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**INVESTIGATING THE DIETARY  
HABITS OF ADOLESCENT  
ACADEMY SOCCER PLAYERS**

**MARC A. BRIGGS**

**PhD**

**2016**

# **INVESTIGATING THE DIETARY HABITS OF ADOLESCENT ACADEMY SOCCER PLAYERS**

**MARC ANDREW BRIGGS**

A thesis submitted in partial fulfilment of  
the requirements of the University of  
Northumbria at Newcastle for the degree of  
Doctor of Philosophy

Research undertaken in the Faculty of  
Health and Life Sciences

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## **ABSTRACT**

Academy soccer players partake in high volumes of training and match-play, but limited information exists regarding the optimal dietary practices to fuel such demands. Accordingly, the aims of the thesis were threefold: (1) to identify an accurate method of energy intake assessment which quantifies any self-reporting bias bespoke to Academy soccer players, (2) to provide a quantification of the energy intake and energy expenditure of Academy soccer players over a 'typical' training week, specifically highlighting any fluctuations in energy balance, (3) to investigate potential strategies to optimise dietary practices of Academy soccer players to reduce any identified energy deficits, whilst also examining the impact on soccer performance variables.

Chapter 3 aimed to explore the agreement between researcher observed energy intake and self-reported energy intake in male Academy soccer players using a combined self-reported, weighed food diary and 24 h recall method. Considering the widely reported bias associated with using isolated self-report measures, the accuracy of a combined method was examined. Findings suggested that the combined dietary data collection method is an acceptable alternative to researcher observed approach when assessing energy intake in Academy soccer players, providing that appropriate adjustment was applied for the minor systematic under-reporting.

Chapter 4 investigated the energy intake and expenditure of Academy soccer players during a competitive week. The combined method was used to measure energy intake in conjunction with accelerometry to quantify energy expenditure. Findings highlighted that the mean daily energy intake of Academy soccer players was lower than the energy

expended during a competitive week, producing significant daily energy deficits. The magnitudes of these deficits were greatest on match and heavy training days. Furthermore, pre-match dietary practices were identified as a concern, reporting inadequate levels of energy intake to fuel match-play.

Chapter 5 investigated the physiological and performance effects of increasing pre-match energy intake prior to simulated soccer match-play, with the aim of reducing the previously identified significant negative energy balance. Findings demonstrated that Academy soccer players are able to increase pre-match energy intake without experiencing abdominal discomfort, addressing the previously identified energy deficit on such days. Furthermore, whilst increasing habitual energy intake produced limited benefits to physical performance, increased dribbling speed was identified, which may have practical application to match-play.

In summary, this research has provided further information concerning the dietary practices of Academy soccer players, a population which has received limited focus, despite substantial implications considering the high demands of training and match-play in combination with maintaining growth and maturation. Overall findings demonstrate that energy intake remains relatively stable throughout the week, failing to account for the periodised approach to training load. Players are subsequently experiencing significant daily energy deficits in particular during heavy training and match-days. Furthermore, whilst strategies to increase pre-exercise energy intake may help reduce such deficits, limited effects on physiological and soccer-specific performance were identified.

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## LIST OF ABBREVIATIONS

The following abbreviations have been used throughout the thesis and have been defined on first appearance in the text.

<b><u>Abbreviation</u></b>	<b><u>Meaning</u></b>
ACSM	American College of Sports Medicine
ADA	American Dietetic Association
AEE	Activity-induced Energy Expenditure
ANOVA	Analysis of Variance
$B_{hab}$	Habitual Breakfast
$B_{inc}$	Increased Calorie Breakfast
BM	Body Mass
BMI	Body Mass Index
BMR	Basal Metabolic Rate
CI	Confidence Interval
CMJ	Countermovement Jump
CO <sup>2</sup>	Carbon dioxide
CV	Coefficient of Variation
DC	Dietitians of Canada
DLW	Doubly Labelled Water
EPPP	Elite Player Performance Plan
FIFA	Federation Internationale de Football Association
HT	Half-Time
<sup>2</sup> H	Deuterium
kJ	Kilojoule

LIST	Loughborough Intermittent Shuttle Test
LOA	Limits of Agreement
METs	Metabolic Equivalent of Task
MJ	Megajoule
MVPA	Moderate-to-Vigorous Physical Activity
$^{18}\text{O}$	Oxygen-18
PAL	Physical Activity Level
P.E.	Physical Education
PHV	Peak Height Velocity
RMR	Resting Metabolic Rate
RNI	Recommended Nutrient Intakes
RSM	Repeat Sprint Maintenance
SACN	Scientific Advisory Committee on Nutrition
SD	Standard Deviation
SEM	Standard Error of Mean
SMS	Soccer Match Simulation
TDEE	Total Daily Energy Expenditure
TEF	Thermic Effect of Food
U	Under
VAS	Visual Analogue Scale
$\dot{V}\text{O}_{2\text{max}}$	Maximal Oxygen Uptake

## PREFACE

*Peer-reviewed publications that have arisen from this thesis:*

**Briggs, M. A.**, Cockburn, E., Rumbold, P. L. S. & Stevenson, E. (2015). Agreement between two methods of dietary data collection in male adolescent academy-level soccer players. *Nutrients*, 7, 5948-5960.

**Briggs, M. A.**, Cockburn, E., Rumbold, P. L. S., Rae, G., Stevenson, E. J. & Russell, M. (2015). Assessment of energy intake and energy expenditure of male adolescent academy-level soccer players during a competitive week. *Nutrients* 7, 8392-8401.

**Briggs, M. A.**, Harper, L. D., McNamee, G., Cockburn, E., Rumbold, P. L. S., Stevenson, E. J. & Russell, M. (2017). The effects of an increased calorie breakfast consumed prior to simulated match-play in Academy soccer players. *European Journal of Sports Science*. In print.

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## **DECLARATION**

I declare that the work contained in this thesis has not been submitted for any other award and that it is all my own work. I also confirm that the thesis has fully acknowledged the opinions, ideas and contributions of others.

Word count: 39,505

Name: Marc Andrew Briggs

Signature:

Date: 28/11/16

## **Chapter 1: Introduction**

Soccer is the world's most popular sport (Stolen, Chamari, Castagna, & Wisloff, 2005), with 265 million people participating worldwide, which includes 21.5 million U18 youth players (FIFA, 2007). In England alone 2.2 million youth players compete recreationally at least once per week (Sport England, 2016), with approximately one third of this number registered to clubs and Academies (i.e., 820,000; FIFA, 2007). Academy soccer players are engaged in robust training and match-play schedules in a season synonymous in length with their adult counterparts. During match-play, Academy soccer players elicit total match distances of ~7-9 km (Goto, Morries & Nevill, 2015), comprised of  $375 \pm 120$  m per half of high intensity running (Russell, West, Harper, Cook, & Kilduff, 2015), at a mean whole-match intensity of 70-80%  $\dot{V}O_{2max}$  (Maximal Oxygen Uptake; Bangsbo, 1994). Such physical demands also coincide with numerous skilled actions associated with competitive match-play (Stolen et al., 2005). Furthermore, with the recent introduction of the Elite Player Performance Plan (EPPP; Premier League, 2015), Academy soccer players in the UK are engaged in mandatory training volumes of up to 20 h per week, encompassing technical and tactical training, strength and conditioning and physical training covering ~3900-4600 m per training session (Abade, Gonalves, Leite, & Samaio, 2014; Wrigley, Drust, Stratton, Scott, & Gregson, 2012). The compulsory training volumes of the EPPP in combination with the associated characteristics of match-play highlight the significant physical demands required to participate in soccer at this level.

Optimised nutritional practices are important to sustain training and match-play demands (Burke, Loucks, & Broad, 2006), however the majority of investigations into soccer-specific nutrition have mainly been explored in adult professional soccer

(Caldaron, Teanquilli, & Giampietro, 1990; Clark, 1994; Maughan, 1997; Reilly, 1994). Investigations of dietary practices have reported a wide range of energy consumption values of 5.2-16.5 MJ·day<sup>-1</sup> (Caldarone, et al., 1990; Maughan, 1997; Reilly, 1994), comprised of ~50-65%, ~12-15% and ~30-35% carbohydrate, protein and fat, respectively (Clark, 1994; Maughan, 1997). It would however, be misleading to extrapolate these findings to the Academy soccer player considering distinct differences in stage of growth and maturation, in addition to differences identified from training and match-play demands (Goto et al., 2015; Harley, Barnes, Portas, Lovell, Barrett, Paul, & Weston 2010; Wrigley et al., 2012). For example, parameters of match-play differ between age groups with respect to pitch size and match timing, in addition to total distance covered as well as distances covered at high-intensity (Harley et al., 2010; Wrigley et al., 2012). Considering the differing physical demands associated with Academy soccer, it is surprising that limited research has examined the dietary practices of this population to determine if habitual energy intake is sufficient to sustain the demands of training and match-play.

In the relatively limited amount of studies investigating nutritional intake of Academy soccer players, researchers have reported equivocal findings as to whether players are optimising dietary practices to fuel the demands of training and match-play (Boisseau, Le Creff, Loyens, & Poortmans 2002; Russell & Pennock, 2011). Conflicting findings suggest that whilst some studies identify adequate energy intake in relation to estimated energy expenditure or recommended dietary allowances (Boisseau et al., 2002; Iglesias-Gutierrez, Garcia-Roves, Rodriguez, Braga, Garcia-Zapico, & Patterson, 2005; Rico-Sanz, Frontera, Molé, Rivera, Rivera-Brown, & Meredith, 1998), others highlight issues of significant negative energy balance (Caccialanza, Cameletti, & Cavallaro, 2007;

Leblanc, Le Gall, Grandjean, & Verger, 2002; Naughton, Drust, O'Boyle, Morgans, Abayomi, Davies, Morton, & Mahon, 2016; Ruiz, Irazusta, Casis, & Gil, 2005; Russell & Pennock, 2011). The contrasting findings could be explained due to the incorporation of inconsistent methodologies, making it difficult to compare results directly. Estimated food diaries have been predominantly used to assess energy intake over a period ranging from 4-12 days (Boisseau et al., 2002; Caccialanza et al., 2007; Leblanc et al., 2002; Rico-Sanz et al., 1998; Russell & Pennock, 2011), with little consideration for the potential under-reporting bias associated with such methods (Livingstone & Robson, 2000). In the limited amount of studies that have attempted to increase the accuracy of energy intake measures by using a weighed food diary, no measurement of energy expenditure was provided to assess energy balance (Iglesias-Gutierrez et al., 2005; Ruiz et al., 2005). Currently no objective methods of assessing energy expenditure have been used to assess energy balance in Academy soccer players, with the majority opting for estimation equations based on self-reported physical activity levels (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Rico-Sanz et al., 1998; Ruiz et al., 2005; Russell & Pennock, 2011).

Despite methodological limitations, the majority of studies which have provided an estimate of energy expenditure are in agreement that dietary practices are inadequate to sustain the demands of training and match-play (Caccialanza et al., 2007; Leblanc et al., 2002; Ruiz et al., 2005; Russell & Pennock, 2011). In an attempt to quantify the negative energy balance associated with Academy soccer players, mean daily deficits of ~2-8.5 MJ have been highlighted across studies in Europe (Caccialanza et al., 2007; Leblanc et al., 2002; Ruiz et al., 2005), with daily deficits of ~3.3 MJ specifically identified in the UK (Russell & Pennock, 2011). Such daily deficits may have

implications as chronic periods of sub-optimal energy intake, coinciding with sustained periods of high training volumes may impair growth and maturation, whilst also instigating acute soccer-specific performance detriments (Meyer, O'Conner, & Shirreffs, 2007; Petrie, Stover, & Horswill, 2004; Thompson, 1998). Research that has investigated chronic inadequate energy intake in adolescent populations has demonstrated many detrimental effects such as short stature, delayed puberty, poor bone health and increased risk of injury (Bass & Inge, 2006). Thus further highlighting the importance of understanding the energy requirements specific to the Academy soccer player not only for performance benefits but more importantly to offset any potential negative health effects.

