23	74.993	5.423	23	15.2%	0.14 [−0.44, 0.72]
Bilsborough et al., 2016b (Inexperienced)	73.284	6.476	22	71.23	6.759	22	14.6%	0.30 [−0.29, 0.90]
Clemente et al., 2019a	64.57	2.36	23	65.97	0.8596	23	14.4%	−0.77 [−1.38, −0.17]
Kapteijns et al., 2021	45.8	4.4	20	44.8	4.6	20	13.7%	0.22 [−0.40, 0.84]
Mara et al., 2015	47.45	4.25	17	47.49	3.97	17	12.2%	−0.01 [−0.68, 0.66]
McEwan et al., 2020	60.61	5.18	20	59.58	5.27	20	13.7%	0.19 [−0.43, 0.81]
Walker et al., 2019	49.63	5.33	25	49.4	5.31	25	16.1%	0.04 [−0.51, 0.60]
Total (95% CI)			**150**			**150**	**100.0%**	**0.02 [−0.26, 0.29]**

Heterogeneity: $Tau^2 = 0.04$; $Chi^2 = 8.45$, $df = 6$ ($P = 0.21$); $I^2 = 29\%$
Test for overall effect: $Z = 0.11$ ($P = 0.91$)

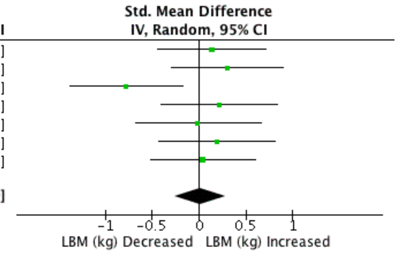


Figure 4.4 Forest plot of standardized mean difference and 95% confidence intervals in lean body mass (kg) between pretest and posttest

Green square: Individual study group effect. Black diamond: Overall effect.
LBM: lean body mass.

remaining five studies saw trivial-to-small gains (Bilsborough et al., 2016a; McEwan et al., 2020; Walker et al., 2019) and/or reductions (Mara et al., 2015). Visual inspection of funnel plots showed no evidence of publication bias (Figure 4.6c), further confirmed by Egger's regression test (−0.0069; p = 0.994).

4.3.4 Fat Mass (kg)

Three studies reported changes in body FM (kg; Bilsborough et al., 2016; Kapteijns et al., 2021; McEwan et al., 2020), whereas three studies reported changes in body fat as a percentage (%) only (Clemente et al., 2019a; Mara et al., 2015; Walker et al., 2019). Findings from Clemente et al. (2019a), Mara et al. (2015), and Walker et al. (2019) were correspondingly converted to kg values. All six studies, consisting of a total of 150 participants, showed an overall small, yet non-significant reduction in FM when summarized (SMD: -0.33, 95% CI [-0.68 to 0.02], p = 0.07; Figure 4.5). Moderate heterogeneity ($I^2 = 56\%$) was observed between studies, with SMD ranging from large reductions (Bilsborough et al., 2016a) to small increases (Clemente et al., 2019). Four of the studies showed a negative effect, ranging from small to large, however only one was statistically significant (Bilsborough et al. 2016a). Two of the studies showed a positive effect, both of which were nonsignificant and ranged from trivial to small (Clemente et al., 2019a, Mara et al., 2015).

Visual inspection of funnel plots showed no evidence of publication bias (Figure 4.6d), further confirmed by Egger's regression test (z = 0.1624; p = 0.871).

Study or Subgroup	Post Mean	Post SD	Post Total	Pre Mean	Pre SD	Pre Total	Weight	Std. Mean Difference IV, Random, 95% CI
Bilsborough et al., 2016a (Experienced)	6.918	1.689	23	9.401	2.711	23	14.1%	-1.08 [-1.70, -0.46]
Bilsborough et al., 2016b (Inexperienced)	7.234	2.187	22	8.256	2.727	22	14.6%	-0.41 [-1.00, 0.19]
Clemente et al., 2019a	11.09	0.98	23	10.78	0.8596	23	14.9%	0.33 [-0.25, 0.91]
Kapteijns et al., 2021	13.2	3	20	14	3.2	20	14.1%	-0.25 [-0.88, 0.37]
Mara et al., 2015	14.57	4.15	17	13.8	3.88	17	13.1%	0.19 [-0.49, 0.86]
McEwan et al., 2020	9.56	1.81	20	10.6	1.88	20	13.9%	-0.55 [-1.19, 0.08]
Walker et al., 2019	12.75	2.35	25	14	2.64	25	15.3%	-0.49 [-1.06, 0.07]
Total (95% CI)			**150**			**150**	**100.0%**	**-0.33 [-0.68, 0.02]**

Heterogeneity: $Tau^2 = 0.12$; $Chi^2 = 13.71$, df = 6 (P = 0.03); $I^2 = 56\%$
Test for overall effect: Z = 1.82 (P = 0.07)

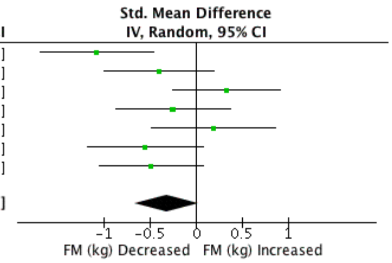
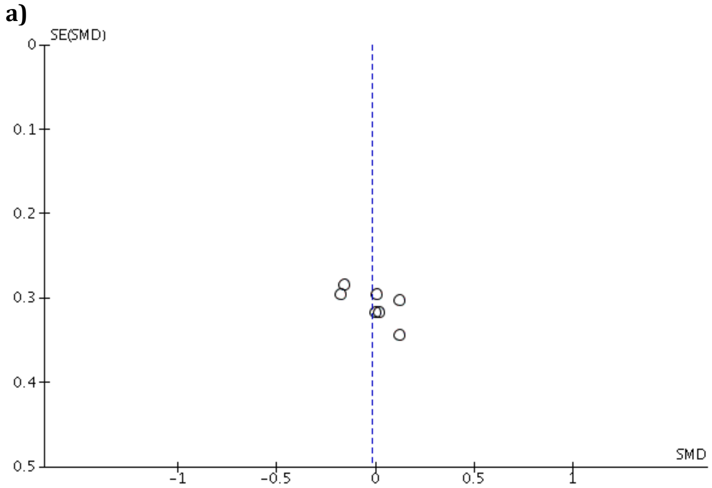


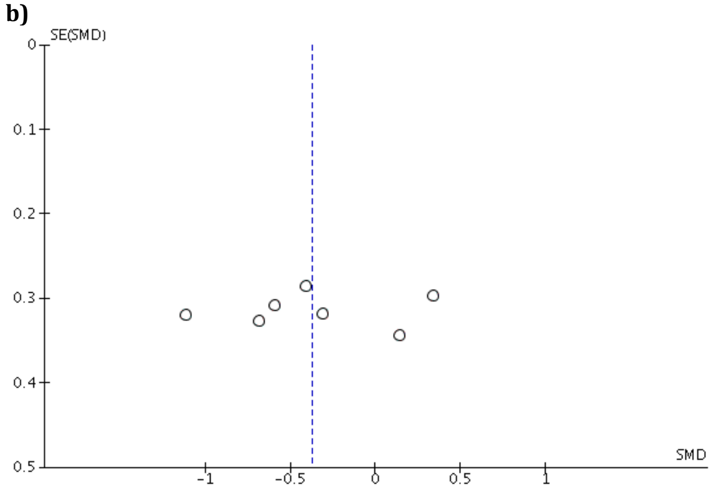
Figure 4.5 Forest plot of standardized mean difference and 95% confidence intervals in fat mass (kg) between pretest and posttest

Green square: Individual study group effect. Black diamond: Overall effect.
FM: fat mass.

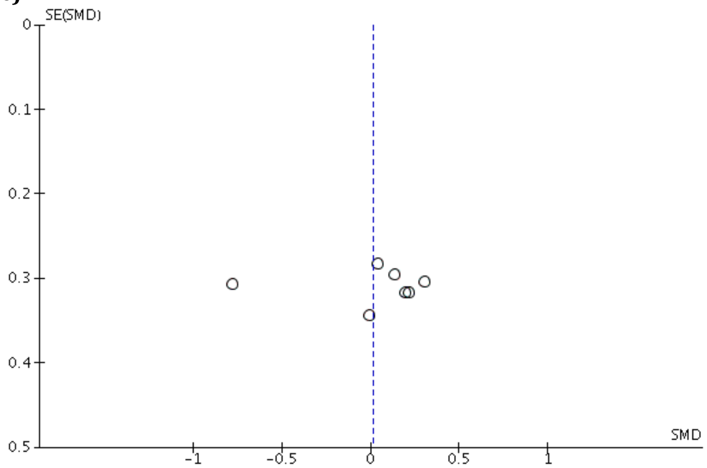
a)



b)



c)



d)

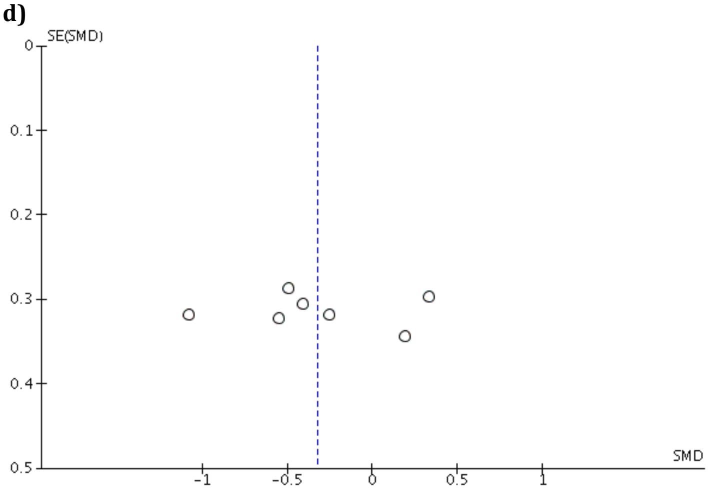


Figure 4.6 Funnel plots
a) Body mass, *b*) Body fat percentage, *c*) Lean body mass, *d*) Fat mass
SE: standard error, *SMD*: standardized mean difference.

4.4 Training Load

Training load was monitored across training and/or matches, with three studies monitoring training sessions only (Bilsborough et al., 2016; Mara et al., 2015; McEwan et al., 2020), one study monitoring matches only (Kapteijns et al. 2021), and two studies monitoring both training and matches (Clemente et al., 2019a; Walker et al., 2019). Training load was quantified using some measure of internal load (Walker et al., 2019), external load (Clemente et al., 2019a; Kapteijns et al. 2021), or both (Bilsborough et al., 2016; Mara et al., 2015; McEwan et al., 2020). Quantified training load findings from the individual studies are summarized in Table 4.2. Owing to the extensive inconsistency and methodological diversity with which training load data was collected, processed, and reported in each of the included studies, original raw study data was retained in the extraction and presentation of results, where a lack of standardization precluded the transformation of these results into more uniform measures. Measures that exhibited some degree of uniformity were further restricted from regression analysis by the limited number of studies. Prior to this decision, all authors were contacted for relevant data as a means to generate consistency across reported training load measures. Unfortunately, only one author provided such data (McEwan et al., 2020), ultimately precluding the pooling and quantitative synthesis of training load results. Training load findings and their relationships with body composition changes are outlined below.