Whilst studies have provided evidence of mean negative energy balance in Academy soccer players (Leblanc et al., 2002; Ruiz et al., 2005; Russell & Pennock, 2011), information is lacking in the literature to determine where the greatest energy deficits are occurring throughout the week. Although studies outline mean energy expenditure values and daily deficits (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Naughton et al., 2016; Rico-Sanz et al., 1998; Ruiz et al., 2005; Russell & Pennock, 2011), these studies do not provide a breakdown of the difference between daily activities (e.g., training, rest, match etc.). Furthermore, such methods used to determine energy intake (estimated food diaries) have previously been questioned due to the associated self-reporting bias and lack of accuracy in youth populations (Livingstone & Robson, 2000). Additionally, assumptions of energy balance were made without using objective methods of assessing energy expenditure or in some cases no measures of energy expenditure were provided. Objective methods of assessing both energy intake and expenditure are necessary to

accurately report energy balance. Although Doubly Labelled Water (DLW) is deemed the gold standard when assessing energy expenditure in free living environments (Plasqui, Bonomi, & Westerterp 2013), its holistic measure of energy expenditure, failing to differentiate between training days and intensity of exercise may offer a lack of insight for researchers and practitioners. An alternative to this approach may be to use accelerometers, which have been demonstrated to elicit valid and reliable measures of physical activity in youth within free-living environments (De Vries, Bakker, Hopman-Rock, Hirasing, & Van Mechelen 2006). Due to the equivocal findings resulting from inconsistent methodologies, clarity of information regarding dietary practices in Academy soccer players is limited. Accurate and objective measures of energy balance are warranted to fully understand the energy cost of training and match-play to determine if dietary practices are sufficient to both optimise performance but more importantly to offset any detrimental effects of chronic sub-optimal energy intake.

## **Chapter 2: Literature Review**

The following literature review will initially discuss the prevalence of youth soccer participation within the Academy structure and the subsequent importance of optimal dietary practices with respect to maturation. The review will also quantify the demands of both training and match-play associated with Academy soccer before examining methods of assessing energy balance in this population. Finally, analysis of dietary habits of Academy soccer players will focus on current practices, diet composition and prevailing energy deficits with comment on potential short and long-term implications. Throughout the review, studies specific to Academy soccer will be the primary focus, however where limited data exists, investigations utilising adult counterparts will be explored.

### **2.1 Academy soccer structure and participation**

Academies are associated with professional soccer clubs, and utilise talent identification strategies to recruit players with high-levels of ability. The aim of an Academy is to nurture the ability of youth soccer players, with the aid of expert coaching, to develop players to represent the first team at the professional level. Introduced in 2012, the EPPP (Premier League, 2015) was created as a long-term strategy aiming to develop more and improved ‘home-grown’ players via the Academy system. The EPPP works across a range of age groups, split in to three phases: Foundation (U9 to U11), Youth Development (U12 to U16) and Professional Development (U17 to U21). For the purpose of the thesis, when referring to the term Academy soccer players, this will relate directly to the Youth Development stage.

Academies are allocated funding from the Premier League based upon their category status, with category one identified as the most elite. Academy status is graded on various factors such as training facilities, coaching, education, welfare and sport science support. However, whilst elements such as strength and conditioning and sport psychology are all prerequisites for category one status, nutrition is not. Subsequently nutritional support is often deemed a lesser priority and given limited consideration. Whilst there may be many factors which determine whether or not an Academy player is deemed talented enough to turn professional, optimising the diet to enable adequate energy for sustained performance and recovery can only be beneficial to performance (Burke et al., 2006). Furthermore, considering the wide age range of players training and competing for Academy soccer clubs, practitioners are faced with the added complexity of accounting for the additional energy required for growth and maturation. However, acknowledgment of maturational status within current studies investigating the dietary requirements of Academy players is seldom considered.

### **2.1.1 Considerations for the adolescent athlete**

Growth and maturation are terms that can often be incorrectly considered synonymous. Whilst both have the potential to influence physical performance in soccer, both are separate concepts, which can occur at differing rates. Growth is characterised as changes in body composition, skeletal and muscular dimensions (Tanner, 1990). Whereas maturation is a process, marking progression toward the adult state, involving the maturation of tissues, organs and systems (Armstrong & van Mechelen, 2008). There is large variability between individuals of the same chronological age with respect to somatic and biological growth and maturation, especially during adolescence (Mirwald, Baxter-Jones, Bailey, & Beunen, 2002). Chronological age is often used as a



method of grouping youth populations both within an educational and sporting setting (Mirwald et al., 2002). However, this is problematic as development in biological maturity is not parallel with chronological age (Malina, Bouchard, & Bar-Or, 2004). It is important to account for biological maturity, considering the variability in the timing and tempo of maturation between individuals (Baxter-Jones, 2008). This is a particularly important consideration, creating further difficulty when attempting to quantify the nutritional requirements of adolescent athletes, since large variability in growth and maturation is evident even within the same age group. Optimal nutritional intake for adolescent athletes is significant, not only for augmenting sports performance and minimising the risk of injury, but more importantly to maintain health, growth and maturation (Meyer et al., 2007). Nutrition for youth athletes therefore needs to be viewed in the context of both acute strategies to enhance performance and chronic practices to support growth and maturation (Unnithan and Gouloupoulou, 2004).

It is considered good practice to identify maturational status in studies using youth populations (Armstrong & van Mechelen, 2008). One method of assessing maturity is to identify age at peak height velocity (PHV; Baxter-Jones, 2008). The concept of PHV is referred to as the maximal rate of physical growth spurt, which is typically identified between 11.3 and 12.2 y in boys (Baxter-Jones, 2008). The age at PHV can be predicted using a non-invasive method utilising anthropometric measures to assess maturity. (Mirwald et al., 2002). The technique involves using sex-specific multiple regression equations, to predict years to or from PHV, using the growth patterns of stature, sitting stature and leg length in addition to body mass and chronological age (Mirwald et al., 2002). Thus, age at PHV can be predicted by relating years from PHV to current age (Baxter-Jones, 2008), providing insight in to the maturational status of the participant.

A study by Malina, Eisenmann, Cumming, Ribeiro, & Aroso (2004) investigated the contribution of maturation to speed, power and aerobic performance of Academy soccer players (13-15 y). Stature, mass and maturation were measured in addition to playing experience. Players were required to participate in three physiological performance tests, which measured; sprint time (30 m run), power output (vertical jump) and aerobic capacity (yo-yo intermittent endurance test). Results indicated that stage of maturation and years of playing experience accounted for 21% of the variance in aerobic capacity; mass and stage of maturation accounted for 50% of the variance in sprint time; whereas stature and stage of maturation accounted for 41% of the variance in power output. Therefore, identifying maturation status as having a significant influence on the functional capacity of Academy soccer players. More recently, a study by McCunn, Weston, Hill, Johnson and Gibson, (2016) provided support for the influence of maturation on functional capacity, identifying a relationship between maturity offset and sprinting speed, suggesting the greatest variability occurs within U14 and U15 Academy playing squads. Findings by Malina et al. (2004) and McCunn et al. (2016) highlight how stage of maturation can affect the functional capacity of Academy soccer players of similar age. Thus providing further support for the identification of maturational status to contextualise the research findings of nutritional investigations.

The importance of optimising energy intake is particularly important for youth athletes engaged in rigorous training schedules as inadequate energy intake may reduce the benefits of sport and in some instances cause detrimental effects (Meyer et al., 2007). Bass and Inge (2006) suggest chronic inadequate energy intake in adolescent athletes may result in short stature, delayed puberty and poor bone health. Whilst energy intake

for adult athletic populations have been recommended (Caldarone et al., 1990; Clark, 1994; Hargreaves, 1994; Maughan, 1997; Reilly, 1994), extrapolating such data to inform dietary practices for young athletes may be ill-advised considering observed differences. Adolescence is a critical period of development (Bass & Inge, 2006), which is further complicated by maturation. For example, adolescents of the same chronological age may represent a similar maturational status to children and others more aligned to adults. Younger athletes have been identified as less metabolically efficient (Bar-Or, 2001), with up to 30% higher energy requirements per kilogram of body mass when compared to adults (Krahenbuhl & Williams, 1992). Reasons for such differences have been attributed to increased stride frequency (Unnithan & Eston, 1990), higher resting energy expenditure (Rowland, 2004), variations in power output and mechanical work (Unnithan, Dowling, Frost and Bar-Or, 1999), differences in substrate utilisation (Armstrong & Welsman, 2007), voluntary dehydration (Williams, 2007) and greater reliance on antagonist leg muscle contraction (Frost, Bar-Or, Dowling, & Dyson, 2002) in younger athletes. However, it is acknowledged that the aforementioned differences are predominantly identified in children and are likely to be less prevalent in adolescents with increasing maturation toward adulthood.

Attempts have been made to produce energy reference values (Scientific Advisory Committee on Nutrition: SACN, 2011) for adolescents, differentiating between sex, age and activity level. These current guidelines are an improvement from the previously established national dietary reference values (Department of Health, 1991), which have been criticised for failing to account for the increased energy cost of highly active adolescent athletes (Petrie et al., 2004), whilst also providing limited consideration for differences in chronological age and maturational development (Meyer et al., 2007).

However, SACN (2011) guidelines take in to consideration the energy cost of growth as well as a range of physical activity levels, providing a more comprehensive estimation of energy requirements. Nevertheless, due to the large inter-individual variability in the energy cost of training, coupled with the unpredictable onset of growth spurts, devising bespoke nutritional guidance for this population is challenging (Petrie et al., 2004). Therefore, despite the improvement in the estimated average requirement values for energy, such advice must be applied with caution. Whilst such recommendations may be used as a guide, practitioners should aim to monitor their athletes' anthropometric variables to ensure energy intake is able to sustain growth and maturation whilst also adequately fuelling individualised training and match-play demands (Meyer et al, 2007).

### **2.1.2 Demands of soccer match-play**

Soccer is an invasive field game, which is typically classified as a high-intensity, intermittent team sport comprised of two 45 min halves (Stolen, et al., 2005). Brief periods of high-intensity anaerobic activity are coupled with a larger contribution from the aerobic system to fuel lower-intensity movement patterns (Drust et al., 2000). Soccer is a complex sport, requiring skilled actions to be completed in rapidly changing environments, under fatiguing conditions (Goto et al., 2015). Thus providing difficulties in quantifying the energy cost of such demands. However, analysis of match-play in both elite and non-elite youth soccer has been documented, albeit predominantly outside of the UK (Buchheit, Mendez-Villanueva, Simpson & Bourdon, 2010a; Castagna, D'Ottavio & Abt, 2003; Castagna, Impellizzeri, Cecchini, Rampinini & Alvarez, 2009; Pereira Da Silva, Kirkendall, & De Barros Neto, 2007; Stroyer, Hansen & Klausen,

2004), with only two studies focusing on UK Academy soccer players (Goto et al., 2015; Harley et al., 2010).

Harley et al. (2010) aimed to understand the demands of match-play across a range of age-groups (U12-U16), whilst competing for English professional soccer Academies. Unsurprisingly, results indicated distinct match variables across the age groups. Total distance covered within match-play was significantly higher at U16 level ( $7672 \pm 2578$  m) than at U12 ( $5967 \pm 1277$  m;  $p < 0.05$ ), U13 ( $5813 \pm 1160$  m;  $p < 0.05$ ) and U14 level ( $5717 \pm 2060$  m;  $p < 0.01$ ). However, it is important to acknowledge that parameters of match-play differ between age groups with respect to pitch size and match timing. Similarly, Goto et al. (2015) identified total match distances from ~7700 m (U16) to ~5800 m (U11), demonstrating a 33% increase ( $p < 0.01$ ) between age groups within the same Academy population. Interestingly, within the U15/16 squads, players who were subsequently retained by the Academy covered a 17% greater total match running distance ( $7901 \pm 1264$  m vs.  $6750 \pm 1428$  m;  $p < 0.05$ ) (Goto et al., 2015). Furthermore, an increase in running distance at high-intensity from the U11 to U16 squads was evident (Goto et al., 2015), a finding also identified by Harley et al. (2010). These findings may suggest that an important characteristic of older, more successful Academy players, is the ability to cover greater distances at higher speeds. Harley et al. (2010) and Goto et al. (2015) provide information to confirm match-play demands differ from their adult counterparts (Bangsbo, Mohr & Krstrup, 2006), thus applying adult-based soccer-specific nutrition guidance to fuel such demands may not be appropriate and bespoke nutritional guidance for Academy soccer players is therefore warranted.

The analysis of match-play demands of UK Academy soccer players is similar to that identified in different countries. For example, total match distances of ~6000-9000 m were observed during 60-90 min match-play, with up to 30% of total distance covered at high intensity (Buchheit, et al., 2010; Castagna et al., 2003; Castagna et al., 2009). A study by Le Gall, Carling, Williams and Reilly, (2010), supports the notion of distinctive characteristics among successful and unsuccessful players (Goto et al., 2015). Results identified significant differences in players from French professional U14-U16 Academy squads who eventually received a professional contract and/or international appearance, highlighting a faster sprint time over 40 m as well as being taller in stature. Whilst match-play demands of Academy soccer appear to be universal, the training demands associated with the EPPP are unique to UK Academies, therefore information quantifying training demands bespoke to this population is warranted.

### **2.1.3 Demands of a soccer training week**

In contrast to match-play demands the quantification of training demands in Academy soccer players are not well documented. Academy soccer players in the UK engage in mandatory training volumes of up to 20 h per week in accordance with the newly adopted EPPP (Premier League, 2015). This is in addition to other physical demands (school P.E.; county and/or national representation and other sporting commitments), independent of Academy training, comprising training loads which are not comparable to non-UK Academy players or indeed UK based full-time scholar soccer players (Professional Development phase) or adult professionals. Thus far no research has investigated a typical training week for the Academy player, encompassing additional energy demands outside of Academy training. However, despite this, studies have

attempted to provide insight into the quantification of training load associated with Academy training schedules.

A study by Wrigley et al. (2012) is the only study to date to quantify the typical weekly training load experienced by youth Academy soccer players during the in-season competitive period in the UK. Players (U14, U16 and U18 squads) were monitored over 2 weeks using heart rate and rating of perceived exertion. Despite differences in training schedules, results attempted to provide a breakdown of training mode across the age groups. Technical/tactical training accounted for 30% of time in U14 and U16, whereas only 23% in U18. Physical training accounting for 20%, 22% and 23% in the U14, U16 and U18 respectively. Strength training contributed to a similar percentage of time across the three age groups (U14, 20%; U16, 22%; U18, 23%). The mean duration of field training was generally greater in U18 (~104 min) and U16 (~102 min) compared to U14 (~90 min). Gym-based training duration was similar across age groups (30–35 min) (Wrigley et al., 2012). Findings demonstrate evidence of age-related increases in the intensity and volume of training, with differences in the periodisation of weekly training load (Wrigley et al., 2012). Whilst findings provide insight into the weekly loads experienced by Academy players, it is worth acknowledging that this data collection period was during the 2010/11 season, prior to the introduction of the EPPP, therefore findings may not fully represent the new training requirements of Academy soccer players and thus need to be interpreted with caution. Furthermore, a quantification of energy demands were not presented, providing limited insight on the energy cost of the reported training load. Thus information upon which to base recommendations of optimal dietary practices to fuel training, still remains unclear.

Albeit not UK based, Abade et al. (2014) aimed to determine a profile of regular training sessions performed during the competitive season by 151 U15, U17 and U19, elite-level Portuguese soccer players. Body-impact (any aspect of contact with the opposition) and time motion analysis was derived from GPS data collection over a 9-week in-season training period. Results identified the highest total distances covered were in the U17 squad ( $4648 \pm 832$  m), followed by U19 ( $4213 \pm 935$  m) and U15 ( $3965 \pm 725$  m) players. With regards to the physicality of the training, total body impacts and relative impacts were lower in U15 players (total:  $491 \pm 310$ ;  $p < 0.05$ ), although no significant differences were identified between U17 (total:  $584 \pm 364$ ) and U19 (total:  $613 \pm 329$ ). However, the U19 players had less high intensity activity (above 16 km/h) and moderate-intensity activity (10.0-15.9 km/h) than U15 and U17. Abade et al. (2014) state there is high variability in periodised programmes between age groups and whilst there are distinct differences caution is needed when extrapolating meaningful trends. The lack of detail presented regarding the frequency and length of training practices within the different age groups provided difficulties in comparing such demands with UK Academy training.

Whilst the findings reported by Wrigley et al. (2012) and Abade et al. (2014) provide an insight into the typical training load of Academy soccer players, no information is provided on energy expenditure. Furthermore, these studies do not account for the additional energy cost of exercise outside of the Academy. This is an important consideration for Academy players who will likely have additional physical exertion in the form of school P.E. or extra-curricular sporting activities. A quantification of energy cost is required in the context of kJ or MJ, to contextualise training load and prescribe nutritional guidelines for this population. Whilst there is evidence to suggest training



load and volume differs between Academy age groups (Abade et al., 2014; Wrigley et al., 2012), it is unclear how this is reflected in terms of energy expenditure. Subsequently, Academy players are unable to accurately fuel the demands of training and match-play, therefore having limited information to offset the modulating effects of soccer performance with regards to fatigue, fuel depletion and dehydration.

#### **2.1.4 Consequences of training and match-play demands**

The ability to sustain the demands of training and soccer match-play is integral to the performance outcome (Krustrup, Mohr, Steensberg, Bencke, Kjaer & Bangsbo, 2006). Transient changes have been identified throughout match-play (Krustrup et al. 2006) and in particular, from 45 min onwards (Harper, Hunter, Parker, Goodall, Thomas, Howatson, West, Stevenson & Russell, 2016a; Harper, Clifford, Briggs, McNamee, West, Stevenson & Russell, 2016b; Mohr, Krustrup & Bangsbo, 2005; Russell, Sparkes, Northeast & Kilduff, 2015; Russell, Benton & Kingsley, 2011b). Sustaining performance levels are likely to be modulated by a number of factors, for example hydration status, rate and type of fuel utilisation and onset of fatigue. The following section will critically examine factors, which affect the ability to maintain performance levels in soccer and their impact on subsequent performance outcomes.

##### **2.1.4.1 Fatigue during training and match-play**

Fatigue can be described as an acute impairment of performance including an increase in perceived effort and/or any reduction in the ability to exert maximal muscle force or power (Rampinini, Bosio, Ferraresi, Petruolo, Morelli & Sassi, 2011). Studies investigating fatigue in elite level professional soccer players have identified decreases in the total amount of sprints, high-intensity running and distanced covered in the

second half (Bangsbo, Norregaard & Thorsoe, 1991; Bangsbo, 1994; Mohr, Krstrup, Bangsbo, 2003a; Rampinini et al., 2011). Whilst the exact cause of fatigue still remains a topic of debate (Mohr et al., 2005; Reilly, Penpraze, Hislop, Davies, Grant & Patton, 2008; Russell, Benton & Kingsley, 2012), detriments to performance and the causes of match-related fatigue are complex and likely to be multifaceted in origin, involving mechanisms acting centrally (Reilly et al. 2008), or peripherally (Alghannam, 2012). Physiological responses impacting the central nervous system (Mohr et al., 2005) and disturbances in acid-base balance (Russell et al., 2012), fibre-specific muscle glycogen concentrations (Krstrup et al., 2006), hydration status (Bangsbo et al., 2006) and reductions in blood glucose concentrations (Bangsbo et al., 2006) are all likely contributors to fatigue. Although fatigue in soccer has been well documented in adult studies, limited findings have been determined for youth players, however in studies investigating adolescent populations, results suggest that responses may not differ markedly (Harper et al. 2016a; Harper et al., 2016b; Russell et al., 2011b).

It is accepted that elite adult soccer performance can be detrimentally affected during the second half and toward the end of match-play, as well as transiently during intensive periods throughout the 90 min period (Mohr et al., 2005). Mohr et al. (2003a) compared the impact of fatigue on top-level vs moderate-level adult professional male soccer players, using time motion analysis to track match-play movement. Results indicated that regardless of playing standard and position, high-intensity running was reduced by 35-45%, in the last 15 mins of match-play when compared to first half performance. Analysis of the most intense period of the match revealed that only 3% of players experienced this in the last 15 mins, with ~40% recording the least intensive activity spell during the same period. Such decrements in performance may indicate that players

are utilising their full physical potential during match-play. Furthermore, after peak periods of high-intensity activity, performance was reduced by 12% in the following 5 mins in relation to the total match-play average (Mohr et al., 2003a). Explanation of such decreases in performance following intense periods of high-intensity activity could be indicative of tactical changes or natural fluctuations in match-play. However, Krustup, Mohr, Steensberg, Bencke, Kjar & Bangsbo, (2003a) supports Mohr's (2003a) findings of temporary fatigue during match-play. Krustup et al. (2003a) highlighted a significantly reduced sprint performance immediately after intense periods throughout the first half, however sprint performance was recovered when assessed at the end of the first half. The findings of Mohr et al. (2003a) and Krustup et al. (2003a) provide evidence of transient fatigue during match-play suggesting it is more complex than a linear effect of time.

Research findings also indicate that immediately after a passive half-time period, performance levels are affected. Mohr et al. (2005) identified the initial stages of the second half as a period of reduction in aspects of team performance. Mohr et al. (2005) findings demonstrate 20% of elite-level soccer players experience their least intense 15 min period following the start of the second half, with a significant reduction in high-intensity running. In support of this finding, Weston, Batterham, Castagna, Portas, Barnes, Harley and Lovell, (2011) also reported that total distance, high-speed running distance and sprinting distance all decreased between 45-60 min in comparison to the first 15 min of match play. Furthermore, a significant increase in risk of injury has been identified in the first 20 mins of the second half (Hawkins & Fuller, 1994). In addition, Rahnama, Reilly and Lees (2002) conducted an analysis of premier league soccer matches throughout a season and found that injuries were most frequent during the first

15 mins of the second half. Whilst factors contributing to increased risk of injury are likely to be multifaceted in origin, the onset of fatigue as a result of first half activity and insufficient recovery during half time may be partly responsible (Russell et al., 2015).

Consistent findings of soccer-related fatigue on physiological parameters have been documented (Bangsbo, 1991; Bangsbo et al., 1994; Harper et al., 2016b; Mohr et al., 2003a; Rampinini et al., 2011), however investigations concerning the effect of fatigue on technical skill-based actions during match-play are seldom reported. Russell et al. (2011b) conducted the only study to date to examine the effects of exercise-induced fatigue on skills performed during a soccer-match simulation in youth populations. Academy soccer players ( $n = 15$ ) volunteered to partake in a soccer-specific protocol which was purposefully designed to replicate the physiological demands of match-play whilst also assessing the precision and success of skilled actions such as passing, dribbling and shooting. Match-related fatigue was evident within shooting precision and passing speed. Shots post-match were  $\sim 26\%$  ( $p < 0.05$ ) less accurate than baseline scores and passing speed reduced by  $\sim 7\%$  ( $p < 0.05$ ) in the last 15 min of match-play in comparison to the first 15 mins. Furthermore, both shooting and passing speeds produced slower execution during the second half when compared to the first half (both;  $p < 0.05$ ), however dribbling performance was deemed to be unaffected throughout match-play. Russell et al. (2011b) suggest soccer-specific skills are also detrimentally affected during match-play, producing similar decrement patterns to reported physiological parameters.