4.4.1 Internal Load

Measures of internal load were quantified in three studies, and ranged from subjective markers, including sRPE (Bilsborough et al., 2016) and self-report questionnaires (Mara et al., 2015) to more complex objective measures, including HR-based training loads and biomarkers (Walker et al., 2019). Bilsborough et al. (2016) utilized sRPE as a tool to capture global load, and monitored total weekly load inclusive of all AFL training sessions (sRPE overall) across a season, as well as separately quantifying sRPE loads acquired through resistance training (sRPE-RT). This was the only study in this review to both report and quantify resistance training, where there was limited reporting and no monitoring of resistance training in the remaining soccer and field hockey studies. Strength and hypertrophy resistance training phases were utilized in the first two phases of preseason in the study by Bilsborough et al. (2016), where resistance training was subsequently maintained across the competitive season albeit with lower loads. The high sRPE-RT loads across

Table 4.2 Summary of findings quantifying training load in the included studies

VARIABLE	Bilsborough et al., 2016a	Bilsborough et al., 2016b	Clemente et al., 2019a	Kapteijns et al., 2021	Mara et al., 2015	McEwan et al., 2020	Walker et al., 2019
				INTERNAL LOAD			
SESSION RPE							
Weekly accumulated training sRPE (A.U.)	Start Preseason: 3374 ± 1003 Midpreseason: 3143 ± 1447 End Preseason: 2414 ± 620 Midcompetition: 2417 ± 902 End Season: 1998 ± 701	Start Preseason: 3680 ± 652 Midpreseason: 3437 ± 1566 End Preseason: 2604 ± 627 Midcompetition: 2511 ± 860 End Season: 2174 ± 742					
Weekly accumulated sRPE-RT (A.U.)	Start Preseason: 1324 ± 385 Midpreseason: 915 ± 447 End Preseason: 644 ± 300 Midcompetition: 659 ± 419 End Season: 469 ± 324	Start Preseason: 1483 ± 281 Midpreseason: 1109 ± 493 End Preseason: 740 ± 280 Midcompetition: 702 ± 359 End Season: 569 ± 328					
Weekly accumulated training RPE (1-10)	Start Preseason: 5.8 ± 0.6 Midpreseason: 5.5 ± 0.7 End Preseason: 5.7 ± 0.6 Midcompetition: 5.6 ± 0.7 End Season: 5.4 ± 0.7	Start Preseason: 5.5 ± 0.7 Midpreseason: 5.5 ± 0.7 End Preseason: 5.8 ± 0.6 Midcompetition: 5.6 ± 0.7 End Season: 5.7 ± 0.8					
PERCEPTUAL WELLNESS SCORES (EACH MORNING)							
Median Fatigue (RPE 1-10)					Preseason: 3.5 Early Season: 3.1 Late season: 3.2		
Median muscle soreness (RPE 1-10)					Preseason: 3.8 Early Season: 3.3 Late season: 3.5		
Mean sleep quantity (# hours)					Preseason: 7.8 ± 0.8 Early season: 7.8 ± 0.5 Late season: 7.7 ± 0.6		
POLAR TRAINING LOAD (A.U.)							
Accumulated TL per phase							T1-T2: ~3550 T2-T3: ~2550 T3-T4: ~ 1950 T4-T5: ~1750
Range of daily TL per phase							T1-T2: ~35-365 T2-T3: ~70-210 T3-T4: ~50-215 T4-T5: ~60-190 T5-End: ~75-310

VARIABLE	Bilsborough et al., 2016a	Bilsborough et al., 2016b	Clemente et al., 2019a	Kapteijns et al., 2021	Mara et al., 2015	McEwan et al., 2020	Walker et al., 2019
BIOMARKERS (end of each phase)							
Total cortisol (nmol/L)							T1: 637.00 ± 276.50 T2: 683.92 ± 322.09 T3: 826.62 ± 275.17 T4: 727.81 ± 281.52 T5: 1,108.69 ± 757.89
Free cortisol (nmol/L)							T1: 19.87 ± 6.90 T2: 19.59 ± 10.76 T3: 34.22 ± 12.42 T4: 27.32 ± 9.66 T5: 36.71 ± 11.86
Sex-hormone binding globulin (nmol/L)							T1: 89.40 ± 56.07 T2: 89.96 ± 60.27 T3: 85.96 ± 52.03 T4: 88.88 ± 60.61 T5: 87.00 ± 63.85
Prolactin (ug/L)							T1: 13.58 ± 6.11 T2: 11.24 ± 5.48 T3: 20.18 ± 10.77 T4: 17.64 ± 8.75 T5: 16.48 ± 7.43
Creatine kinase (U/L)							T1: 137.96 ± 148.28 T2: 263.84 ± 224.00 T3: 162.60 ± 133.45 T4: 130.56 ± 86.64 T5: 306.45 ± 373.60
Interleukin-6 (pg/mL)							T1: 1.18 ± 0.80 T2: 1.32 ± 0.81 T3: 1.74 ± 1.41 T4: 1.04 ± 0.38 T5: 3.16 ± 4.10
Triiodothyronine (T3; ng/dl)							T1: 1.49 ± 0.34 T2: 1.88 ± 0.41‡ T3: 1.63 ± 0.36‡ T4: 1.54 ± 0.31 T5: 1.57 ± 0.38
Omega-3 (%)							T1: 4.06 ± 3.04 T2: 2.02 ± 0.59 T3: 2.54 ± 0.47 T4: 2.06 ± 0.54 T5: 2.21 ± 0.53
Vitamin-D (ng/mL)							T1: 49.16 ± 12.23 T2: 48.56 ± 9.20 T3: 49.88 ± 12.60 T4: 44.36 ± 13.03 T5: 44.40 ± 13.52

VARIABLE	Bilsborough et al., 2016a	Bilsborough et al., 2016b	Clemente et al., 2019a	Kapteijns et al., 2021	Mara et al., 2015	McEwan et al., 2020	Walker et al., 2019
Iron (umol/L)							T1: 21.52 ± 10.59 T2: 12.40 ± 4.84 T3: 14.67 ± 8.93 T4: 15.02 ± 7.07 T5: 9.63 ± 5.06
Ferritin (ug/L)							T1: 35.64 ± 13.20 T2: 25.52 ± 11.46 T3: 23.88 ± 11.08 T4: 22.84 ± 10.86 T5: 23.48 ± 10.93
Percent saturation (%)							T1: 32.57 ± 13.33 T2: 17.70 ± 8.42 T3: 22.24 ± 13.14 T4: 22.24 ± 12.26 T5: 13.34 ± 6.70
Total iron-binding capacity (umol/L)							T1: 67.36 ± 9.56 T2: 70.34 ± 11.96 T3: 70.15 ± 12.42 T4: 71.24 ± 11.60 T5: 73.96 ± 12.64
Hematocrit (%)							T1: 43.26 ± 2.71 T2: 41.77 ± 2.51 T3: 42.14 ± 2.28 T4: 40.57 ± 3.03 T5: 40.53 ± 2.95
EXTERNAL LOAD							
DURATION (min.)							
Weekly accumulated training duration			Week 1: ~530 Week 2: ~740 Week 3: ~750 Week 4: ~650 Week 5: ~390 Week 6: ~580 Week 7: ~575 Week 8: ~460 Week 9: ~420 Week 10: ~250			Week 1: 580 ± 168 Week 2: 471 ± 202 Week 3: 609 ± 237 Week 4: 277 ± 111 Week 5: 235 ± 85 Week 6: 345 ± 119	
Mean weekly accumulated training duration per phase	Start Preseason: 437 ± 155 Midpreseason: 444 ± 207 End Preseason: 304 ± 69 Midcompetition: 277 ± 87 End Season: 234 ± 74	Start Preseason: 471 ± 129 Midpreseason: 465 ± 211 End Preseason: 316 ± 63 Midcompetition: 275 ± 86 End Season: 240 ± 85					
Mean match duration				37 ± 7			
Accumulated training + matches			5383.3 ± 158.3				

VARIABLE	Bilsborough et al., 2016a	Bilsborough et al., 2016b	Clemente et al., 2019a	Kapteijns et al., 2021	Mara et al., 2015	McEwan et al., 2020	Walker et al., 2019
TOTAL DISTANCE (m)							
Weekly accumulated training			Week 1: ~30100 Week 2: ~40800 Week 3: ~50200 Week 4: ~40600 Week 5: ~30200 Week 6: ~30900 Week 7: ~30700 Week 8: ~30400 Week 9: ~30200 Week 10: ~10900			Week 1: 29,815 ± 3094 Week 2: 26,943 ± 11,861 Week 3: 33,705 ± 12,118 Week 4: 15,632 ± 6137 Week 5: 14,152 ± 5046 Week 6: 18,912 ± 6772	
Weekly mean training session					Week 1: ~5350 Week 2: ~7350 Week 3: ~6750 Week 4: ~6650 Week 5: ~8100 Week 6: ~6500 Week 7: ~5500 Week 8: ~6100 Week 9: ~5000 Week 10: ~5150 Week 11: ~5750 Week 12: ~5600 Week 13: ~7300 Week 14: ~5000 Week 15: ~4750 Week 16: ~5100 Week 17: ~4000 Week 18: ~4100		
Mean training session per phase					Preseason: 6646 ± 111 Early Season: 5437 ± 106 Late Season: 4604 ± 110		
Mean match				5384 ± 835			
Accumulated training + matches			371215.5 ± 9652.8				
ZONE 2 Distance (m)							
Mean match Z2 distance (0.7–6 km·h−1)				1358 ± 682			
ZONE 3 Distance (m)							
Mean match Z3 distance (6.1–11 km·h−1)				1576 ± 347			

VARIABLE	Bilsborough et al., 2016a	Bilsborough et al., 2016b	Clemente et al., 2019a	Kapteijns et al., 2021	Mara et al., 2015	McEwan et al., 2020	Walker et al., 2019
ZONE 4 Distance (m)							
Mean match Z4 distance (11.1–15 km·h−1)				1402 ± 285			
HIGH-SPEED RUNNING DISTANCE (m)							
Weekly accumulated training (19.8–25.09 km·h−1)						Week 1: 1167 ± 903 Week 2: 1294 ± 1215 Week 3: 1574 ± 1277 Week 4: 732 ± 510 Week 5: 611 ± 450 Week 6: 908 ± 657	
Weekly mean training session (>3.4 m/s)					Week 1: ~ 1000 Week 2: ~1700 Week 3: ~1400 Week 4: ~1350 Week 5: ~2000 Week 6: ~1200 Week 7: ~ 1000 Week 8: ~1200 Week 9: ~950 Week 10: ~1000 Week 11: ~1050 Week 12: ~1100 Week 13: ~1400 Week 14: ~850 Week 15: ~900 Week 16: ~975 Week 17: ~800 Week 18: ~850		
Mean training session per phase (>3.4 m/s)					Preseason: 1415 ± 42 Early Season: 1027 ± 40 Late Season: 742 ± 41		
Mean match (Z5 Distance; 15.1–19 km·h−1)				796 ± 221			
SPRINTING DISTANCE (m)							
Weekly accumulated training (≥25.1 km·h−1)						Week 1: 95 ± 107 Week 2: 82 ± 73 Week 3: 97 ± 124 Week 4: 96 ± 118 Week 5: 55 ± 76 Week 6: 128 ± 98	

VARIABLE	Bilsborough et al., 2016a	Bilsborough et al., 2016b	Clemente et al., 2019a	Kapteijns et al., 2021	Mara et al., 2015	McEwan et al., 2020	Walker et al., 2019
Weekly accumulated training + matches (>20 km·h−1)			Week 1: ~250 Week 2: ~900 Week 3: ~1800 Week 4: ~1020 Week 5: ~1050 Week 6: ~990 Week 7: ~800 Week 8: ~650 Week 9: ~1200 Week 10: ~150				
Mean match (Z6 Distance; ≥19.1 km·h−1)				274 ± 105			
Accumulated training + matches (>20 km·h−1)			8882.2 ± 465.4				
WORK RATE (m/min.)							
Mean match				147.0 ± 16.0			
ACCELERATIONS (n)							
Weekly accumulated training (>3 m·s−2)						Week 1: 688 ± 344 Week 2: 799 ± 482 Week 3: 905 ± 426 Week 4: 400 ± 201 Week 5: 364 ± 151 Week 6: 460 ± 214	
Mean training session per phase (>2 m·s−2)					Preseason: 56 ± 19 Early Season: 49 ± 14 Late Season: 32 ± 18		
Mean match (>3 m·s−2)				27 ± 12			
DECELERATIONS (n)							
Weekly accumulated training (>3 m·s−2)						Week 1: 655 ± 301 Week 2: 737 ± 466 Week 3: 850 ± 428 Week 4: 372 ± 195 Week 5: 355 ± 141 Week 6: 435 ± 206	
Mean training session per phase (>2 m·s−2)					Preseason: 22 ± 10 Early Season: 20 ± 10 Late Season: 12 ± 9		
Mean match (>3 m·s−2)				40 ± 15			
ACCELERATION-SUM LOAD (A.U.)							
Accumulated training + matches			20807.7 ± 530.0				

VARIABLE	Bilsborough et al., 2016a	Bilsborough et al., 2016b	Clemente et al., 2019a	Kapteijns et al., 2021	Mara et al., 2015	McEwan et al., 2020	Walker et al., 2019
Weekly accumulated training + matches			Week 1: ~1800 Week 2: ~2600 Week 3: ~2950 Week 4: ~2500 Week 5: ~1800 Week 6: ~2200 Week 7: ~2050 Week 8: ~1750 Week 9: ~1650 Week 10: ~1000				
SPRINT COUNT (n)							
Mean training session per phase count (>5.4 m/s)					Preseason: 27 ± 15 Early Season: 24 ± 9 Late Season: 15 ± 9		
HIGH METABOLIC LOAD DISTANCE (m)							
Mean match (Z5 Distance + Z6 Distance + Distance of accelerations and decelerations (≥2 m·s−2) completed by a player above 25.5 W·kg−1 (APEX; STATSports®)				959 ± 248			
SUMMATION OF RT LOADS (kg)							
Weekly mean load per phase	Start Preseason: 8724 ± 3270 Midpreseason: 7629 ± 5133 End Preseason: 5124 ± 2694 Midcompetition: 4770 ± 3259 End Season: 4395 ± 3094	Start Preseason: 10,985 ± 3656 Midpreseason: 8810 ± 3413 End Preseason: 6247 ± 2971 Midcompetition: 5272 ± 2618 End Season: 4963 ± 2182					
			METABOLIC MARKERS				
ENERGY EXPENDITURE (kcal)							
Weekly Mean Estimate (Viper Pod, Statsports®, Northern Ireland)						Week 1: 641 ± 179 Week 2: 611 ± 148 Week 3: 650 ± 399 Week 4: 418 ± 172 Week 5: 418 ± 302 Week 6: 447 ± 129	
Accumulated per phase (Polar® Team² system; Polar Electro Co., Woodbury, NY, USA)							T1-T2: ~23000 T2-T3: ~16500 T3-T4: ~ 13000 T4-T5: ~12500
ENERGY COST (kJ/kg)							

VARIABLE	Bilsborough et al., 2016a	Bilsborough et al., 2016b	Clemente et al., 2019a	Kapteijns et al., 2021	Mara et al., 2015	McEwan et al., 2020	Walker et al., 2019
Weekly Mean Estimate (Viper Pod, Statsports®, Northern Ireland)						Week 1: 36.6 ± 10.8 Week 2: 35.4 ± 8.4 Week 3: 37.5 ± 24.0 Week 4: 24.6 ± 10.2 Week 5: 24.2 ± 16.9 Week 6: 25.2 ± 7.0	
METABOLIC POWER (W/kg)							
Weekly Mean Estimate (Viper Pod, Statsports®, Northern Ireland)						Week 1: 5.9 ± 0.2 Week 2: 5.5 ± 0.5 Week 3: 5.2 ± 0.8 Week 4: 6.1 ± 1.7 Week 5: 6.0 ± 1.3 Week 6: 5.2 ± 1.2	

Data are presented as mean ± SD, unless denoted otherwise.
~values are approximated from results represented in graph/figure form.
AU: arbitrary units, *RPE*: rating of perceived exertion, *RT*: resistance training, *TL*: training load, *Z2*: zone 2, *Z3*: zone 3, *Z4*: zone 4, *Z5*: zone 5, *Z6*: zone 6.

the full season in this study may be linked to the substantial improvements in body composition adaptations observed, with players reporting large (significant; Bilsborough et al., 2016a) and small-to moderate (non-significant; Bilsborough et al., 2016b) reductions in BF% and FM.

Self-reported measures were also monitored in the study by Mara et al. (2015) using an adapted version of the Borg CR-10 scale. However, this study collected subjective well-being scores each morning using a wellbeing questionnaire, as opposed to perception of effort quantified through post-exercise sRPE loads in the study by Bilsborough et al. (2016). In the study by Mara et al. (2015), players specifically reported on perceived levels of fatigue, muscle soreness, as well as last night's hours of sleep. Scores of fatigue, muscle soreness, and sleep hours were relatively consistent across the soccer season (Mara et al., 2015), where the steadiness in these adequate neuromuscular responses may be linked to relatively stable body composition observed, with minimal changes consisting of small non-significant gains in FM.

In contrast to the subjective nature of Borg's RPE scale utilized by these two studies (Bilsborough et al., 2016; Mara et al., 2015), Walker et al. (2019) implemented multiple objective measures to monitor internal responses in a team of NCAA Division 1 female soccer players across the college season. Individual workload (AU) was calculated through the use of a HR-based training impulse model employed by the Polar® Team^2 system (Polar Electro Co.), where all training sessions and matches were continuously monitored across the season (Walker et al., 2019). Training loads (AU) accumulated in the study by Walker et al. (2019) were very similar to those attained by the AFL players in the study by Bilsborough et al. (2016), along with comparable patterns of loading to both Mara et al. (2015) and Bilsborough et al. (2016), where training load was highest during the preseason and early season phases, before significantly tapering in the subsequent in-season phases. However, unlike the 44-week long full season consisting of a 23-week preseason in the study by Bilsborough et al. (2016), the loads accumulated by players in the study by Walker et al. (2019) spanned less than 20 weeks in total, with only two weeks of preseason. Moreover, preseason observed the regular occurrence of double sessions, where this phase was superseded by an in-season involving several weeks with multiple matches (Walker et al., 2019). While match loads and regular training day loads maintained a degree of consistency across the season in the study by Walker et al. (2019; ~150-200 AU), deloads were observed in the day(s) leading up to and following match days. In addition to the accumulated loads quantified with Polar®, Walker et al. (2019) also monitored a range of blood biomarkers through regular blood draws, including inflammatory markers (free and total cortisol, creatine kinase, interleukin-6), sex hormones (prolactin, sex-hormone binding globulin), thyroid hormones (triiodothyronine), hematological markers (iron, hematocrit, ferritin, percent saturation, total iron-binding capacity), and dietary markers (vitamin D, omega-3 FA). Across the season, general elevations were observed in inflammatory markers, prolactin (delayed), triiodothyronine, and total iron-binding capacity in addition to reductions in iron, ferritin, hematocrit, vitamin D, and omega-3 fatty acids (Walker et al., 2019). Walker reports a delayed response in many of these markers, many of which also incurred changes in the opposite direction or in a fluctuating manner. These biomarker fluctuations combined with the constraint of training loads within a shorter season may be linked to the small reduction in FM and BF% (nonsignificant) observed in the players of this study (Walker et al., 2019). This study also stated minimal resistance training that was not monitored, which may have had an additional impact on these body composition changes, including minimal changes in LBM and BM.

4.4.2 External Load

Measures of external training load were quantified with the use of GPS (10 Hz or greater) and/or accelerometer-based wearable tracking technologies in four studies of this review (Clemente et al., 2019a; Mara et al., 2015; McEwan et al., 2020; Kapteijns et al. 2021), as well as summation of resistance training loads in one study (Bilsborough et al., 2016). Of the GPS and/or accelerometer-derived external load metrics monitored, four studies quantified TD (Clemente et al., 2019a; Kapteijns et al., 2021; Mara et al., 2015; McEwan et al., 2020); four studies quantified distance covered in various speed zones (Clemente et al., 2019a; Kapteijns et al., 2021; Mara et al., 2015; McEwan et al., 2020), including three studies quantifying HSRD and/or SprD in training (Clemente et al., 2019a; Mara et al., 2015; McEwan et al., 2020); two studies quantified number of sprint counts (Kapteijns et al., 2019; Mara et al., 2015); three studies quantified the number of maximal (> 3 m/s^2; Kapteijns et al., 2021; McEwan et al., 2020) and moderate (> 2 m/s^2; Mara et al., 2015) accelerations and decelerations; one study quantified total acceleration-sum load (i.e., accelerometer-derived loads; PlayerLoad™), three studies quantified duration (Bilsborough et al., 2016; Clemente et al., 2019a; Kapteijns et al., 2021), one study quantified high metabolic load distance (Kapteijns et al., 2021), one study quantified work rate (Kapteijns et al., 2021), and one study quantified metabolic power (McEwan et al., 2020).

A qualitative synthesis of the relationship between these external training load measures and body composition changes across the included studies revealed that such adaptations appear to be linked to the intensity, volume, and overall load distribution patterns across specific movement demands in which external training load was accumulated. In particular, high volumes of SprD and/or HSRD loads in the studies of this review tended to be negatively associated with changes in body composition (i.e. greater high-intensity distance loads related to suboptimal body composition changes). Greater HSRD and/or SprD loads also tended to be accompanied by increased TD. To illustrate, McEwan et al. (2020) who reported a significant large reduction in BF% and small-to-moderate reduction in FM also reported particularly low SprD loads, while TD and HSRD in this study were higher, albeit still lower than other studies of this review (Clemente et al., 2019a; Mara et al., 2015). In contrast, both SD and TD were considerably higher in the study by Clemente et al. (2019a), who also reported very large and large negative correlations between SprD ($r=-0.71$, 90% CI [−0.95 to 0.06]) and TD ($r=-0.63$, 90% CI [−0.93 to 0.21]), respectively, with %

change in LBM. Indeed, the study by Clemente et al. (2019a) was the only study in this review who reported significant large reductions in LBM (kg) (SMD -0.77, 95% CI [-1.38 to -0.17]), or a negative LBM effect in general, in addition to small gains in FM (kg) (SMD -0.33, 95% CI [-0.25 to 0.91]). Clemente et al. (2019a) also reported sprinting loads in this study to demonstrate the greatest acute spikes and irregular weekly fluctuations (CV: 52.40%; 90% CI: [618.43 to 1158.01]) when compared to TD and acceleration-sum load.

Acceleration/deceleration metrics in this review were generally consistent across monitoring periods, with deloads observed in the latter half of preseason training periods and/or throughout the competitive season in three out of these four studies (Clemente et al., 2019a; and Mara et al., 2015; McEwan et al., 2020), while the fourth study monitored mean match load only (Kapteijns et al., 2021). When comparing the studies that quantified accelerations/decelerations in training using count-based measures (Mara et al., 2015; McEwan et al., 2020), McEwan et al. (2020) reported notably high counts of accelerations and decelerations (>3 m/s^2), even when measured at a higher threshold than that observed in the study by Mara et al. (2015) (>2 m/s^2). These loading patterns were in contrast to the running loads observed in these two studies (Mara et al., 2015; McEwan et al., 2020), where Mara et al. (2015) also reported high HSRD and TD loads in comparison to McEwan et al. (2020). When observing the markedly distinct body composition changes acquired across these three studies (Clemente et al., 2019a; Mara et al. 2020; McEwan et al., 2020), training loads that emphasized high-intensity loading through acceleration/deceleration activity compared to running volume, such as that observed in the study by McEwan et al. (2020), appear to be linked to substantially more optimal adaptations.

4.5 Methodological Quality Assessment and Risk of Bias

4.5.1 Methodological Quality Assessment

Results from the methodological quality assessment are provided in Table 4.3. Original question numbers from the checklist were retained to increase transparency. The criteria used in this study evaluated elements of reporting, external validity, and internal validity (bias) in its methodological assessment of each study (Gorber et al., 2007). Scores ranged from 7 to 10, out of a maximum possible score of 11.

4.5.2 Risk of Bias

Low to moderate heterogeneity was observed across all study outcomes. Individual funnel plots for each outcome were further visually examined to assess for publication bias (Figure 4.6), while noting the influence of study quality and heterogeneity. Inspection of funnel plots for asymmetry and small study bias were confirmed by Egger's regression test; however, it must be acknowledged that such tests may be statistically underpowered for the number of studies in this meta-analysis. As such, sensitivity analyses for each study in each outcome model were performed to further investigate any potential biases, and effect sizes employed the use of Hedge's g as a means to account for small sample size bias. No studies were excluded for either methodological quality or risk of bias.

Table 4.3 Downs & black checklist used for methodological quality assessment of the included studies

Reference	**Reporting (/6)**						**External Validity (/2)**		**Internal Validity (/3)**			**Total (/11)**
	Q1	Q2	Q3	Q6	Q7	Q10	Q11	Q12	Q16	Q18	Q20	
Bilsborough et al. 2016	1	1	1	1	1	1	U	0	1	1	1	9
Clemente et al. 2019a	0	1	1	1	1	0	U	0	1	1	1	7
Kapteijns et al. 2021	0	1	1	1	1	1	U	0	1	1	1	8
Mara et al. 2015	0	1	0	1	1	1	U	0	1	1	1	7
McEwan et al. 2020	0	1	1	1	1	1	U	0	1	1	1	8
Walker et al. 2019	1	1	1	1	1	0	U	0	1	1	1	8

1 = Yes, 0 = No, U = Unable to determine
Q: Question number (Retained from D&B original checklist to maintain transparency).