Information on the impact of fatigue on performance variables within youth soccer populations is limited, which is especially concerning considering physiological differences between youth and adults (Armstrong and Welsman, 2007; Bar-or, 2001; Rowland, 2004; Unnithan et al., 1999). Findings of a biopsy study of 22 males (5–37 y) found a highly significant negative relationship between the proportion of type I fibres in the vastus lateralis and age (Lexell, Sjoström & Nordlund, 1992). The proportion of type I fibres decreased from ~65% at 5 y to ~50% at 20 y, with a levelling off thereafter, suggesting an age related decline toward full maturation. Furthermore, an increase in type I fibres during childhood may highlight a greater oxidative capacity, due to the increased mitochondrial density and oxidative capacity associated with type I muscle fibres, coinciding with a decreased capacity for PCr and glycogen content as well as a reduction in ATPase and glycolytic enzyme activity (Armstrong and Welsman, 2007). Therefore, such differences may influence the energy stores and subsequent substrate utilisation of Academy players, (dependent upon stage of maturation), impacting on the mechanisms of fatigue. Whilst ATP stores in adolescents appear to be similar to adults ( $5 \text{ mmol} \cdot \text{kg}^{-1}$  wet weight muscle; quadriceps femoris), PCr concentrations seem to be age dependant (Eriksson 1980). Pre-pubertal males averaged  $14.5 \text{ mmol} \cdot \text{kg}^{-1}$  wet weight, rising to values comparable with adults,  $23.6 \text{ mmol} \cdot \text{kg}^{-1}$  wet weight, at 15 y (Eriksson 1980). Furthermore, muscle glycogen at rest averaged  $54 \text{ mmol} \cdot \text{kg}^{-1}$  wet weight at 11 y, progressively increasing to  $87 \text{ mmol} \cdot \text{kg}^{-1}$  wet weight by 15 y, similar to adult findings (Eriksson 1980). However, total glycogen stores in adolescents will still be lower, considering differences in muscle mass.

From the limited amount of studies available findings suggest that the Academy soccer players' response to match-play is similar to their adult counterparts (Harper et al.,

2016b), however, although stage of maturation was not provided, caution must be applied as mean age was  $17 \pm 1$  y suggesting players were beyond PHV. Harper et al. (2016b) investigated the physiological responses and acid-base balance of Academy soccer players during a soccer match simulation. Results demonstrate a reduction in second half sprint speed compared to first half performance. Furthermore, perception of exertion of all aspects of soccer match-play was significantly higher in the second half compared to the first ( $p < 0.05$ ). However, mean and peak heart rate in addition to blood lactate concentrations produced similar values throughout 90 mins of match-play (Harper et al., 2016b).

Detriments to performance and the causes of match-related fatigue are complex, however, depletion of liver and muscle glycogen has been attributed as one of the main mechanisms of fatigue in soccer match-play (Krustrup et al. 2006). Therefore, restoring muscle glycogen stores post-match has been a topic of interest, highlighting post-exercise glycogen synthesis rate an important factor in determining the time needed to recover. To optimise glycogen synthesis rates, sufficient amounts of carbohydrate should be ingested (Bergstrom and Hultman, 1966; Ivy, Lee, Brozinick & Reed, 1988). An early study by Blom, Hostmark, Vaage, Kardel and Maehlum, (1988) reported maximised muscle glycogen synthesis when carbohydrate was consumed at 2 h intervals in doses equivalent to  $0.35 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ . In a similar study Ivy et al. (1988), reported greater carbohydrate intake ( $0.75 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ ) optimised glycogen synthesis, although an intake of  $1.5 \text{ g}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$  provide no significant increase in storage rate. Higher glycogen synthesis rates have been reported in studies in which carbohydrates were ingested more frequently and at higher ingestion rates. Specifically in soccer players, Jenjens and Jeukendrup (2003), suggested an optimal carbohydrate intake of

1.2 g·kg<sup>-1</sup>·h<sup>-1</sup> post-exercise, and at 15-60 min intervals for up to 5 h enables maximum resynthesis of muscle glycogen stores, resulting in improved recovery for subsequent exercise.

Whilst mechanisms of match-related fatigue are complex, depletion of liver and muscle glycogen can be modulated by pre-exercise nutritional status (Anderson, Orme, Di Michele, Close, Morgans, Drust & Morton, 2016), and recovery strategies (Jenjen and Jeukendrup, 2003), suggesting optimising energy intake, in particular pre-exercise, may attenuate the onset of fatigue during match-play. Furthermore, considering the high demands of training and match-play experienced by the Academy player, combined with increased energy requirements to sustain growth and maturation, limited information is available on optimising such dietary practices to offset fatigue.

#### **2.1.4.1.1 Fuel depletion during training and match-play**

Optimising nutritional practices is deemed important to sustain training and match-play demands (Burke et al., 2006). Consequently, research attempting to minimise fuel depletion during exercise has received considerable attention. In an early study, Saltin (1973) demonstrated the importance of muscle glycogen for subsequent exercise performance. Results revealed that players commencing exercise with greater pre-match muscle glycogen concentrations reduced the rate of glycogen depletion observed at half-time, covered 25% more total match distance, and experienced ~10% increases in high-intensity running when compared to a low carbohydrate group. Whilst contrasting findings have been demonstrated (Jacobs, Westlin, Karlsson, Rasmusson & Houghton, 1982; Leatt & Jacobs, 1989), reporting more sustained levels of muscle glycogen during soccer performance, the findings of Krstrup et al. (2006) support Saltin (1973) results

of match-related fatigue. Krstrup et al. (2006) identified a 43% decrease in muscle glycogen, with further analysis reporting that 50% of single muscle fibres experienced depletion or near depletion in glycogen concentrations as a result of match-play, as well as experiencing fatigue transiently throughout the 90 mins. More recently, when compared to ingestion of 3 g·kg<sup>-1</sup> BM carbohydrate, Souglis, Chryssanthopoulos, Travlos, Zorzou, Gissis, Papadopoulos & Sotiropoulos, (2013) observed improved match performance (i.e., total match distances, including increased distance covered in all running intensities performed) when players commenced competition after consuming 8 g·kg<sup>-1</sup> BM of carbohydrate for the 3.5 days prior to the game. Thus highlighting energy intake in the days preceding match-play as an important area of consideration. In addition, Goedecke, White, Chicktay, Mahomed, Durandt, & Lambert (2014) identified an improved time to fatigue during a simulated soccer match when players consumed a 7% carbohydrate solution during match-play, offering a within match-play strategy to attenuate the effects of fatigue.

Previous research has predominately recruited adult soccer players, with limited investigations examining the role of fuel depletion during Academy soccer match-play, primarily due to ethical issues associated with invasive procedures. To address the scant studies available, Rico-Sanz, Zehnder, Buchli, Dambach & Boutellier, (1999) used non-invasive magnetic resonance spectroscopy to determine individual muscle glycogen depletion during a soccer-match simulation with elite youth players. Whilst pre-exercise nutritional intake is not reported, results indicated a reduction in muscle glycogen content of ~35% at the end of ~45 mins. Rico-Sanz et al. (1999) also identified a significant correlation between glycogen utilisation and time to exhaustion ( $p < 0.05$ ), suggesting glycogen is an important factor for soccer match-play, and carbohydrate



intake should be considered pre-exercise. Therefore, it may seem that the impact of glycogen depletion of soccer performance is similar to that of adult counterparts (Krustrup et al., 2006; Saltin, 1973), however this may be expected considering the mean age of the sample was  $17.4 \pm 0.8$  y, which would insinuate a maturation status similar to their adult counterpart, however no determination of maturity was measured. In a subsequent study, Zehnder, Rico-Sanz, Kuhne and Boutellier (2001) examined whether habitual dietary practices of youth soccer players were sufficient to restore glycogen levels following fatiguing match-play. Results identified a diet comprised of  $4.8 \text{ g}\cdot\text{kg}^{-1}$  carbohydrate replenished glycogen stores by up to 90% of pre-exercise levels within 24 h. However, the sample consisting of players with a mean age of  $17.5 \pm 0.8$ , again, more than likely representing full maturation status comparable with adults.

In the relatively limited research within youth soccer, studies have focused on methods of attenuating fatigue-induced performance detriments. Phillips, Turner, Gray, Sanderson and Sproule (2010) published the first study to examine the influence of carbohydrate ingestion immediately before and during a soccer-specific exercise protocol with adolescent (12-14 y) participants. A 6% maltodextrin solution was compared to a taste, colour and texture-matched placebo. The dose was comprised of  $5 \text{ mL}\cdot\text{kg}^{-1}$  BM 5 min pre-exercise and  $2 \text{ mL}\cdot\text{kg}^{-1}$  BM every 15 min during exercise. Findings highlight a significant increase (24%) in time to exhaustion consuming carbohydrate compared to placebo (Phillips et al., 2010). Whilst this study supports the findings of adult-based research using similar methods (Davis, Welsh & Alderson, 2000; Nicholas, Williams, Lakomy, Philips & Nowitz, 1995; Welsh, Davies, Burke & Williams, 2002), the improvement is lower than previously reported (32-52%). The large improvement in high-intensity intermittent endurance capacity within adult studies

is explained by the sparing of endogenous muscle glycogen as a consequence of carbohydrate ingestion, increasing blood glucose uptake and oxidation (Davis et al. 2000; Nicholas et al., 1995; Welsh et al., 2002). However, Phillips et al. (2010) was unable to support such conclusions due to no collection of blood metabolite data.

One possible reason to explain the lower, yet significant, improvement in time to exhaustion within adolescent participants (Phillips et al., 2010), compared to adult findings replicating similar methodologies (Davis et al. 2000; Nicholas et al., 1995; Welsh et al., 2002), may be due to the physiological maturity of the participants. The participants within the study conducted by Phillips et al. (2010) were a mean age of 13 y. Lower muscle glycogen concentrations have been identified in early adolescents (12-14 y) compared to adults (Aucouturier, Baker & Duche, 2008), although this is correlated with maturation, with more comparable responses observed in adolescents with maturation status toward adulthood. Furthermore, while endogenous carbohydrate utilisation during exercise is lower in early adolescence than during adulthood, the relative oxidation of exogenous carbohydrate is considerably higher (Timmons, Bar-Or & Riddell, 2003). Therefore, the greater reliance on exogenous carbohydrate in early adolescence may be important in preserving endogenous stores. This may suggest that although the 6% carbohydrate solution ingested in Phillips et al. (2010) study resulted in augmenting performance compared to the placebo, this may still not be sufficient to match performance improvements identified in adult populations and a higher dose may be required. However, with the lack of metabolic measures, conclusions are difficult to determine.

In a later study by Phillips, Turner, Sanderson and Sproule (2012), the focus shifted to examining the optimal carbohydrate dose for performance improvements. Performance effects of maltodextrin concentrations of 2%, 6% and 10% were investigated, consuming 5 mL·kg<sup>-1</sup> BM 5 min pre-exercise and 2 mL·kg<sup>-1</sup> BM every 15 min during a modified version of the Loughborough Intermittent Shuttle Test (LIST) protocol. Findings highlight the 6% solution as the most effective, demonstrating a 34% significant improvement in time to exhaustion when compared to 10% solution, in addition to a 15% improvement against 2% solution, albeit not statistically significant (Phillips et al., 2012). Interestingly this study provides insight in to the potential optimal guidelines for youth soccer performance, suggesting these may not be synonymous with adult recommendations (Jeukendrup, 2004), with adult studies reporting non-significant improvements (Nassis, Williams & Chisnall, 1998) when ingesting similar rates to Phillips et al. (2012). In an attempt to explain the lack of influence during the 10% trial, Phillips et al. (2012) posit that the reasons are inconclusive and may not be simply a case of exceeding the maximal rate of carbohydrate absorption or oxidation. Moreover, a preferred justification of findings was attributed to the large variation in participants' time to exhaustion and relative small sample size (Phillips et al., 2012), suggesting an individualised response to this level of carbohydrate intake.

Regardless of carbohydrate dose, evidence suggests a limited influence on anaerobic performance (Phillips et al., 2010; Phillips et al., 2012) in youth soccer players. The non-significant treatment effect on sprint performance support similar studies in adult populations (Davis et al., 2000; Nicholas et al., 1995), who were also unable to offset sprinting decrements with exogenous carbohydrate supplementation. Furthermore, sprinting performance not only declined but interestingly the magnitude of the decline

was greater than that demonstrated in adult populations. Whilst previous adult studies have shown a mean sprint time increase of 0.08 sec between the first and last block of exercise in both carbohydrate and placebo trials (Ali, Williams, Nicholas & Foskett, 2007), a 0.20 and 0.19 sec sprint time increase was identified in carbohydrate and placebo trials respectively during Phillips et al., (2010) study. This finding provides contrasting evidence to the suggestion that adolescents may display a greater resistance to fatigue compared to their adult counterparts (Ratel, Duche, Hennegrave, Van Praagh & Bedu, 2002).

With regards to the improvements associated with carbohydrate supplementation during soccer performance, studies have attempted to explain the mechanisms underpinning the purported benefits. A 22% reduction in type I and type II muscle glycogen utilisation during the first ~75 min of soccer specific exercise has been reported when consuming a carbohydrate beverage (Nicholas et al., 1995). This has been attributed to exogenous carbohydrate oxidation, sparing endogenous stores; greater activity of the pyruvate dehydrogenase complex due to hyperinsulinaemia; lower blood lactate concentration and glycogen resynthesis in type II fibres due to elevated blood glucose and insulin levels (Nicholas et al., 1995). However, it is important to note that only a small amount of exogenous carbohydrate appears to be oxidised or made available for oxidation, in the first hour of exercise regardless of whether carbohydrate exerts an ergogenic effect (Jeukendrup, Brouns & Wegenmakers, 1997) or not (McConell, Canny & Daddo, 2000). Furthermore, whilst significantly greater carbohydrate oxidation rates have been highlighted in studies investigating the effects of carbohydrate ingestion (Ali et al., 2007), along with a strong trend for attenuating blood free fatty acid (Davis et al., 2000) and fat oxidation (Ali, 2009), this has not always been consistent (Nassis et al., 1998).

Nassis et al. (1998) reported no increase in carbohydrate oxidation despite carbohydrate supplementation, although this may be explained by protocol issues, as infrequent blood sampling and small sample size may impact findings.

A significantly lower heart rate has been reported in carbohydrate trials when compared with a placebo (Davis et al., 2000), suggesting reduced stress on the cardiovascular system, enhancing the ability to maintain higher intensities at a given heart rate, possibly contributing to an improved intermittent exercise capacity. However, contrasting evidence demonstrates that carbohydrate exerts limited influence on heart rate and plasma volume during team game exercise, suggesting heart rate response is an ineffective mechanism to explain carbohydrate supplementation (Ali et al., 2007). Furthermore, Ali et al. (2007) highlighted increased heart rate during soccer-specific exercise when consuming carbohydrate, mainly due to the increased ability to elicit faster sprint times during the run to exhaustion. Improved sprint performance during carbohydrate-electrolyte trials have been attributed to maintenance of blood glucose levels, enabling greater muscle and cerebral metabolism (Ali et al., 2007; Welsh, 2002), therefore maintaining central nervous system function, allowing better maintenance of power output and muscle glycogen sparing. However, such conclusion have received criticism as blood glucose concentrations did not reach hypoglycaemic levels in the carbohydrate-electrolyte or placebo trials in both Ali et al. (2007) and Welsh et al. (2002) studies. Participants in Ali et al. (2007) were in a fasted state pre-exercise with depleted glycogen stores, which may explain the improved sprint performance in the carbohydrate-electrolyte trial, as short duration, maximal intensity exercise can be attenuated if muscle glycogen levels fall below a critical threshold ( $\sim 200$  mmol $\cdot$ kg dry weight; Bangsbo et al., 2006). Therefore, ingestion of carbohydrate may have provided

a sufficient supply of glucose to the muscle to enable greater sprint performance in the glycogen-depleted state compared with placebo.

Despite some contrasting findings, current research investigating the effects of a pre-exercise carbohydrate solution in youth soccer players, present clear evidence of augmenting time to exhaustion (Phillips et al., 2012; Phillips et al., 2010). However, it is the technical actions such as passing accuracy to create a goal scoring opportunity or shooting precision to convert such opportunities which ultimately determine the results of match-play. Russell et al. (2012) is the only study to date to examine the influence of carbohydrate ingestion on the execution of soccer-specific skills in an adolescent population. Utilising a 90 min soccer match simulation, eliciting movement patterns and intensities relative to match-play; speed, precision and success were examined for dribbling, passing and shooting execution. Findings demonstrated a 6% carbohydrate electrolyte beverage attenuated detriments in shot speed by 10% compared to placebo (Russell et al., 2012). Whilst mechanisms to determine improvements remain unclear, it is conceivable that the exogenous carbohydrate increased blood glucose concentrations influencing the decision-making processes and subsequent performance of the skill (Russell et al., 2012). This idea is supported by Bandelow, Maughan, Shirrefs, Ozgunen, Kurdak, Ersoz, Binnet and Dvorak (2010), reporting faster fine-motor speed during periods of higher blood glucose concentrations after soccer match-play. However, such explanations fail to account for the lack of influence over other elements of skill execution within Russell et al. (2012) study, combined with the omission of cerebral glucose flux measures, offers a lack of support for the purported benefits. Blood glucose concentrations during the carbohydrate-electrolyte trial were elevated beyond placebo both pre-exercise and at half-time, although carbohydrate treatment was

unable to sustain the higher levels immediately after half-time and at 90 mins (Russell et al., 2012). This finding suggests that a 6% carbohydrate-electrolyte beverage is unable to attenuate glycaemic responses indicative of match-play during the commencement of the second half and towards the end of 90 mins (Russell et al., 2012), which may be critical for successful execution of soccer-specific skills and subsequent performance outcome.

While it is important to understand the impact of fuel depletion on training and match-play and the subsequent effect on soccer performance variables, limited studies have considered energy balance. For example, pre-match energy intake requirements may be effected if players are in a state of negative energy balance the previous day. Additionally, studies investigating the performance effects of pre-match intake often administer the intervention dose in a fasted state (Phillips et al., 2012; Phillips et al., 2010), questioning the ecological validity of the research design. Furthermore, seldom information exists to understand the habitual dietary practices of Academy soccer players both on training days and pre-match to understand if energy intake is optimal.

#### **2.1.4.1.2 Dehydration during training and match-play**

Increased energy expenditure resulting from training and match-play coincides with an increase in metabolic activity. Such activity is associated with high levels of metabolic heat production, as ~75-80% of energy is converted into heat within the working muscles (Shirreffs, Aragon-Vargas, Chamorro, Maughan, Serratos & Zachwieja, 2005). Moreover, during high ambient temperatures the body's heat load can be further increased (Laitano, Runco & Baker, 2014). The primary mechanism to remove the accumulation of body heat is via the evaporation of sweat from the surface of the skin

and a modified blood flow to the periphery for heat dissipation (Convertino, Armstrong, Coyle, Mack, Swaka, Senay & Sherman, 1996). While sweating is a necessary response to exercise to maintain core body temperature, this may result in sweating-induced dehydration (Maughan, Merson, Broad & Shirreffs, 2004). Dehydration is characterised as the process of body water loss and is often contextualised in terms of changes in body mass pre and post exercise (Laitano et al., 2014). Furthermore, it is generally accepted that sweat losses equivalent to >2% of body weight may induce performance degradations (Cheuvront, Montain & Swaka, 2007).

McGregor, Nicholas, Lakomy and Williams (1999) and Maughan et al. (2004) examined the effects of dehydration during elite soccer performance. Whilst McGregor et al. (1999) study design was lab based, participating in 90 min of soccer-specific exercise in two conditions (either abstaining from fluid intake or consuming 5 ml·kg<sup>-1</sup> BM immediately before exercise and 2 ml·kg<sup>-1</sup> BM every 15 min during the protocol), Maughan et al. (2004) offered a more free-living design. Dehydration of 2.5% was reported in the no fluid condition, resulting in an increased rating of perceived exhaustion when compared to the fluid intake trial, which produced dehydration of 1.4% (McGregor et al., 1999). Comparable findings were identified by Maughan et al. (2004) with sweat loss resulting in moderate hypohydration (mean body weight decrease of ~1.4%). However, only the group abstaining from fluid, displaying dehydration of 2.5% slowed sprint performance and reduced dribbling speed by 5% post exercise. Conversely, dehydration did not affect cognitive function (McGregor et al., 1999), a key aspect of the decision making process within soccer. Both studies highlighted large individual variability, with Maughan et al. (2004) suggesting the rate of sweat loss of both water and solute can vary substantially in soccer players despite



competing within the same training session and environmental conditions. In contrast a study by Owen, Kehoe and Oliver (2013) reported no effect on passing and shooting accuracy despite differing levels of dehydration (2.5%, 1.1% and 0.3%), although skills tests used were not comparable to that of McGregor et al. (1999).

The aforementioned studies investigating hydration in elite soccer have all used adult participants with only a limited number of studies providing information on youth elite populations. Whilst similar trends may be evident, it is important to acknowledge the issues surrounding physical and physiological differences influencing thermoregulation in young people. Characteristics that change during growth and maturation (E.g. body surface area to mass ratio, blood volume per unit of body surface area, sweat gland size, etc.; Falk and Dotan, 2008), affect the body's ability to both dissipate or preserve body heat. However, as these occur at differing rates the thermoregulatory effects are difficult to quantitatively evaluate. Therefore, when attempting to extrapolate findings derived from research investigations on hydration, it is important to consider the maturational status of the participants.

In one of the limited hydration investigations with elite youth soccer players, Da Silva, Mündel, Natali, Filho, Alfenas, Lima, Belfort, Lopes, and Marins (2012) assessed the pre-game hydration status and fluid balance during habitual match-play, albeit in high ambient temperatures. Mean sweat lost was ~2.2 L, with *ad libitum* fluid intake equating to ~1.1 L. Findings also indicted that players were in a state of moderate hypohydration pre-exercise, questioning practices leading up to the onset of match-play. In addition, no relationship was reported between the total volume of sweat lost during match-play and the volume of fluid ingested, with players only consuming fluid

equivalent to ~50% of their sweat loss resulting in a dehydration state of ~1.6%. Whilst performance variables were not measured, dehydration trends when consuming fluids *ad libitum* were similar to adult counterparts (Owen et al., 2013). Williams and Blackwell (2012) investigated the hydration status and fluid intake of English professional Academy players, in more appropriate temperature conditions for this population (average temperature in the UK). In agreement with findings from Da Silva et al. (2012), 14 of the 21 participants were deemed to be in a hypohydrated state pre-exercise. Fluid lost during exercise equated to ~1.7% body mass, however when accounting for the *ad libitum* fluid intake this resulted in only a 0.5% dehydrated state. Considering the purported detrimental performance effects of competing in a hypohydrated state (Maughan et al., 2004; McGregor et al., 1999), youth soccer players should consider both strategies to address this during match-play but more importantly pre-exercise (Da Silva et al., 2012; Williams and Blackwell, 2012).