Chapter 5: Discussion

5.1 General Discussion

The aim of this systematic review was to investigate the effects of team sport on changes in body composition. A meta-analysis was performed to examine changes in BM, BF%, LBM, and FM across periods of regular team sport training and/or competition. Primary findings from the pooled studies suggest that BF% is significantly influenced by team sport, with this variable demonstrating a small reduction when summarized (SMD: -0.37, 95% CI [-0.74 to -0.01], $p = 0.04$, $I^2 = 59\%$), and mean % difference ranging from 2.92 to -24.76 across studies. This effect appears to be associated with small (non-significant) reductions in FM (SMD: -0.33, 95% CI [-0.68 to 0.02], $p = 0.07$, $I^2 = 56\%$), with no overall effect observed in LBM (SMD: 0.02, 95% CI [-0.26 to 0.29], $p = 0.91$, $I^2 = 29\%$) or BM (SMD: -0.02 [95% CI -0.25 to 0.21], $p = 0.87$, $I^2 = 0\%$). These results suggest that intermittent team sport generally sees the decline of athlete adiposity as an effect of the cumulative loads and stimuli associated with playing at the elite/ professional level, while LBM and BM tend to be maintained. These findings support this review's initial hypothesis and are also consistent with BM and FM findings reported in the literature, whereas LBM has been observed to be more variable (Caldwell & Peters, 2009; Carling & Orhant, 2010; Milanese et al., 2015; Ostojic and Zivanic, 2001).

These results may be explained by the unique physiological, metabolic, and hormonal response characterized by intermittent team sport. Previous literature observes that the frequent bouts of high-intensity actions interspersed with periods of lower-intensity work simultaneously acquire energy from both aerobic and anaerobic means, relying on the availability of several different substrates (Bangsbo, Iaia, & Krustrup, 2007; Bangsbo, Mohr, & Krustrup, 2006; Holway & Spriet, 2011; Thomas et al., 2016). In contrast to the finite stores of glycogen in the body, triglycerides located within the muscles (intramuscular triglycerides) and adipose tissue provide a considerably more abundant fuel source, with fat constituting the largest endogenous energy stores in the body (Jeukendrup, 2003). During a match/sport-specific exercise, low to moderate intensity work has been reported to particularly upregulate the oxidation of fat as a means to support the high energy demands required in elite and professional sport (Bangsbo et al., 2006a, 2007; Randell et al., 2019; van Loon et al., 2001). The increased blood flow stimulation to the muscles and adipose tissue reserves during team sport activity prompts the mobilization and release of fatty acids (FA), where the corresponding elevation in plasma free fatty acids (FFA) levels effectively permit the continuous replenishment of endogenous FA within the working muscles for metabolism (Bangsbo et al., 2006a, 2007; Krustrup et al., 2006; Purdom, Kravitz, Dokladny, & Mermier, 2018). Indeed, it has been suggested that fat oxidation may account for up to 40% of substrate utilization in sports such as soccer (Alghannam, 2012, 2013), where periods of standing, walking, jogging, and rest constitute a more substantial portion of the game that favourably stimulate fat oxidation, particularly of FFA derived from adipose tissue (Bangsbo et al., 2006a; Randell et al., 2019). Similarly, the increased number of rotations and player substitutions within Australian Football and newer field hockey regulations permit more frequent bouts of rest, in addition to active recovery and walking periods maintained during the game (Kapteijns et al., 2021; Varley et al., 2014). In a study by Krustrup et al. (2006), plasma FFA levels were illustrated to be further elevated during halftime, owing to the dedicated period of rest permitted during this intermission. As the duration of exercise or match progresses (i.e. second half or latter portion of a match), lipolytic rates generally increase, which has been attributed to the progressive decline in glycogen availability and corresponding insulin secretion (Bangsbo et al., 2006a, 2007; Jeukendrup, 2003; Krustrup et al., 2006). Bangsbo et al. (2006a) have noted that this latter component highlights the hormone-mediated mechanisms that may moderate the rate of fat oxidation (Bangsbo et al., 2007; Jeukendrup, 2003). In the fed state, insulin typically suppresses the release of FFAs (Jeukendrup, 2003). However, during exercise, circulation of catecholamines, cortisol, growth hormone, and cytokines typically rises, enhancing the rate of lipolysis as well as muscle triglyceride utilization, which may consequently facilitate the maintenance of blood glucose levels (Bangsbo et al., 2006a, 2007; Jeukendrup, 2003; Krustrup et al., 2006; Purdom et al., 2018). In most team sports, literature observes the accumulation of fatigue to become evident during this latter half, with a notable reduction in performance and intensity, collectively promoting the elevation of lipolytic rates and plasma FFA levels into the recovery period (Bangsbo et al., 2006a, 2007; Krustrup et al., 2006).

In this review, results from Bilsborough et al. (2016) and McEwan et al. (2020) produced the greatest reductions in BF% and FM. This may be attributed to the higher training and professional level of these players (i.e., "eliteness"; Swann et al., 2015, p. 9), consisting of first league players from the Australian Football League and Spanish La Liga, respectively. Maximal fat oxidation (MFO) as well as utilization of fat for the same relative exercise intensity (higher absolute) has been observed to increase with training level, most likely due to refined adaptations at the mitochondrial, cellular, and hormonal level (Purdom et al., 2018; Randell et al., 2017, 2019; van Loon et al., 1999; Venables et al., 2005). Increased levels of intramyocellular lipid, beta-oxidative mitochondrial enzymes, transport proteins, and improved hormonal regulation may all contribute to optimal fat oxidation capacity and fuel selection found in these players (Carter, Rennie, Hamilton, & Tarnopolsky, 2001; Goodpaster, He, Watkins, & Kelley, 2001; Phillips, Green, Tarnopolsky, Heigenhauser, & Grant, 1996; Purdom et al., 2018; Tarnopolsky et al., 2007; Randell et al., 2017). In addition, the high levels of FFM reported in these players may have further moderated adaptations and the subsequent changes observed. Indeed, previous research has highlighted that FFM is one of the most significant predictors of MFO (Randell et al., 2017, 2019; Venables et al., 2005). This has been speculated to reflect the higher resting metabolic rate and increased endogenous substrate stores of individuals with greater FFM, and may highlight the capacity for an enhanced mitochondrial and beta-oxidative potential of the corresponding muscle tissue (Purdom et al., 2018; Randell et al., 2017, 2019; Venables et al., 2005). Accordingly, a study conducted by Randell et al. (2017) examined groups of different team sport athletes and found rugby/Australian football players to report the highest absolute MFO rates. Collision-based intermittent sports such as Australian football have been observed to place greater emphasis on accruing and optimizing LBM, such as that observed in the study by Bilsborough et al. (2016), so as to effectively manage the more intense physical nature of the sport (Bilsborough et al., 2015). It is plausible then that resistance training was also a significant component in this study, and may provide an explanation for the significant BF% reductions and small LBM gain observed in players from this study (Bilsborough et al., 2016). However, when normalized for FFM, findings from the study by Randell et al. (2017) study found MFO/FFM to be highest in soccer players, followed closely by field hockey/lacrosse players. This variance was found to be partly explained by aerobic capacity, where these players tend to possess relatively high $VO2_{max}$ values and lactate thresholds in response to the large endurance-based component and metabolic conditioning stipulated in both these sports (Randell et al., 2017, 2019; Reilly & Borrie, 1992; Stølen et al., 2005; Venables et al., 2005). Despite a lower FFM, muscle fibers have been observed to develop increased mitochondrial density and capillarization in response to aerobic conditioning, as well as a more dominant type 1 distribution that collectively optimize the capacity for an enhanced mitochondrial and beta-oxidative potential of the corresponding muscle tissue (Purdom et al., 2018; Proctor et al., 1995; Randell et al., 2017, 2019; Tarnopolsky et al., 2007; Venables et al., 2005). The resultant association with fat oxidation may explain the FM and BF% reductions observed in many of the soccer and field hockey studies in this review (McEwan et al., 2020; Kapteijns et al., 2021; Walker et al., 2019. Apart from the male soccer players examined in the studies by McEwan et al. (2020) and Clemente et al. (2019), the remaining studies of this review examined female soccer (Mara et al., 2015; Walker et al., 2019) or field hockey players (Kapteijns et al., 2021). While females also tend to have lower levels of FFM, such as that observed in this review, studies from both athletic (Randell et al., 2017) and non-athletic populations (Venables et al., 2005) suggest that after standardizing for FFM, MFO rate is observed to be higher in females than males, with females possessing a greater absolute lipolytic rate and relative contribution of fat to both oxidative metabolism and total energy expenditure, even with a lower overall energy expenditure (Horton, 1998; Randell et al., 2017; Tarnopolsky et al., 1990; Venables et al., 2005). These findings have been attributed to sex differences in hormone and catecholamine levels influenced by the menstrual cycle, as well as increased intramuscular lipid availability and utilization in females (Purdom et al., 2018; Roepstorff et al., 2002; Steffensen et al., 2002; Tarnopolsky et al., 1990, 2007), explaining how sex may have further influenced the results of this review. As such, differences due to sport, training level, body composition, aerobic capacity, and sex may serve as key factors that influence fat oxidation and observed body composition changes across intermittent team sport, and provide some explanation for the variations in fat changes observed between studies of this review.

Dietary intake and nutritional patterns represent another key aspect of the training process that may have modulated the adaptive response and moderated these body composition changes further. Specific acute and chronic macro and micronutrient distribution, underpinned by overall energy intake, has been observed to subsequently influence substrate utilization to varying degrees (Aragon et al., 2017; Burke et al., 2006; Jeukendrup, 2003; Thomas et al., 2016). Similar to the findings by the study of Bilsborough et al. (2016), the BF% reductions observed in this review appear to suggest a negative energy balance among athletes, while the maintenance of LBM may imply an adequate intake of protein in the presence of such speculated energy deficits (Aragon et al., 2017; Areta et al., 2014; Burke et al., 2006; Mettler, Mitchell, & Tipton, 2010; Thomas et al., 2016). Indeed, while carbohydrates typically comprise the most critical fuel source for team sport athletes, recent reviews report that energy and carbohydrate intakes of these athletes often do not meet recommendations (Collins et al., 2021; Holway & Spriet, 2011; Jenner et al., 2019). This was corroborated by the study of Bilsborough et al. (2016) in this review, whom observed such findings when examining energy intake patterns of their AFL players. In contrast, literature observes intake of protein and fat to be relatively consistent and either meet or exceed recommendations (Anderson et al., 2017a, 2017b; Bettonviel et al., 2016; Briggs et al., 2015; Collins et al., 2021;

Holway & Spriet, 2011; Jenner et al., 2019; Oliveira et al., 2017), where these patterns were further supported by the findings of the study by Bilsborough et al. (2016). Previous literature (Anderson et al., 2017b; Briggs et al., 2015; Collins et al., 2021; Ranchordas, Dawson, & Russell, 2017; Thomas et al., 2016), as well as the study by Bilsborough et al. (2016), have suggested that these patterns may reflect a lack of appropriate periodization of energy and carbohydrate intake to optimally support the varying energy costs of training, performance, recovery, and adaptation. Team sport demands and individual energy requirements have been noted to fluctuate considerably across the weekly training structure and specific training phase, where low energy and glycogen availability are believed to consequently occur on days or periods where energy expenditure and fuel requirements are particularly high, such as intensified training, matches, and/or congested fixtures (Bilsborough et al., 2016; Briggs et al., 2015; Burke et al., 2006; Collins et al., 2021; Ranchordas et al., 2017; Thomas et al., 2016). Players and positions with higher individual nutrient requirements, such as midfielders and larger/leaner individuals, may be particularly vulnerable to the effects of such deficiencies (Bangsbo et al., 2006a; Briggs et al., 2015; Ranchordas et al., 2017). Several researchers have explained that during higher load days, dietary intake may differ or be lower than an average day, where typical eating patterns may be altered as a result of training, match, and/or travel schedules; exercise and pre-match stress may blunt appetite and/or pose gastrointestinal discomfort; and players may have insufficient time or opportunity for optimal feeding in between the rigorous demands of the day (Burke et al., 2006; Collins et al., 2021; Holway & Spriet, 2011; Ranchordas et al., 2017). When combined with a higher fat intake ostensibly consumed in the team sport athletes of this review, low carbohydrate intake has been demonstrated to subsequently increase the utilization and oxidation of both exogenous and endogenous fat sources within the body, potentially reflecting a means to spare limited glycogen supply (Aragon et al., 2017; Briggs et al., 2015; Jeukendrup, 2003). From our results, the small reduction in FM paired with no overall LBM or BM effects appear to reflect the presence of ostensibly small and/or sporadic energy deficits, as reasoned by the study of Bilsborough et al., (2016), where athletes were capable of managing and adapting to load, and perhaps upregulating fat oxidation for fuel without further detrimental losses in LBM or BM seen with larger deficits and/or a negative training status (Aragon et al., 2017; Thomas et al., 2016). Based on previous research (Areta et al., 2014; Mettler et al., 2010), and as posited by Bilsborough et al., (2016), a speculated sufficient protein intake may have further preserved LBM during these deficits, providing a possible explanation for the minimal LBM change observed in the current review. Collectively, these changes may have been insignificant in altering total BM, owing to the lower density of adipose tissue.