Considering the impact of fatigue, fuel depletion and dehydration, resulting from the high demands of training and match-play, habitual dietary intake, including choice of food and fluid, may therefore have consequences on maintenance of physical and technical soccer performance. However, thus far limited information exists on the accurate quantification of energy expenditure experienced by the Academy soccer player to objectively inform dietary practices. Whilst studies have attempted to investigate training and match-play loads, quantification of energy expenditure is lacking (Harley et al., 2010; Goto et al., 2015; Wrigley et al., 2012). Furthermore, utilising accurate and objective measures to determine energy expenditure is fundamental to the development of accurate and reliable information.

## **2.2 Current methods of energy balance assessment**

Energy balance occurs when energy intake is equal to energy expenditure, with disturbances in this equilibrium creating either a positive or negative status. Considering the demands of training and match-play combined with growth and maturation, youth athletes are particularly affected by energy imbalance (Thompson, 1998). Energy needs of youth athletes are defined as the dietary intake required to balance the energy necessary for both internal and external work, as well as growth and repair of tissues (Giovannini, Agostoni, Gianni, Bernardo, & Riva, 2000). However, seldom have studies implemented valid and reliable designs to accurately measure energy balance in youth athletic populations (Thompson, 1998), providing limited understanding of this concept. Subsequently any guidelines derived from findings based on inaccurate data collection methods should be interpreted with caution. The following section will address the current methods of energy balance assessment and associated issues of practical application in free-living designs.

### **2.2.1 Estimation of energy expenditure**

Energy expenditure can be described as the energy cost of behaviour (Hills, Mokhtar & Byrne, 2014), which encompasses Basal Metabolic Rate (BMR)/Resting Metabolic Rate (RMR), Thermic Effect of Food (TEF) and Activity-induced Energy Expenditure (AEE). These factors constitute total daily energy expenditure (TDEE). BMR can be described as the energy required to maintain and preserve the integrity of vital functions, whereby metabolic rate is generally measured immediately upon waking after ~8 h of sleep following a 12 h fast (Westerterp, 2007). RMR assesses the same components as BMR albeit under less restricted conditions, allowing measurements in more practically applied settings, although findings can be slightly elevated beyond

BMR values (Westerterp, 2007). TEF can be defined as the increase in energy expenditure above basal fasting levels after food ingestion (Hills et al., 2014). TEF is related to the stimulation of energy-requiring processes during the post-prandial period, including the intestinal absorption of nutrients, the initial steps of their metabolism and the storage of the absorbed but not immediately oxidised nutrients (Westerterp, 2007). The energy cost of TEF usually reaches its maximum within 1 h following a meal, however large variability exists between individuals (Hills et al., 2014). It is commonly accepted that when a subject is in energy balance, TEF equates to ~10% of total energy expenditure (Westerterp, 2007). However, this is dependent on the macronutrient composition of the subjects' meals. Theoretically, based on the amount of ATP required for the initial steps of metabolism and storage, carbohydrate, protein and fat, are estimated to be 5-10%, 20-30% and 1-3% of total energy expenditure respectively (Westerterp, 2007). AEE is the most variable component of energy expenditure, depending upon a number of factors such as the training status of the participant and the method of data collection. The following sub-chapter will critically examine both subjective and objective methods of quantifying physical activity to provide a subsequent estimation of energy expenditure.

It is important to outline the distinction between energy expenditure and physical activity as often these terms are used inconsistently within the field of nutrition. Whilst understanding the energy cost of physical activity is important to quantify both the amount and intensity of movement patterns within training sessions and match-play, an appreciation of energy expenditure encompassing training as well as general living and daily tasks would provide greater insight in to habitual daily demands (Hills et al., 2014). The ability to accurately estimate free-living energy expenditure in youth athletes

will enable coaches and practitioners to monitor the energy cost of training, whilst also allowing more individualised nutritional recommendations to be developed to fuel such training and competition demands in addition to habitual daily tasks.

Developing objective and valid methods of estimating energy expenditure, is important to accurately quantify the energy demands of youth athletes (Ainslie, Reilly & Westerterp, 2003). The chosen method needs to consider both the application to 'real-world' environments and the financial cost of implementation (Dodd, 2007), whilst also taking in to account the burden placed on participants, impacting on subsequent compliance (Livingstone, Prentice, Coward, Strain, Black, Davies, Stewart, McKenna, & Whitehead, 1992). Traditionally, the most accurate measure of estimating energy expenditure was direct calorimetry (Dauncey and James, 1979). The technique involves measuring total heat loss from the body by placing the participant in a thermally-isolated chamber, whilst accurately and precisely measuring the heat dissipated from the participant (Jequier, 1985). The technique is based on the assumption that heat produced by the body during periods of both rest and physical activity are proportional to energy expended (Ainslie, et al., 2003). Although considered an accurate measure of energy expenditure, direct calorimetry is limited in terms of practical application when quantification of energy expenditure is warranted in free-living populations (Ainslie, et al., 2003). However, there are a range of alternative methods which offer more practical solutions to measuring free-living energy expenditure, which will be discussed within the following sections of the review.

### **2.2.1.1 Subjective measures of energy expenditure**

Subjective measures are indirect approaches to estimate physical activity often requiring an element of self-report from the participant (Ridgers & Fairclough, 2011). Self-report measurement tools were traditionally the most widely used approach to estimate physical activity in free-living environments (Sallis & Saelens, 2000). However fundamentally, all subjective measures of physical activity have the potential for reporting bias (Hills et al., 2014). Examples of subjective measures of physical activity include self-reported activity diaries, researcher observation, physical activity questionnaires and retrospective interviews (Hills et al., 2014).

Whilst there are a range of subjective measurement tools available to estimate physical activity, this provides difficulties when comparison of results across studies is necessary (Hills et al., 2014). Studies investigating physical activity in youth populations are criticised for developing additional subjective measurement approaches rather than systematically exploring standardised principles (Sallis & Saelens, 2000) to gain greater insight into energy cost of exercise. Evidence of valid methods are lacking due to the quality of the self-report tool and the criterion measure to compare. Studies of youth populations seldom report attempts to validate self-report and also lack the ability to measure the intensity of physical activity (Sallis & Saelens, 2000).

The incorporation of objective measures in research designs are warranted to remove the potential bias evident in self or proxy reports of physical activity, especially in youth populations (Reilly, 2008). Studies have highlighted evidence of over-reported physical activity levels in youth (Reilly, 2006) suggesting biases should be expected when implementing subjective methods. Furthermore, the obstacle of self-reporting bias is

also prevalent in observational studies aiming to quantify physical activity and subsequent energy expenditure (Reilly, 2008). A review of subjective methods designed to estimate physical activity reported that self-report techniques are not accurate, in particular when information is required on type, duration, frequency and intensity of physical activity (Sallis & Saelens, 2000). Moreover, conclusions recommend objective measures to provide a more accurate quantification of physical activity (Sallis & Saelens, 2000).

#### **2.2.1.2 Objective measures of energy expenditure**

Objective methods of estimating energy expenditure have been developed and implemented within research designs investigating youth populations. Contrary to direct calorimetry, indirect calorimetry assesses the amount of heat produced by the body indirectly. Indirect calorimetry is based on the premise that by measuring oxygen consumption during sport-specific tasks then the energy cost of such exercise can be determined. Indirect calorimetry can be conducted using a chamber, hood, mask or mouthpiece (Manore and Thompson, 2000), with subsequent energy expenditure derived using methods such as the Weir equation (Weir, 1949). It is acknowledged that the accuracy of indirect calorimetry has been established in youth populations (Moon, Vohra, Jimenez, Puyau, & Butte, 1995; Trueth, Schmitz, Butte, 1998), however due to the restricting methodology, this process is limited when assessment of free-living energy expenditure is required (Dodd, 2007). Therefore, the lack of ecological validity evident within whole body indirect calorimetry may lack practical application to quantify energy expenditure in youth athletes' training environment. Although developments have enabled indirect calorimetry to be used in free-living environments through specifically designed portable equipment, these systems are often limited to 1-5

hours of collection (Ainslie et al., 2003). Furthermore, the financial cost restricts the number of participants, making investigation of team-sports difficult and time consuming (Ainslie et al., 2003).

The development of heart rate receivers worn on the wrist and telemetry straps attached to the chest offer a more practical approach to quantifying free-living energy expenditure (Dodd, 2007). Utilising heart rate monitoring to estimate energy expenditure is based on the assumption of a linear relationship between heart rate and oxygen consumption (Hills et al., 2014). This method has received criticism, as the relationship between heart rate and oxygen consumption differs during upper and lower body activities (Li, Deurenberg & Hautvast, 1993), questioning its application to whole-body movements as seen in soccer. Furthermore, despite the very close relationship between heart rate and energy expenditure during exercise, this is not replicated during sedentary periods and low-levels of activity (Ceesay, Prentice, Day, Murgatroyd, Goldberg, Scott, & Spurr, 1989; Luke, Maki, Barkey, Cooper, & McGee 1997). However, subsequent studies have demonstrated the ability of the FLEX heart rate method to eradicate such issues by using individually predetermined heart rates to differentiate between rest and exercise (Stubbs, Hughes, Johnstone, Whybrow, Horgan, King, & Blundell, 2003). Despite the development of the FLEX heart rate technique, issues are still prevalent. For example, it is also accepted that heart rate may be influenced by a number of other variables such as emotional state, the environment (ambient temperature and humidity), hydration status, energy intake, and fatigue (Keytel, Goedecke, Noakes, Hillokorpi, Laukkanen, Van Der Merwe, & Lambert, 2005). A study by Livingstone et al. (1992) investigating energy expenditure in youth populations reported a significant underestimation using heart rate when compared to DLW. The percentage difference in energy expenditure was up to 14%. Livingstone et



al., (1992) concluded that heart rate monitoring offers acceptable estimates of energy expenditure at the group level, however the accuracy at the individual level is limited.

#### **2.2.1.2.1 Doubly Labelled Water (DLW)**

The DLW technique is widely accepted as the ‘gold standard’ method for the estimation of energy expenditure within free-living environments (Dodd, 2007). The technique, first reported by Schoeller and van Santen (1982) and subsequently validated (Schoeller and Hnilicka, 1996), is commonly used as the criterion measure to validate other energy expenditure estimation tools, due to the accuracy and precision of its methods (Hills et al., 2014). The DLW method is non-invasive, imposing minimal burden to the participant, quantifying total free-living energy expenditure for periods ranging between 4-20 days (Ainslie et al., 2003). The technique is summarised by Hills et al. (2014) stating that the participant will be required to consume an oral dose of water containing a known amount of stable isotopes (hydrogen and oxygen). Daily urine samples are collected during the stipulated period and analysed using isotope ratio mass spectrometry. The stable isotopes, specifically, deuterium ( $^2\text{H}$ ) and oxygen-18 ( $^{18}\text{O}$ ) mix with the normal hydrogen and oxygen in the body water. During energy expenditure carbon dioxide ( $\text{CO}_2$ ) and water are produced and subsequently removed from the body. Consequently, as  $^{18}\text{O}$  is contained with both  $\text{CO}_2$  and water, it is lost from the body more rapidly than  $^2\text{H}$ , which is only contained within water. The elimination of the isotopes from the body is tracked and the difference between the elimination rates of  $^2\text{H}$  and  $^{18}\text{O}$  is equivalent to the rate of  $\text{CO}_2$  production, which can be converted in to energy expenditure using indirect equations and calculations.

The DLW technique has been used effectively within youth populations (Livingstone et al., 1992) to quantify free-living energy expenditure, however the method is not without limitations. Despite the accuracy and precision when calculating average daily energy expenditure, it fails to provide a breakdown of activity type, intensity or duration during the collection period (DeLany and Lovejoy, 1996). Information, which would likely be of interest to soccer practitioners who apply a periodised approach to training. Furthermore, the analysis of the urine samples requires sophisticated and expensive (lab-based) equipment, which needs trained technicians to conduct the process (Hills et al., 2014), thus reducing its practical application. Nevertheless, the results obtained using DLW provide the closest measurements available for estimation of energy expenditure in free-living environments, hence demonstrating a valuable reference technique for validating other methods of estimating energy expenditure (Ainslie et al., 2003). However, due to the restrictions outlined when using the DLW technique, practitioners and field-based researchers are opting for less-expensive and more applicable alternatives.

#### **2.2.1.2.2 Accelerometry**

Given that limitations exist within methods of estimating energy expenditure, accelerometry has been identified as a potential alternative (Troiano, 2005; Troiano, Berrigan, Dodd, Masse, Tilert, & McDowell, 2008; Trost, 2001). Accelerometry is an objective measure of free-living physical activity which can be translated into energy expenditure via validated conversion equations (Trost, Loprinzi, Moore & Pfeiffer, 2011). Accelerometers provide activity counts based on both the rate and displacement of the body's centre of mass during movement, which are subsequently calibrated with energy expenditure to provide biological meaning (Freedson, Pober, & Janz, 2005).

Accelerometry utilises acceleration (defined as the rate of change of velocity over time), to enable the frequency, volume and intensity of movement to be quantified (Hills, et al., 2014). Thus allowing greater insight in to the energy cost of training and match-play, an advantage to that of DLW.

Accelerometry is acknowledged as the most popular method of physical activity quantification within free-living environments (Cain, Sallis, Conway, Van Dyck & Calhoun, 2013; Rowlands, 2007). A range of accelerometer brands are available, for example ActiGraph<sup>TM</sup>, RT3<sup>TM</sup> and Actial<sup>TM</sup>, possessing the ability to measure acceleration in one (uniaxial), two (biaxial) or three (triaxial) orthogonal planes (vertical, medio-lateral and antero-posterior) (Rowlands, 2007). However, ActiGraph is most commonly used, in particular with research involving youth populations (Trost, McIver & Pate, 2005). Comparison studies of available devices support the greater accuracy of the ActiGraph models, specifically at the moderate to vigorous intensity level of physical activity (Romanzini, Petroski, Ohara, Dourado, & Reichert, 2014). ActiGraph uses a piezoelectric acceleration sensor to filter and convert the signals produced from the sensor in samples collected at a preset frequency in hertz. The samples are summed over a user-specified time sampling interval, called an epoch (Kim, Beets & Welk, 2012).

Youth activity is often defined as spontaneous, intermittent and of high intensity (Bailey, Olson, Pepper, Porszasz, Barstow & Cooper, 1995), with mean bouts of high-intensity activity lasting approximately 3-22 s (Baquet, Stratton, Van Praagh & Berthoin, 2007), albeit usually more prevalent in younger children. Nevertheless, the increased ability to capture such movements with shorter (1-15 s) epochs, may provide

important insights for energy cost of activity in youth populations (Logan et al., 2016). Using accelerometers restricted to longer epoch rates may potentially dilute the intensity of accelerations, subsequently identifying inaccurate intensity of movements during training and match-play. Santos-Lozano, Santín-Medeiros, Cardon, Torres-Luque, Bailón, Bergmeir, Ruiz, Lucia, and Garatachea (2013) highlighted that movement measured using triaxial accelerometry is more sensitive in youth than found in adult counterparts, suggesting epoch length deemed appropriate for adults may produce erroneous results when assessing physical activity intensity in youth. Edwardson and Gorely (2010) investigated the effect of different epoch lengths (5, 15, 30, and 60 s) on derived levels of physical activity in youth. A total of 234 adolescents aged 12-16 y wore a triaxial accelerometer for 7 consecutive days. A significant main epoch effect was seen for time spent in vigorous physical activity, light physical activity and rest (all  $p < 0.05$ ). However, the Bland–Altman method showed that considerable agreement was observed between all epochs during moderate-vigorous and moderate physical activity, purporting that the bias was close to zero, and 95% limits of agreement were small. Edwardson and Gorely (2010) suggest epoch may be irrelevant if only interested in evaluating moderate or moderate-vigorous intensities of physical activity. However, if investigating time spent in free-living physical activity, which is likely intermittent in nature, then a short epoch is recommended for youth populations. This finding was supported by Logan et al. (2016) investigating the effect of epoch lengths (1, 5, 15, 30, and 60 s) on physical activity quantification in youth. Similarly, a triaxial GT3X+ accelerometer was worn for 8 consecutive days with a sample of 409 male and female adolescents aged 12-16 y. Logan et al. (2016) reported a ‘diluting effect’ when attempting to quantify physical activity with increasing epoch length. Furthermore, differences were evident in exercise intensities across all epoch lengths in contrast to

Edwardson and Gorely (2010), suggesting caution must be applied if comparing data obtained using differing epochs across all forms of physical activity intensities.

Activity counts, converted from the accelerations over a given epoch, are recorded to the internal memory of accelerometers (Chen & Bassett, 2005). ActiGraph have developed a number of devices from the 7164 model in the early 1990s, which was a uniaxial accelerometer with limited storage capacity, to the current model (GT3X+) launched in 2010. The GT3X+ (ActiGraph™, LLC, Pensacola, Florida, USA) accelerometer is triaxial, having the ability to differentiate accelerations for all three orthogonal planes as well as providing a composite measure (Rowlands, 2007), an advantage over previous models. It is lightweight, weighing only 19 g, with the acceleration output digitised by a 12-bit analog-to-digital converter at a user specific rate of 30-100 Hz. The GT3X+ has a greater storage capacity (256 mb) allowing the epoch or frequency of sampling to be recorded at a rate of 1 s for significantly longer periods of time compared to previous models (Logan, Duncan, Harris, Hinckson & Schofield, 2016). Furthermore, the GT3X+ allows the retrospective setting of epoch lengths, allowing the user greater flexibility during the analysis stage, which is in contrast to earlier models requiring a definitive setting of epoch lengths and selection of axis prior to data collection (Logan et al., 2016). Such characteristics of the GT3X+ are ideal for use within free-living studies whereby the collection of energy expenditure over several days within fluctuating physical activity thresholds is warranted.

Due to the inevitable technological advancements, manufacturers are continually improving accelerometry devices and designing new models. However, such practices provide researchers with difficulties in comparing data sets from different versions used

within studies. Differences such as memory size, battery life, sampling frequency, epoch setting and number of axis they can measure, may contribute to the lack of standardised practice during measurement of physical activity (Hills et al., 2014). Sasaki, John and Freedson (2011) conducted the first study to compare the activity counts derived from separate ActiGraph models (GT1M and GT3X). Participants were instructed to walk and run at varying speeds on a treadmill. Results indicate a strong agreement, with no significant differences in activity counts obtained via the vertical axis during all stipulated activity speeds. Although antero-posterior and vector magnitudes (combination of both axis) produced significantly higher activity counts ( $p < 0.01$ ) in the GT3X device, demonstrating greater sensitivity. Sasaki et al. (2011) suggested comparison of data attained from GT1M and GT3X should be avoided when using more than the vertical axis. However, the study design utilised adult participants and conducted physical activity in a lab-based setting, providing limited information for comparison of devices in free-living youth populations.

Robusto and Trost (2012) conducted a study to investigate the agreement between three generations of Actigraph accelerometers (GT1M, GT3X and GT3X+). The study required youth participants (mean age  $14.2 \pm 3.0$  y), to conduct a range of activities, albeit within a lab-based design. Interestingly, the results demonstrated similarity between all accelerometry devices. Intraclass correlation coefficients for total vertical axis counts, total vector magnitude counts and resulting time spent in moderate-vigorous physical activity were 0.99, 0.98 and 0.99 respectively (Robusto & Trost (2012). This finding suggests that researchers can use different generations of ActiGraph models interchangeably within research designs using youth populations. Whilst no study has assessed the reliability of the most recent GT3X+ model in habitual

free-living studies using youth populations, investigations have been conducted with adult counterparts. Jarrett, Fitzgerald and Routen (2015) investigated the inter-instrument reliability of the GT3X+ for 24 hours, with participants wearing two devices (one on each hip). Findings demonstrate high inter-instrument reliability ( $CV < 5\%$ ) for sedentary, moderate and moderate-vigorous intensity outputs. However, a criticism of the GT3X+ is that vigorous ( $CV = 12\%$ ) and very vigorous ( $CV = 18\%$ ) had reduced reliability. Jarret et al. (2015) acknowledges this issue, suggesting reliability may decrease at intensities beyond moderate levels of physical activity. However, it is important to note that it is common practice within accelerometry literature to combine moderate and vigorous activity to form a MVPA classification of physical activity (Reilly et al., 2008). Furthermore, when inter-instrument reliability was investigated at the MVPA level, the GT3X+ was deemed to exhibit strong reliability ( $CV = 2.85$ ,  $ICC = 0.99$ ; Jarret et al., 2015). Although this information is useful as a guide, it is important to acknowledge that this was not conducted with youth participants.

Whilst activity counts generated by accelerometers have been highlighted as a reliable, objective measure of physical activity (Jarrett et al. 2015; Robusto and Trost, 2012), the interpretation of such raw data accelerations in to the classification of exercise intensity and subsequent energy expenditure is not standardised (Logan et al., 2016). Considering accelerometry is a measure of physical activity, conversion equations are required to provide an interpretation with regards to energy expenditure. A study by Trost et al. (2011) evaluated the accuracy of five sets of independently developed conversion equations, which have previously been published for youth populations (Evenson, Cattellier, Gill, Ondrak & McMurray, 2008; Freedson et al., 2005; Mattocks, Leary, Ness, Deere, Saunders, Tilling, Kirkby, Blair & Riddoch, 2007; Puyau, Adolph, Vohra,

& Butte, 2002; Treuth, Schmitz, Catellier, McMurray, Muray, Almeida, Going, Norman, & Pate, 2004). The study compared the five cut point equations (derived from triaxial accelerometry) against indirect calorimetry, which was used as the criterion reference to measure energy expenditure during 12 standardised activities. The 209 youth participants completed 12 tasks, designed to elicit responses equivalent to all intensity thresholds. The results indicated that conversion equations identified by Evenson et al. (2008) and Freedson et al. (2005) exhibited significantly better agreement with indirect calorimetry across all exercise intensities when compared to Mattocks et al. (2007) Puyau et al. (2002) and Treuth et al. (2004). Subsequently, Freedson et al. (2005) conversion equation has been selected as the default setting on ActiLife software for all ActiGraph accelerometers when covering raw accelerations to biological meanings of energy expenditure. Additionally, Santos-Lozano et al. (2013), conducted a similar study to Trost et al. (2011), investigating the validity of the GT3X+ when using Freedson (2005) conversion equation to provide a measure of energy expenditure. Energy expenditure derived from the GT3X+ was compared to indirect calorimetry during varying speeds utilising youth populations ( $14.7 \pm 1.1$  y). No significant difference was observed between the two methods, however a quantification of absolute agreement identified a minor under-reporting bias of  $-0.05 \text{ kcal} \cdot \text{min}^{-1}$  (Santos-Lozano et al., 2013). Despite this non-significant bias, the GT3X+ accelerometer, using Freedson (2005) conversion equation to estimate energy expenditure, was accepted as a valid alternative to indirect calorimetry.