Unfortunately, the influence of such moderators is difficult to ascertain, owing to limited reporting of nutritional intake in all but two studies of this review (Bilsborough et al., 2016; McEwan et al., 2020). In the study by Bilsborough et al. (2016), energy and nutrient intakes of players at multiple points throughout an AFL season were examined, whereas the soccer players in the study by McEwan et al. (2020) received nutritional guidance and individualized recommendations to facilitate the training response. It must be acknowledged that such nutritional provisions involved merely recording and guiding nutritional intakes in these two studies, and nutrition was not manipulated in any of the six included studies. Nutrition education programs appear to be implemented in both clubs, further supported by the recurring provision of food (Bilsborough et al., 2016; McEwan et al., 2020). In a recent systematic review, Tam et al. (2019) have highlighted that these types of programs significantly improve nutritional knowledge among athletes, and may ostensibly lead to a more optimal dietary intake. When considering the studies of this review, it is likely that the playing standard may have influenced the amount of player/team resources available for optimizing performance, as similarly reasoned by Bilsborough et al. (2016), including that of appropriate nutritional attention, education, and qualified sport nutrition staff (Heaney et al., 2011; Trakman et al., 2017). In contrast, nutrition may be extensively more difficult to control in lower-level teams, where clubs may lack funding and/or adequate resources to provide effective nutritional support (Heaney et al., 2011; Trakman et al., 2017). This latter point may offer a possible reason for the minimal reporting in the remaining studies. Lack of nutritional knowledge and guidance may substantially modulate individual dietary intake and its impact on the adaptive response, and is further influenced by factors such as time, convenience, personal preferences, religion, food intolerances/restrictions, and various psychological, social, and economic factors (Birkenhead & Slater, 2015; Collins et al., 2021; Heaney et al., 2011; Tam et al., 2019; Thomas et al., 2016; Trakman et al., 2017). This represents a considerable level of nutrient intake variability between players with different dietary and energy needs, fluctuating over the course of specific days and weeks, which will subsequently and significantly impact the degree to which body composition and training adaptations are acquired and maintained during this time. This highlights a key limitation when monitoring body composition changes in real-world sport settings, where a lack of nutritional consideration, monitoring, and reporting significantly restricts the degree to which reasons for body composition effects may be ascertained.

5.2 Training Load and Body Composition in Team Sport

Although the monitoring and examination of body composition provides insight into longitudinal adaptive responses and individual fitness-fatigue status during specific seasonal phases and monitored training periods (Harley et al., 2011), the degree to which these changes are influenced by training and competitive loads requires the appropriate quantification of these loads (Bilsborough et al., 2016). As such, the secondary aim of this review was to synthesize and analyze the influence of monitored training load variables on changes in body composition. Owing to the limited number of studies and inconsistencies in which training load was monitored, data could not be standardized and pooled for quantitative synthesis. Monitored internal and external load variables and their relationship with FM, LBM, and BM changes across the six studies are discussed below.

5.2.1 Internal Load

While data provided by each unique internal load measure monitored in this review offered important insight, lack of uniformity across studies limited the scope of analysis. In line with the hypotheses of this review, high sRPE loads as a measure of global workload (and by extent, energy expenditure) appeared to be associated with changes in body fat. In particular, high sRPE-overall and sRPE-RT loads were accumulated in the study by Bilsborough et al. (2016), and may have had a synergistic effect in influencing body composition (Atherton & Smith, 2012; Børsheim & Bahr, 2003; Hawley et al., 2011; Ormsbee et al., 2007). As mentioned earlier, resistance training constitutes an essential and regular component in Australian football in line with the more physical demands of the sport (Bilsborough et al., 2015, 2016; Caia et al., 2013; Johnston et al., 2018; Veale et al., 2010; Woods et al., 2015; Young et al., 2005), whereas there was limited reporting and no monitoring of resistance training in most of the remaining soccer and field hockey studies. This may be attributed to the greater endurance component and higher power: LBM ratio demanded in these latter field sports (Stølen et al., 2005). Previous research has demonstrated high sRPE-RT loads to be particularly reflective of heavier loads and high-intensity resistance training (Day, McGuigan, Brice, & Foster, 2004; Sweet, Foster, McGuigan, & Brice, 2004), and highlight the strength and hypertrophy phases utilized in the first two preseason phases in the study by Bilsborough et al. (2016), designed to increase LBM and optimize physique. Indeed, the very stimulation and process of muscle protein synthesis in response to the extensive muscle damage induced by both resistance training as well as various team sport activity significantly heightens energetic demands (Børsheim & Bahr, 2003). Additionally, the inter-set recovery bouts during resistance training may further provide a favourable opportunity for fat metabolism (Ormsbee et al., 2007). In this regard, lipolytic rates have been found to be elevated during both resistance training and post-exercise, in addition to increased whole-body fat oxidation and energy expenditure when examined immediately after and up to 2, 15, and 38h following resistance training (Binzen, Swan, & Manore, 2001; Melby, Scholl, Edwards, & Bullough, 1993; Ormsbee et al., 2007; Schuenke, Mikat, & McBride, 2002). The high excess post-exercise oxygen consumption; low respiratory exchange ratio; progressive reduction in glycogen availability; as well as the rise in catecholamine, cortisol, growth hormone, and testosterone levels thereby permit FAs to become an important substrate in the recovery phase following resistance training, in synergy to intermittent team sport activity responses (Bangsbo et al., 2006a, 2007; Børsheim & Bahr, 2003; Ormsbee et al., 2007; Poehlman & Melby, 1998). Moreover, weekly accumulated sRPE-overall loads in the study by Bilsborough et al. (2016) were additionally higher than those reported in Australian football literature (Johnston et al., 2018; Ritchie et al., 2016), where the former were accumulated through training sessions alone, as opposed to the inclusion of both match and training monitoring reported in the literature. Bilsborough et al. (2016) acknowledges that the training level and playing standard of the first league professional team observed in their study are likely to have influenced both the training load as well as subsequent adaptive responses. Indeed, such loads may have been necessary to elicit adaptations at this training level, where players appeared to maintain high training status and adaptive capacity (Bilsborough et al., 2016). According to Bilsborough et al. (2016), this is reflected in the FFM gains and FM reductions that occurred in training phases in which both overall load and sRPE-RT loads were particularly elevated. It is important to note that, although the separation of sRPE and sRPE-RT loads in this study is ideal, discerning the influence of physiological stress versus mechanical stress arising from sport-specific sRPE loads has been observed to be more ambiguous with sRPE alone (Vanrenterghem et al., 2017). Recent literature has proposed the monitoring of differential sRPE (respiratory/physiological; musculoskeletal/biomechanical; and mental/cognitive) to better delineate these underlying mechanisms, and may offer particularly valuable insight when examining the cumulative effects of sport-specific stimuli on LBM and FM (Fox et al., 2018; McLaren et al., 2018; McLaren, Smith, Spears, & Weston, 2017; Vanrenterghem et al., 2017; Weston, Siegler, Bahnert, McBrien, & Lovell, 2015).

Self-reported measures are among the most common and straightforward tools to monitor training load, by which the simplicity of the questionnaire used in the study by Mara et al. (2015) may have further facilitated ease of daily utilization among players (Taylor et al., 2012; Thorpe et al., 2017). The consistency in scores of fatigue, muscle soreness, and sleep quantity coupled with the minimal body composition changes observed in this study suggest that fatigue induced by the high day-to-day and cumulative external loads in this study were adequately tolerated and managed by the team (Mara et al., 2015), which aligns with previous literature (Buchheit et al., 2013; Gastin, Meyer, & Robinson, 2013; Saw et al., 2015). According to Thorpe et al. (2015), these results may, in part, be attributed to the recovery-focused weekly periodization structure adopted in the competitive phase of the study by Mara et al. (2015), revolving around one match per week, where players were subsequently afforded two recovery days and conditioning was limited to once per week. Thorpe et al. (2015) highlights that a recovery-focused competitive structure may promote lower variability in perceived wellness scores, including sleep and muscle soreness (Buchheit et al., 2013; Gastin et al., 2013). The steady scores observed in the players of the study by Mara et al. (2015) may thus reflect an adequate fitness-fatigue status that was maintained across the season, resulting in a relatively stable body composition and only small non-significant gains in FM (Buchheit et al., 2013; Gastin et al., 2013; Harley et al., 2011; Mara et al., 2015).

Training loads and patterns in the study by Walker et al. (2019) highlight the condensed nature of the collegiate soccer season in North America, where double sessions and congested fixtures are increasingly likely. While previous literature finds deloads leading up to a match to be quite common in intermittent team sport (Anderson et al., 2016; Malone et al., 2015; Martín-García et al., 2018; Moreira et al., 2015; Reilly, 2006), deloads observed in this specific group of athletes may represent the need to capitalize on limited and therefore crucial opportunities to mitigate fatigue and reduce staleness throughout a congested college season (Walker et al., 2019). Indeed, the small reductions in FM observed in the players of this study may reflect metabolic adaptations that developed as a means to continue supporting fuel requirements in the presence of high daily physiological and energetic demands with limited rest days that collegiate athletes often face (Aragon et al., 2017; Walker et al., 2019). The underlying metabolic and physiological responses in the players may be more precisely explained by the blood biomarkers additionally monitored in this study. Walker et al. (2019) highlights the disruption of the HPA-axis and the anabolic: catabolic milieu, with elevations in inflammatory markers, including cortisol, interleukin-6, and creatine kinase, potentially offering additional sources of explanation for the increases in fat oxidation (Fischer et al., 2003; McMurray & Hackney, 2005; Steinacker et al., 2005). Similar to the catecholamine-mediated effect, Walker et al. (2019) noted that many of these inflammatory markers are particularly responsive to low muscle glycogen, which may offer insight into the players' corresponding nutritional patterns, and provide a potential underlying factor in the subsequent modulation of fat oxidation rates (Jeukendrup, 2003; Fisher et al., 2003; McMurray & Hacknet, 2005; Steinacker et al., 2005). However, in contrast, the erratic spike in prolactin and reductions in iron, ferritin, hematocrit, vitamin D, and omega-3 FA levels may have interfered with lipolytic rates (Gabrielsen et al., 2012; Ma, Jia, Xiong, Feng, & Du, 2021; Salehpour et al., 2012; Walker et al., 2019; Wood, 2008). Interestingly, while many of these reported biomarkers appear to suggest reductions in muscle protein synthesis rates, corresponding muscle mass, as well as bone mineral density, the non-negative LBM changes observed in this study may be partly attributed to the increase in triiodothyronine, which may have attenuated potential LBM loss (Lee et al., 2017; McMurray & Hackney, 2005; Pucci, Chiovato, Pinchera, 2000; Steinacker et al., 2005; Walker et al., 2019). This reiterates the likelihood that nutritional patterns, although not reported, may have modulated adaptive responses, and may have been further enhanced by the minimal resistance training stated in this study (not monitored), ostensibly preserving LBM in favour of FM during these congested loads (Aragon et al., 2017; Areta et al., 2014; Atherton & Smith, 2012; Hawley et al., 2011). Indeed, the results observed in the study by Walker et al. (2019) highlight the complexity of the cumulative internal stress response purportedly incurred by these collegiate female athletes, and further elucidated by the examination of this range of biomarkers. In general, body composition changes appear to suggest relatively good training status considering the demands faced by these athletes, with minimal BM and LBM loss observed (Harley et al., 2011; Walker et al., 2019).

Interestingly, the Polar® system utilized by the study by Walker et al. (2019) may offer particularly relevant implications for examining body composition changes. Through the quantification of time spent in various HR intensity and corresponding metabolic zones, individual workload measures in the study by Walker et al. (2019) may include consideration of both the absolute and relative energy contributed by the different metabolic pathways (Nissilä & Kinnunen, 2008, Perrotta et al., 2017, Polar® Website, 2022). Though this means, HR-monitoring systems aim to estimate the differentiation and integration of specific substrate utilization in their impulse and energy expenditure calculations (Polar® Website, 2022). Currently, however, the diversity and ambiguity with which such measures may be defined and derived across various training load technologies and algorithms warrant further investigation and standardization.

5.2.2 External Load

The significant reduction in LBM and small gains in FM observed in the study by Clemente et al. (2019a) may be reflective of training overload and chronic catabolic stress that are likely attributed to the high volume, acute spikes, and irregular weekly fluctuations in SprD incurred in this study. Sprinting and high-speed running loads generally inflict a significant degree of metabolic and mechanical stress on the muscle (Hader et al., 2019; Young et al., 2012), and more so when these workloads are unaccustomed, undergo large rapid spikes, and/or become excessive (Colby, Dawson, Heasman, Rogalski, & Gabbett, 2014; Duhig et al., 2016; Gabbett, 2016; Gabbett & Ullah, 2012; Jaspers et al., 2018; Malone, Roe, Doran, Gabbett, & Collins, 2017; Malone et al., 2018; Murray, Gabbett, Townshend, Hulin, & McLellan, 2017; Soligard et al., 2016; Young et al., 2012). Correspondingly, such tissue microtrauma and muscle damage subsequently demands a greater level of recovery to repair and restore muscle function and capacity to pre-exercise levels (Jaspers et al., 2018; Nédélec et al., 2012). In the study by Clemente et al. (2019a) study (Table 3.2), training and match frequency appear to be evident of recurring double sessions and/or multiple matches per week. It is possible that players suffered inadequate opportunity to effectively repair muscle tissue, attenuate accumulating levels of residual fatigue, and cope with the cumulative training stress constrained within this congested training structure. When coupled with insufficient recovery, the large spikes and cumulative volume of SprD loads may have exceeded the athlete's tolerance capacity and subjected them to a state of overload (Colby et al., 2014; Duhig et al., 2016; Gabbett & Ullah, 2012; Jaspers et al., 2018; Malone et al., 2017b, 2018; Murray et al., 2017; Soligard et al., 2016). Indeed, such factors have been reported to increase risk of overtraining and/or non-contact soft tissue-injury (Colby et al., 2014; Duhig et al., 2016; Gabbett & Ullah, 2012; Jaspers et al., 2018; Malone et al., 2017b, 2018; Murray et al., 2017; Soligard et al., 2016), where subsequent muscle atrophy may occur. Such training overload states are associated with tissue failure, disruption of adaptive mechanisms, and perturbations in muscle morphology and metabolic processes, including a lowered basal metabolic rate, impaired fat metabolism, attenuated muscle protein synthesis response, and an elevation in protein degradation (Cadegiani & Kater, 2018, 2019; Esmaeili et al., 2018; Lambert & Borresen, 2006; Kumar, 2001; Soligard et al., 2016; Vanrenterghem et al. 2017). Suboptimal nutritional patterns, specifically a negative energy balance and/or inadequate nutrient availability, would have augmented the risk and degree of such maladaptations, and has been demonstrated to often be present in overtrained states (Cadegiani & Kater, 2018, 2019). These factors may provide some potential explanation for the significant LBM loss and small FM gain observed in this study, elucidating a possible link between excessive running loads and the maladaptive responses observed, and offer some insight into the physiological disturbances behind these negative body composition changes. Unfortunately, literature is currently unclear on whether these body composition alterations are a cause or result of overtraining, and where precisely HSRD and/or SprD loads fit into this relationship (Cadegiani & Kater, 2018, 2019). Further research is warranted to explore this complex interaction and the mechanisms in which muscle tissue is affected (Cadegiani & Kater, 2018).

Previous literature has demonstrated that female athletes tend to report lower distance overall as well at higher-speeds than their male counterparts (Bradley, Dellal, Mohr, Castellano, & Wilkie, 2014; Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Mohr, Krustrup, Andersson, Kirkendal, & Bangsbo, 2008; McFadden, Walker, Bozzini, Sanders, & Arent, 2020). Moreover, training loads are generally lower than those reported in female match play (Collins et al., 2021). However, training sessions completed by the players in the study by Mara et al. (2015) appear to more closely emulate mean TD and HSRD loads reported in female competition literature, exceeding average loads reported in female training as well as HSRD loads reported in male training (Collins et al., 2021; Datson et al., 2014; McFadden et al., 2020). As described earlier, the relatively stable internal load scores and minimal changes in body composition reported in the players of the study by Mara et al. (2015) appear to suggest tolerable management of this high training volume, with players possibly benefitting from the recovery-focused training week structure in the competitive season to attenuate fatigue (Buchheit et al., 2013; Gastin et al., 2013; Harley et al., 2011; Saw et al., 2015; Thorpe et al., 2015). In line with previous literature (Buchheit et al., 2013; Colby et al., 2014; Gabbett & Ullah, 2012), it is possible that this advantage helped minimize more adverse physiological responses and metabolic adaptations that may be induced by a high in-season training volume characterized by locomotor loads, such as that observed in the study by Clemente et al. (2019a). Unfortunately, limited research exists on training loads in female soccer, with the study by Mara et al. (2015) being one of the first to monitor loads across training sessions as opposed to match play. In a similar manner, very few studies have quantified training and/or match loads in female field hockey, with the study by Kapteijns et al. (2021) representing the single study in this review to have monitored solely match loads. Match loads are generally more consistent than training loads in team sport; however, without match data from remaining studies, it is impossible to appropriately analyze and compare loading patterns, and/or assess their influence on body composition adaptations. This highlights the paucity of literature in female team sport, necessitating increased emphasis in future research.

The acceleration-sum load quantified by Clemente et al. (2019a) was slightly lower than that observed in previous literature (Casamichana et al., 2013; Clemente et al., 2019b). However, these previous studies reported significantly lower TD and SprD as well as twice the monitoring period length in comparison (Clemente et al., 2019b). This supports earlier speculations of congestion in the study by Clemente et al. (2019a). Moreover, it also highlights a greater accelerometer-sum load contribution from vertical accelerations (*z*-axis) generated by foot strikes that are accumulated through large running volumes and TD, as was observed in this study (Clemente et al., 2019a), rather than accelerations accrued through more abrupt sport-specific actions and/or impacts (Boyd et al., 2011; Bredt et al., 2020; Casamichana et al., 2013; Davies et al., 2013; Gallo et al., 2015; Julien, 2020; Scott et al., 2013b). Interestingly, external loading patterns and cumulative loads in the study by McEwan et al. (2020), whom reported particularly high accelerations/deceleration activity as opposed to locomotor volume, are similar to those reported in other Spanish La Liga and English Premier League players (Akenhead, Harley, & Tweddle, 2016; Martín-García et al., 2018). However, this was merely not the case when compared to players in less competitive leagues, including teams of this review (Clemente et al., 2019a, Mara et al., 2015), and previously reported Dutch Eredivisie professional, Norwegian elite, and American NCAA leagues (Baptista et al., 2019; Curtis et al., 2021; Stevens et al., 2021). Indeed, the study by McEwan et al. (2020), as well as previous literature (Carling et al., 2008; Martín-García et al., 2018; Silva et al., 2022), have highlighted that playing standard, club culture, coaching philosophy, and regional differences likely influence the type of playing and training styles, and thus the activity demands emphasized in training, which offers a possible explanation for the differences in loading patterns observed in this review. In contrast to the negative soft tissue implications of high HSRD and SprD loads described earlier, Gabbett and Ullah (2012) demonstrate that accelerations and decelerations, along with distances completed at lower intensities, may in fact offer a protective advantage against non-contact soft tissue injury, despite the high levels of muscle damage they often induce (Hader et al., 2019; Harper et al., 2019; Harper & Kiely, 2018; Jaspers et al., 2018; McBurnie et al., 2022; Young et al., 2012). In this regard, Akenhead et al. (2013, 2015) note that accelerations are associated with a greater neural activation compared to constant-velocity running (Mero & Komi, 1987), and may therefore enable the athlete to effectively absorb greater levels of load (Elliot, Zarins, Powell, & Kenyon, 2011). This may suggest a greater affinity for these activities to optimize the adaptive, stress-bearing capacity, efficiency, and neuromuscular coordination of LBM tissue through repeated exposure, thus enhancing LBM integrity and resiliency in a way that running loads may not (Elliot et al., 2011; Harper et al., 2019; Harper & Kiely, 2018; Gamble, 2004; McBurnie et al., 2022; Vanrenterghem et al. 2017). In turn, these adaptations would provide a more effective ability to attenuate high forces and cope with biomechanical loads, including subsequent agility demands associated with competition (Elliot et al., 2011; Harper et al., 2019; Harper & Kiely, 2018; Gamble, 2004; McBurnie et al., 2022). Interestingly, previous literature has observed in-season injury incidence to be associated with significantly lower average accelerometer-derived loads and significantly higher relative distance (m/min.) in the weeks prior, further emphasizing the disparate adaptive biomechanical impact between these otherwise high-intensity loading parameters (Ehrmann et al., 2016; Jaspers et al., 2018). Furthermore, increasing accelerations has been demonstrated to involve a greater metabolic cost compared to constant-velocity running (Cavagna, Komarek, & Mazzoleni, 1971; di Prampero et al., 2005; Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010). This may have played an important role in influencing the physiological responses underpinning the significant large body fat reductions observed in the study by McEwan et al. (2020). Osgnach et al. (2010) have illustrated that even at lower-speed distances, metabolic demands may be similar to that during sprinting when accelerations are increased (Cavagna et al., 1971; di Prampero et al., 2005; Gaudino et al., 2013). Team sport involves frequent accelerations and decelerations, undertaken anywhere around 500 times a match, and therefore such activities have been asserted to ostensibly constitute critical sources of high instantaneous metabolic demand to significantly elevate total energy expenditure (Akenhead et al., 2015, 2016; Bloomfield, Polman, & O'Donoghue; 2007; Casamichana et al., 2013; Coutts et al., 2015; Dalen, Jørgen, Gertjan, Havard, & Ulrik, 2016; di Prampero & Osgnach, 2018; Gaudino et al., 2013; Osgnach et al., 2010). In a similar regard, discrete sport-specific actions such as kicks, jumps, turns, and tackles/impacts in addition to unorthodox movements (e.g., backward/sideways running) may be fleeting with minimal changes in distance; however, the intensity and frequency with which they occur induce considerable physiological and biomechanical stress, thereby heightening metabolic costs in a comparable, exponential manner (Akenhead et al., 2015, 2016; Carling et al., 2008; Dalen et al., 2016; Iaia, Ermanno, & Bangsbo, 2009; Montgomery, Pyne, & Minahan, 2010; Polglaze & Hoppe, 2019; Reilly, 1997; Reilly & Bowen, 1984; Scott et al., 2013b; Vanrenterghem et al. 2017). This highlights the considerable metabolic load imposed by brief high-intensity activities beyond high-speed running and sprinting. Furthermore, previous literature has described muscle contractions to look different between constant-velocity sprinting/high-speed running compared to accelerations/decelerations, where the former relies more on the stretch-shortening cycle and elastic energy, whereas accelerations and decelerations predominately generate force through concentric and eccentric contractions, respectively, to optimize ground reaction impulse and rapidly produce/dissipate kinetic energy (Cavagna et al., 1971; Delaney et al., 2018; Harper et al., 2019). Collectively, the accumulation of these brief high-intensity actions has important implications for influencing internal responses of both physiological and biomechanical nature, and thus resultant adaptations, including those of body composition (Akenhead et al., 2015, 2016; Carling et al., 2008; Dalen et al., 2016; Delaney et al., 2018; Harper, et al., 2019; Gaudino et al., 2013;

Iaia et al., 2009; Reilly, 1997; Reilly & Bowen, 1984; Scott et al., 2013b; Vanrenterghem et al. 2017). Indeed, accelerometer-derived PlayerLoad™ has often been demonstrated to have significant large correlations with both physiological and perceptual measures of internal load, emphasizing this link, while these correlations are much lower for HSRD and SprD (Casamichana et al., 2013; Coutts et al., 2008; Dalen et al., 2016; Gallo et al., 2015; McLaren et al., 2018; Montgomery et al., 2010; Scott et al., 2013a, 2013b). However, Scott et al. (2013b) have noted that lower correlations for HSRD may also be due to the reduced accuracy of GPS to quantify loads at higher speeds and should be acknowledged in the interpretation of results (Coutts & Duffield, 2010). Nonetheless, the results of this review highlight the differences between various external load measures and specific movement demands to influence the adaptive response and overall metabolic load through which body composition changes may occur. Here, accelerations/decelerations and sport-specific high-intensity activities appear particularly noteworthy in enhancing and optimizing these responses. Indeed, more recently proposed models of energy expenditure derivations, such as the metabolic power method, now account for the elevated energetic cost of accelerations/decelerations and their interaction with speed to provide a higher and more comprehensive estimate of the metabolic demands of locomotion compared to either measure alone (di Prampero et al., 2005; Gaudino et al., 2013; Osgnach et al., 2010; Polglaze & Hoppe, 2019). Moreover, this model has now been updated to address the cost of changing direction, backwards/lateral running, walking versus running, and air resistance, as well as offering the potential to model aerobic-anaerobic energy contribution (di Prampero & Osgnach, 2018; Osgnach & di Prampero, 2018, pp. 588, 592; Polglaze & Hoppe, 2019). Metabolic power has thereby been suggested to provide a useful addition to external load monitoring alongside these measures, particularly in team sports where “variable-speed” (Polglaze & Hoppe, 2019, p. 407) and “multi-directional” (Gaudino et al., 2013, para. 2) locomotion is common (di Prampero et al., 2005; Gaudino et al., 2014b; Osgnach et al., 2010; Osgnach & di Prampero, 2018). Unfortunately, on the whole, research investigating the quantification of acceleration/deceleration and sport-specific activities has been noted to be a relatively novel focus with greater methodological diversity when compared to more traditional time-motion analysis based on distance covered in various speed zones (Akenhead et al., 2016; Casamichana et al., 2013; Cardinale & Varley, 2017; Coutts et al., 2015; Cummins et al., 2013; Dalen et al., 2016; Delaney et al., 2018; Delves et al., 2021; Gaudino et al., 2013, 2014b; Harper et al., 2019; Osgnach et al., 2010; Malone et al., 2017a; Scott et al., 2013b; Varley et al., 2017). As such, the validity, reliability, and sensitivity with which these activities are quantified remains somewhat ambiguous (Cardinale & Varley, 2017; Casamichana et al., 2013; Delaney et al., 2018; Delves et al., 2021; Harper et al., 2019; Malone et al., 2017a; Varley et al., 2017). This highlights key limitations in current training load monitoring methods, where these stochastic demands and the subsequent adaptive response(s) they elicit may be poorly reflected, thus underrepresenting and/or misconstruing contribution from a significant component of intermittent team sport, and restricting the comprehensiveness with which the relationship between intermittent team sport and adaptation may be examined (Akenhead et al., 2016; Dalen et al., 2016; di Prampero et al., 2005; Cardinale & Varley, 2017; Carling et al., 2008; Delaney et al., 2018; Delves et al., 2021; Gaudino et al., 2013, 2014b; Malone et al., 2017a; Osgnach et al., 2010; Polglaze & Hoppe, 2019; Scott et al., 2013b; Varley et al., 2017). As such, the degree to which body composition adaptations may be explained by these current training load methods is consequently constrained by such limitations, warranting further investigation and standardization in order to improve load quantification and permit a greater understanding of these discrete dynamic activities (Akenhead et al., 2016; Casamichana et al., 2013; Cardinale & Varley, 2017; Dalen et al., 2016; Delves et al., 2021; Gaudino et al., 2013, 2014b; Malone et al., 2017a; Varley et al., 2017).

5.3 Practical Implications

Findings from this review provide important implications in tracking body composition changes as a tool to improve the athlete monitoring process, and facilitate enhanced understanding of the adaptive response, physiological status, and training effectiveness experienced by the team sport athlete across the training process. This may offer critical insight to practitioners across a range of disciplines, including coaches, sport scientists, and dietitians, which can guide and inform the effective prescription, monitoring, and adjustment of training loads together with nutritional intake patterns to optimize athlete management and development at both the health and performance level.

For one, the reduction in adiposity observed in this review may reflect the possibility of inadequate nutritional intake in athletes to effectively support the high energy demands associated with elite/professional team sport (Bilsborough et al., 2016; Burke et al., 2006; Collins et al., 2021; Jenner et al., 2019; Thomas et al., 2016). Unfortunately, the minimal nutritional reporting across many of the included studies highlights a significant barrier to ascertaining the dietary intake patterns of players, and their subsequent influence on any body composition and training adaptations observed. Improved nutritional reporting together with body composition monitoring may permit team dietitians to better examine both variables and their relationship, and thereby facilitate the prescription of individual-specific nutritional recommendations and/or interventions in response to the information garnered. The inclusion of nutritional resources and support (e.g., guidelines, education programs) paired with an emphasis on promoting adequate energy intake and dietary patterns periodized to the demands of training/competition and individual differences would collectively serve to facilitate proper athlete nutrition in alignment with individual needs, goals, and sport-specific training objectives (Anderson et al., 2017b; Bilsborough et al., 2016; Burke et al., 2006; Collins et al., 2021; Mujika et al., 2018; Oliveira et al., 2017; Ranchordas et al., 2017; Thomas et al., 2016). Indeed, both overall energy intake as well as specific nutrient distribution patterns may influence substrate utilization, which when combined with strength and metabolic conditioning, represent key modifiable variables to optimize physique and the adaptive response, including an enhanced metabolic capacity and preservation and/or increase of LBM (Aragon et al., 2017; Atherton & Smith, 2012; Bilsborough et al., 2016; Burke et al., 2006; Collins et al., 2021; Jeukendrup, 2003; Hawley et al., 2011; Purdom et al., 2018; Thomas et al., 2016). Collectively, these adaptations may improve athlete capacity and physical fitness to manage team sport loads, optimize performance, promote enhanced recovery, and support overall health and wellbeing.

In addition, the prescription and monitoring of training loads may be informed by the preliminary evidence offered in this review surrounding its moderating effect on body composition changes. Chiefly, accelerations/decelerations and sport-specific high-intensity efforts may produce a particularly exponential rise in metabolic cost, where training activities that emphasize the inclusion of such dynamic skill-based activities have been suggested to be an effective means to increase training load intensity, optimize tissue capacity, and enhance conditioning with a reduced volume, particularly when compared to running loads (Ade, Harley, & Bradley, 2014; Gabbett, 2002b, 2006; Gabbett & Ullah, 2012; Gamble, 2004; Iaia et al., 2009; Reilly, 1997; Scott et al., 2013b). In support of previous literature, this review therefore recommends that training loads and specific training modes/styles be prescribed in consideration of these findings, particularly when certain training objectives are desired. Traditional forms of metabolic conditioning, such as interval training and/or running drills, for instance, have been observed to place excessive emphasis on high-speed running/sprinting volumes, which may contribute to significant training stress and increased risk of overuse injury when loads are unaccustomed, rapidly increased, congested, and/or not effectively dissipated with appropriate recovery (Ade et al., 2014; Colby et al., 2014; Duhig et al., 2016; Gabbett, 2002b, 2016; Gabbett & Ullah, 2012; Jaspers et al., 2018; Malone et al., 2017b, 2018; Murray et al., 2017). In contrast, small-sided games (SSGs) offer a more practical, “skill-based” approach to [on-field] conditioning, whereby their versatility and specificity further permit multiple training components and objectives to be addressed, often simultaneously (Bujalance-Moreno, Latorre-Román, & García-Pinillos, 2019; Gabbett, 2002b, 2006; Gabbett & Mulvey, 2008; Gamble, 2004; Hill-Haas, Dawson, Coutts, & Rowsell, 2009; Hill-Haas, Dawson, Impellizzeri, & Coutts, 2011; Iaia et al., 2009). In this regard, factors such as pitch size, number of players, and rules of the game have been demonstrated to provide simple modifications as a means to optimize different facets of physiological and physical fitness, technical and tactical proficiency, as well as specific movement patterns/external loads (Bujalance-Moreno et al., 2019; Hill-Haas et al., 2009b, 2011; Iaia et al., 2009; Owen, Twist, & Ford, 2004). Moreover, small-sided games are often associated with reduced distances, particularly at high-speeds, while accelerations/decelerations and internal loads remain high, tending to stimulate or exceed intensities achieved in competition (Ade et al., 2014; Buchheit et al., 2015; Clemente et al., 2019b; Gabbett & Mulvey, 2008; Gaudino, Alberti, & Iaia, 2014a; Gaudino et al., 2014b; Hill-Haas et al., 2009b, 2011; Martín-García et al. 2018). Indeed, when examining time-motion characteristics between different SSG formats, Hill-Haas et al. (2009b) have asserted TD to provide a poor representation of global workload, demonstrating no significant differences between game formats, despite significant variability in physiological and perceptual intensity measures. These authors have suggested such findings to be influenced by the possession style of play in various SSG formats and sport-specific training activities/circuits, which often necessitate reducing speed in order to maintain ball control and technical ability within a finite space; in spite of this, activities with a ball are generally associated with a greater metabolic cost compared to those without (Buchheit et al., 2015; Hill-Haas et al., 2009b; Iaia et al., 2009; Owen et al., 2004; Reilly & Ball, 1984). Furthermore, Gabbett (2002b) demonstrates the rate of injuries sustained in SSGs to be considerably lower compared to generic conditioning drills with no skill component (e.g., running without a ball). This further emphasizes the disparate internal-external load relationship between the two training styles, and supports previous literature for SSGs as an efficient yet effective skill-based/game-specific method of conditioning compared to traditional running drills in team sport athletes (Ade et al., 2014; Bujalance-Moreno et al., 2019; Gabbett, 2002b, 2006; Gamble, 2004; Hill-Haas et al., 2009a, 2011; Iaia et al., 2009; Polglaze & Hoppe, 2019). These recommendations are also in line with previous literature that realizes the benefits resulting from training that is similar and specific to the competitive environment, whereby such loading patterns may optimize physiological, psychological, and biomechanical adaptations as well as transfer unto the sport (Bompa & Buzzichelli, 2019; Bujalance-Moreno et al., 2019; Gabbett, 2002b, 2006; Gamble, 2004; Harper & Keily, 2018; Hill-Haas et al., 2011; Iaia et al., 2009; Vanrenterghem et al. 2017). At the same time, however, it is important to acknowledge that sprint training does have its place with team sport regimens, and is observed to often be necessary to optimize skills such as repeated sprint ability for associated high-intensity competition demands (Buchheit et al., 2015; Casamichana, Castellano, & Castagna, 2012; Gabbett & Mulvey, 2008). Indeed, Buchheit et al. (2015) highlight that training styles conducive to maximizing metabolic loads and/or enhancing conditioning and body composition may not necessarily optimize the full spectrum of multifaceted skills necessary to flourish in intermittent team sport, where the inclusion of various training styles are often deemed necessary to meet and compliment different training objectives and optimize peak skill development and performance capacity (McLaren et al., 2018; Weaving, Marshall, Earle, Nevill, & Abt, 2014). In this regard, training modes and styles play a key role in governing external loading patterns in addition to the internal adaptive response, including the coupling/uncoupling of these loads in which changes in physical and physiological training status/fitness capacity (including body composition), technical-tactical proficiency, and sport-specific skill competence may be determined (Bourdon et al., 2017; Halson, 2014; McLaren et al., 2018; Weaving et al., 2014). As such, training load monitoring should include measures of both internal and external load, suited to the training mode, in order to consistently and carefully monitor this relationship across the training process (Bourdon et al., 2017; Halson, 2014; McLaren et al., 2018). Indeed, the use of only one or the other alone may consequently neglect the complex interplay between these two components, where their interaction elucidates critical insight on the dose-response relationship, facilitate the detection and clarification of any discrepancies, and provide a more integrative and holistic player monitoring approach (Bourdon et al., 2017; Halson, 2014; McLaren et al., 2018).

5.4 Limitations

A high degree of rigour was maintained at each step of the review to ensure a robust and comprehensive examination. However, some limitations must be acknowledged. While recognizing the complexity and limitations implicated in body composition assessment (Ackland et al., 2012; Aragon et al., 2017; Wagner & Heyward, 1999), particular exclusion was given to the use of skinfolds. However, as noted by Heydenreich et al. (2017), this exclusion factor may have also excluded a number of otherwise potentially relevant studies, as skinfolds provide one of the most accessible field measures to measure body composition in sport settings (Meyer et al., 2013). Additionally, the scope of the review was significantly influenced and further constrained by the investigation of the effect of training load on body composition, which consequently limited the number of studies garnered and the broader examination of intermittent team sport alone. Indeed, the inclusion of skinfolds and/or the synthesis of body composition changes occurring from team spot alone may have led to a greater breadth of evidence, slightly different results, and an ultimately more robust conclusion.

The small number of included studies, extensive methodological diversity, and inconsistent reporting between studies, particularly in the monitoring and quantification of training load (in addition to nutritional reporting), consequently represent key limitations in the examination of the relationship between training load and body composition. Although a range of training load measures were employed across studies, limited uniformity in training metrics restricted the quantitative synthesis of these measures against body composition. Indeed, despite the use of wearable tracking technologies and the inclusion of both two-dimensional (GPS) and three-dimensional (accelerometry) external load monitoring across four of the six studies, differences in the collection, filtering, processing, and reporting of training load data created difficulty in ascertaining the respective influence of external load metrics at this time (Cardinale & Varley, 2017; Dalen et al., 2016; Delves et al., 2021; Malone et al., 2017a, Varley et al., 2017). In addition to the variable expression of a particular training load measure or metric (e.g., acceleration counts vs acceleration-sum), GPS and accelerometer-derived measures have been observed to typically be subject to differences between products, manufacturers, sampling frequencies, models, as well as software/firmware (Akenhead et al., 2016; Cardinale & Varley, 2017; Cummins et al., 2013; Delaney et al., 2018; Delves et al., 2021; Harper et al., 2019; Malone et al., 2017a; McLaren et al., 2018; Varley et al., 2017). These "technology-driven differences" (Delves et al., 2021, p. 3) in filtering and processing, as well as any variations attributable to sport/cohort/sex-specific algorithms, for instance, may explain the inconsistencies in activity descriptors and specific threshold classifications for both distance and acceleration variables observed in the studies of this review (Cardinale & Varley, 2017; Cummins et al., 2013; Hader et al., 2017; Malone et al., 2017a, Varley et al., 2017). Although threshold-based classifications are indeed some of the most common methods of load quantification, the arbitrary selection and minimal reporting of filtering methods and minimum effort duration further tends to result in variable inter-unit reliability and questionable validity, where the quantification of high-intensity activities may be either underestimated or overestimated (Cardinale & Varley, 2017; Delaney et al., 2018; Delves et al., 2021; Harper et al., 2019; Malone et al., 2017a; Varley et al., 2017). In this latter regard, current training load monitoring methods may significantly misconstrue the metabolic cost and overall demand associated with these dynamic activities, where further investigation is warranted to improve the quantification of these stochastic demands throughout the training process (Akenhead et al., 2016; Carling et al., 2008; Dalen et al., 2016; Delaney et al., 2018; Delves et al., 2021; di Prampero et al., 2005; Gaudino et al., 2013, 2014b; Malone et al., 2017a; Osgnach et al., 2010; Polglaze & Hoppe, 2019) Moreover, the reporting of training load data alone varied extensively across the studies of this review, where loads were reported as weekly totals (McEwan et al., 2020), weekly totals per seasonal training phase (Bilsborough et al., 2016), average session per seasonal training phase (Mara et al., 2015), average match data (Kapteijns et al., 2021), and accumulated sums (Clemente et al. 2019a). As the number of weeks in the monitoring period was not consistently disclosed, this impeded the accuracy with which quantified loads could be compared and standardized at the session/match, weekly, and cumulative level. Ultimately, when coupled with the small number of studies in this review, these collective discrepancies significantly limited the ability to standardize and synthesize studies, ultimately precluding a comprehensive quantitative synthesis of the relationship between training load and body composition. Aims to increase the standardization of these technology-derived external loads, corresponding filtering methods, and reporting schemes have frequently been advocated for in recent literature as a means to increase consistency and transparency (Cummins et al., 2013; Delaney et al., 2018; Delves et al., 2021; Harper et al., 2019; Malone et al., 2017a; Varley et al., 2017). However, owing to the diversity posed by technological, sport-specific, and contextual considerations, Malone et al. (2017a) have asserted that attempts to standardize thresholds, filtering/processing methods, and/or reporting guidelines may be somewhat ambitious for practical application. Rather, detailed reporting and rationales for specific training load quantification, filtering, minimum effort duration, and processing methods, as well as the utilization of individualized values against arbitrary thresholds has been proposed to improve the accuracy and sensitivity with which the dose-response relationship may be quantified (Cardinale & Varley, 2017; Cummins et al., 2013; Delves et al., 2021; Hader et al., 2019; Harper et al., 2019; Malone et al., 2017a). Moreover, this review additionally recommends a multidimensional approach to the monitoring and reporting of training load data, according to previous work by Williams, Trewartha, Cross, Kemp, & Stokes (2017). In this regard, training load measures should reflect cumulative loads, changes in loads (both absolute and relative), as well as acute/daily loads in order to capture the unique aspects of training load and optimize the scope of training load monitoring (Williams et al., 2017).

Furthermore, beyond the discrepancies in training load quantification, general training and participant characteristics such as the sport, playing standard/level, sex, and positions of athletes as well as the seasonal phase(s) and length of time in which they were monitored provide important sources of heterogeneity in the results. Unfortunately, however, the small number of studies as well as the inconsistent reporting in the latter two covariates precluded any subgroup analysis to explore and synthesize the effect of these covariates. Indeed, such factors play key roles in establishing and modifying body composition profiles and adaptations, where differences may be attributed to activity profiles, training status, and fluctuating objectives and workloads. Moreover, training modes and dietary intake patterns also exert substantial confounding influence on body composition, particularly when resistance training and nutritional intake are considered (Aragon et al., 2017; Atherton & Smith, 2012; Bilsborough et al., 2016; Burke et al., 2006; Jeukendrup, 2003; Hawley et al., 2011; Purdom et al., 2018; Thomas et al., 2016). As described in this review, these variables may represent appreciable explanatory power for the large body composition changes observed, although reporting on these confounding variables was often extremely limited and inconsistent across the included studies, making it difficult to ascertain effects. Future body composition studies should aim to report and/or control these specific confounders where possible. Collectively, all of these variables demonstrate key challenges in monitoring and analyzing body composition effects in real-world team sport settings, particularly in studies of observational design, where a large portion of the training environment is uncontrolled (McLaren et al., 2018; Malone et al., 2017a). The difficulty of isolating the sole effect of training load on body composition must be recognized, owing to the multitude of complex factors influencing body composition changes both within and across sport.

5.5 Conclusions

This systematic review and meta-analysis synthesized the relationship between team sport and changes in body composition, with a secondary examination investigating the influence of specific training load variables. Understanding this relationship provides fundamental insight into the link between intermittent team sport loads and adaptations across the training process, providing a more comprehensive assessment of athlete monitoring and management. Findings from this review suggest that BF% decreases as an effect of playing elite/professional level team sport, where this reduction appears to be associated with a loss of FM, while LBM and BM generally tend to be maintained. These physical changes are reflective of body composition adaptations occurring as a cumulative effect and byproduct of the various loads, stimuli, and individual responses underpinning team sport training and competition, as opposed to prescribed training and/or nutritional interventions designed to alter physique. These changes are likely due to the heavy reliance on fat metabolism to support the energy demands associated with high level team sport. The degree to which fat is utilized and LBM maintained may be influenced by training status, energy intake and nutritional patterns, aerobic capacity, FFM and resistance training, and sex, where the playing standard may be a key moderator of these relationships, and provide a plausible explanation for many of the differences observed in the results of this review (Burke et al., 2006; Hawley et al., 2011; Jeukendrup, 2003; Purdom et al., 2018; Randell et al., 2017, 2019; Thomas et al., 2016; van Loon et al., 1999; Venables et al., 2005). Many of these variables are also modifiable in nature, and can be optimized to increase metabolic capacity and associated adaptations. Further, this review has preliminary findings to suggest that training load is an unclear, although possibly important moderator of body composition. This review highlights that external workloads accrued through an emphasis on dynamic sport-specific skills, with particular reference to accelerations/decelerations, may increase the intensity, adaptive tissue capacity, and metabolic load of training to optimize conditioning and match preparation when compared to constant-velocity high-speed running and sprinting loads, in line with previous literature (Ade et al., 2014; Buchheit et al., 2015; Gabbett, 2002b, 2006; Gamble, 2004; Gabbett & Ullah, 2012; Harper et al., 2019; Iaia et al., 2009; Reilly, 1997; Scott et al., 2013b). Here, a skill-based physical conditioning approach may permit the concurrent improvement of multiple aspects of athlete development and adaptation through a more practical, effective, and efficient means compared to traditional running drills (Ade et al., 2014; Bujalance-Moreno et al., 2019; Gabbett, 2002b; 2006; Gabbett & Mulvey, 2008; Gabbett & Ullah, 2012; Gamble, 2004; Gaudino et al., 2013, 2014a; Hill-Haas et al., 2009a, 2009b, 2011; Iaia et al., 2009). These findings provide key considerations for the tracking of body composition as a tool to inform effective training planning and athlete monitoring practices for coaches, dietitians, and sports science practitioners across team sports, including the creation, prescription, and adjustment of training load and dietary patterns to optimize individual adaptations while reducing excessive and/or stressful loads. Unfortunately, there is a paucity of studies examining the effect of training load on body composition in team sport, where inconsistencies and diversity in training load monitoring and reporting, including an underestimation of dynamic high-intensity activities, as well as minimal nutritional reporting further complicate the certainty with which body composition adaptations may be interpreted and these relationships ascertained. Combined with these methodological limitations, the small number of studies and sample sizes in this review restrict the statistical power of findings at this time, where future research aiming to address these limitations and implement a more consistent, standardized method of monitoring and reporting of training load and nutrition alongside body composition is warranted to better ascertain these effects.

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Appendices

Appendix A Master search strategy designed in Ovid MEDLINE ®

1. training load*.mp.
2. (load* or work or workload* work-load* or work load*).tw,kf.
3. (quantif* adj4 (training or load* or work or work-load* or work load*)).tw,kf.
4. (monitor* adj4 (training or load* or work or work-load* or work load*)).tw,kf.
5. (dose-response or dose response).tw,kf.
6. (training adj4 (impulse or stress)).mp.
7. (training adj3 response).mp.
8. (internal training load* or internal load* or internal TL).mp.
9. Physical Exertion/
10. "rating of perceived exertion".mp.
11. (RPE or sRPE or s-RPE).mp.
12. (Borg adj4 scale).mp.
13. (perceive* adj3 exertion).mp.
14. "perception of effort".mp.
15. (external training load* or external load* or external work or external TL).mp.
16. (Player Load or PlayerLoad or Body Load).mp.
17. Polar*.tw,kf.
18. Geographic Information Systems/
19. (global positioning system or GPS or (track* adj2 system)).tw,kf.
20. exp Accelerometry/
21. acceleromet*.tw,kf.
22. (time motion or time-motion).mp.
23. motion analysis.mp.
24. exp Acceleration/
25. (acceleration* or deceleration*).tw,kf.
26. (distance adj3 (total or covered)).tw,kf.
27. exp Team Sports/
28. Basketball/ or Football/ or Soccer/
29. Youth Sports/
30. rugby.mp.
31. (handball or netball).mp.
32. (basketball or football* or soccer or futsal or player*).tw,kf.
33. Team sport*.tw,kf.
34. exp Body Composition/
35. body composit*.tw,kf.
36. Anthropometry/
37. anthropometr*.tw,kf.
38. exp "Body Weights and Measures"/
39. (body fat or body fat percent* or BF%).tw,kf.
40. (fat* mass or fat* tissue or fat loss or adipose mass or adipose tissue or adipos*).tw,kf.
41. muscle mass.mp.
42. (fat* free mass or fat-free mass or FFM or LBM or LMM).mp.
43. (lean adj3 (mass or tissue or weight)).mp.
44. (muscle adj3 (growth or gain or size or hypertrophy or loss or maintain or maintenance or preserv*)).mp.
45. Absorptiometry, Photon/
46. (dexa or dual energy x-ray absorptiometry or dxa).tw,kf.
47. Electric Impedance/
48. (bioelectric* impedance or bio-impedance or bio?impedance or BIA).tw,kf.
49. (air displacement plethys* or ADP or Bod Pod or BodPod).tw,kf.
50. (hydrostat* or hydrodens*).tw,kf.
51. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15 or 16 or 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26
52. 27 or 28 or 29 or 30 or 31 or 32 or 33
53. 34 or 35 or 36 or 37 or 38 or 39 or 40 or 41 or 42 or 43 or 44 or 45 or 46 or 47 or 48 or 49 or 50
54. 51 and 52 and 53
55. limit 54 to (english language and humans)

tw: text word, *kf*: keyword heading word, *mp*: multi-purpose