There have been a range of ‘cut-points’ created to differentiate raw data in to sedentary, light, moderate, moderate-vigorous, and vigorous physical activity thresholds (Trost et al., 2011). The fact that there are a selection of cut-points to choose from may introduce



a degree of bias (Kim et al., 2012) when interpreting the intensity of physical activity performed. Such lack of standardised practice between research designs may limit the ability to compare the results between studies. The method generally used to identify cut points involves calibrating the energy expenditure of activities, derived from indirect calorimetry, to the range of acceleration counts during the particular physical tasks (Logan et al., 2016). However, within these independent studies there are no standardised set of activities performed, or an agreed set of algorithms to identify cut points from the acceleration counts when related to METs (Metabolic Equivalent of Task) achieved during the physical tasks (Logan et al., 2016). However, Trost et al. (2011) demonstrated that Evenson et al. (2008) cut points provided acceptable classification accuracy of all exercise intensities. Trost et al. (2011) therefore recommend Evenson et al. (2008) cut points (Sedentary Activity  $\leq 100$ , Light Physical Activity  $>100$  and  $<2296$ , Moderate Physical Activity  $\geq 2296$  and  $<4012$ , Vigorous Physical Activity  $\geq 4012$ ) as the most accurate measure to estimate time spent in all intensities of physical activity in youth populations, thus providing a more accurate quantification of energy expenditure.

The activity counts derived from accelerometry provide MET values based on the cut points applied. The following MET thresholds are accepted as the most appropriate for use within youth populations to describe the intensity of the activity: sedentary  $< 1.5$  METs; light 1.5 to  $< 4$  METs; moderate 4 to  $<6$  METs; vigorous  $> 6$  METS (Trost et al., 2011). While in many research designs it may be relevant to refer to energy cost in terms of accelerometry generated METs, when assessing energy balance a conversion to MJ would provide more direct comparisons to energy intake. For example, if investigating time spent in intensity thresholds then accurate comparisons can be made

across groups or instruments without converting MET scores to other measures of energy expenditure. However, energy balance studies require a figure comprising all contributions to total energy expenditure to understand whether the participant is experiencing positive or negative energy deficit. Ridley, Ainsworth and Olds (2008) created a calculation to accommodate such requirement, converting MET values to total energy expenditure using Schofield's age, gender and mass specific prediction equation (Schofield, 1985) to estimate RMR:

Energy Expenditure (MJ) = MET value x child RMR ( $\text{MJ} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) x kg body weight  
x number of minutes activity performed

Resting Metabolic Rate (RMR) =  $17.686 \times \text{kg body weight} + 658.2$

An important consideration is the relative placement of the accelerometer on the body. It is recommended that the device is attached as close as feasibly possible to the body's centre of mass (Troost et al., 2005). However, consideration is warranted to both participant burden and restriction during sport-specific movement patterns. Accelerometers can be worn on multiple sites of the body, however primarily research has focused on either the wrist or the waist, more specifically, positioned above the anterior spine of the iliac crest in line with the anterior axillary line of the dominant hip (Troost et al., 2005). A study by McMinn, Acharya, Rowe, Gray and Allan (2013) investigated the agreement between waist and wrist placed accelerometer energy expenditure, using indirect calorimetry as the criterion measure. The GT3X+ was worn simultaneously during three treadmill walking and running intensities. Results indicated an underestimation of energy expenditure when the accelerometer was worn on the

wrist compared to the waist during moderate and high intensities. McMinin et al. (2013) demonstrated the importance of accelerometer placement, suggesting wrist-mounted accelerations are not comparable with waist-mounted, and researchers should consider placement on the waist where feasible.

Accelerometry provides substantial improvements over self-report methodologies (Dencker & Anderson 2011; Trost, 2001) and the combination of practical use with high levels of accuracy and reliability (Jarrett et al. 2015; Robusto and Trost, 2012), provide an advantage over other objective methods of energy expenditure estimation. Furthermore, the non-invasive, lightweight, small size and increased capacity to record multiple days/weeks (Ainslie, et al. 2003) without requiring subjective information from participants, makes it an ideal choice when investigating energy expenditure in free-living environments (Hills et al., 2014). Accelerometry has enabled greater accuracy and precision of physical activity across a range of exercise intensities (Robusto and Trost, 2012) in youth populations. However, it is not without its limitations, like all investigations, adaptation of habitual behaviour may be evident when participants know their respective movements are being monitored. However, this can be overcome by selecting data collection periods long enough to offset acute occurrences of this (Hills et al., 2014). Moreover, the inconsistent use of epochs, cut points and monitor placements provide difficulties in comparison of findings across multiple studies to provide guidelines and recommendations (Ainslie et al., 2003). Nevertheless, when considering the limitations to all forms of field-based assessment of energy expenditure, accelerometry offers the most practical solution, whilst exhibiting high-levels of accuracy and reliability (Robusto and Trost, 2012). Thus, accelerometry is the preferred

method in the literature to quantify energy expenditure in free-living, youth populations (Ainslie et al., 2003; Hills et al., 2014; Logan et al., 2016; Rowlands, 2007).

### **2.2.2 Assessment of energy intake**

Accurately understanding the energy cost of training and match-play, provides information to establish nutritional requirements for youth soccer players to determine optimal energy intake. Optimising dietary intake is important to aid both acute physical and technical performance improvements (Meyer et al., 2007; Mielgo-Ayuso, Maroto-Sánchez, Luzardo-Socorro, Palacios, Palacios Gil-Antuñano & González-Gross, 2015), as well as long-term health benefits (Bass & Inge, 2006). However, to be able to assess if optimal recommendations are being met, both accurate and reliable measurement of energy intake is essential. Traditional methods of assessing energy intake have been questioned, for example, whilst diet recalls provide a quantitative assessment of energy intake, recollection periods are usually limited (Livingstone, Robson & Wallace, 2004). Furthermore, food-frequency questionnaires and diet history methods may offer greater insight into habitual energy intake but have been criticised for their seasonality and lack of detail for individual quantification of energy intake (Livingstone, Robson & Wallace, 2004). Thus, food diaries have been identified as a more accurate method of nutritional assessment, involving the weighing or estimated quantification of food and drink items (Ashley and Bovee, 2003).

Research designs utilising self-reported methods of energy intake assessment in youth populations have primarily focused on children (Bandini, Cyr, Must, & Dietz, 1997; Champagne, DeLany, Harsha & Bray, 1996; Champagne, Baker, DeLany, Harsha, & Bray, 1998; Livingstone et al., 1992), female adolescents (Bandini, Schoeller, Cyr &

Dietz 1990; Bandini, Must, Cyr, Anderson, Spadano, & Dietz, 2003; Bratteby, Sandhagen, Fan, Enghardt, & Samuelson, 1998; Livingstone et al., 1992; Perks, Roemmich, Sadow-Pajewski, Clark, Thomas & Weltman 2000) and obese adolescents (Bandini et al., 1990; Singh, Martin, Hickey, Teegarden, Campbell, & Craig, 2009). Limited data exists for the quantification of energy intake in Academy soccer players, with unique nutritional requirements, considering the associated high-intensity training schedules. Studies which have assessed energy intake within normal weight, male adolescent populations, albeit not highly trained, have utilised methods such as estimated and weighed food diaries and diet histories (Bandini et al., 1990; Bandini, Vu, Must, Cyr, Goldberg, & Dietz, 1999; Bratteby et al., 1998; Livingstone et al., 1992).

The context of research in youth populations has focused on assessing energy intake in laboratory-based environments, with intake recorded by observers (Bozinoviski, Bellissimo, Thomas, Pencharz, Goode, & Anderson, 1999; Tanofsky-Kraff, Haynos, Kotler, Yanovski, & Yanovski, 2007). However, increased ecological validity within research designs is needed to understand habitual energy intake for specific populations. Whilst studies have attempted to combat the lack of ecological validity by incorporating more representative real-world environments through free-living designs (Blundel, de Graff, Hulshof, Jebb, Livingstone & Lluich, 2010; Rumbold, St Clair Gibson, Allsop, Stevenson, & Dodd-Reynolds, 2011b), this creates concerns over control and accuracy, with self-reported estimated or weighed food diaries and 24 h recall techniques most widely used (Dodd, 2007). Considering the aforementioned issues surrounding dietary data collection, the following sections will review the accuracy and validity of self-reported food diaries and 24 h recall interviews for assessing free-living energy intake in adolescent males.

#### **2.2.2.1 Self-reported, weighed food diaries**

Weighed food diaries are an example of a quantitative, prospective technique used to analyse energy intake (Trabulsi & Schoeller, 2001). Participants are required to weigh and record details of all food and beverages consumed over a designated period of time. A 7-day collection period has been demonstrated as optimal (Black, Goldberg, Jebb, Livingstone, Cole & Prentice, 1991) to maintain participant motivation and engagement, an issue particularly pertinent in youth populations (Livingstone and Robson, 2000). Due to the ability to capture quantitative information, weighed food diaries have been used as the standard to which other dietary intake methodologies have been compared (Ashley & Bovee, 2003; Black et al., 1991; Trabulsi and Schoeller, 2001). However, it is important to acknowledge that food diaries may also be susceptible to reporting bias (Livingstone et al., 2004).

Livingstone et al. (1992) conducted a study investigating the validity of energy intake measures using a free-living 7-day weighed food diary against total energy expenditure measured by the DLW technique. The use of DLW to validate energy intake methods is based on the assumption that participants are in a state of energy balance, which can be supported by the stability of body mass during the collection period. Therefore, if body mass is unchanged and energy intake does not equal energy expenditure resulting from DLW measures, then it is assumed that energy intake has been under-reported. Livingstone et al. (1992) reported a significant difference between energy intake derived from the weighed food diary and total energy expenditure in both 15 and 18 y males ( $p < 0.01$ ). Serious under-reporting was identified in both 15 y ( $88.0 \pm 9.7\%$ ) and 18 y ( $68.0 \pm 30.7\%$ ) males, when expressed as a percentage of total energy expenditure

(Livingstone et al., 1992). Comparable findings were also evident in a similar study conducted by Bratteby et al. (1998). Mean energy intake expressed as a percentage of total energy expenditure equated to  $81.9 \pm 17.7\%$ , adding to the evidence that weighed food diaries underestimate free-living habitual energy intake in male adolescents (Bratteby et al., 1998). Similarly, Bandini et al. (1990) conducted a study to investigate the validity of self-reported energy intake within adolescent ( $14.7 \pm 2.0$ ) populations, albeit utilising an estimated food diary. In agreement with previous findings an under-reporting bias was evident. Mean energy intake was  $80.2 \pm 22.6\%$  (mean daily energy intake:  $9.01 \pm 2.51$  MJ; mean daily TDEE  $11.53 \pm 2.51$  MJ) of total energy expenditure when adjustments were made for body mass composition (Bandini et al., 1990). These findings were echoed in a study by Ambler, Eliakin, Brasel, Lee, Burke and Cooper (1998) also using estimated food diaries to assess energy intake in male adolescents (age 15-17 y). Results indicated total energy expenditure was significantly greater ( $p < 0.05$ ) than reported energy intake, with no subsequent change in body mass, therefore highlighting an under-reporting bias. Whilst conclusions highlight concerns over using estimated diaries to quantify habitual energy intake in adolescent populations (Ambler et al. 1998; Bandini et al., 1990), similar bias are also evident using weighed food diaries (Livingstone et al., 1992), thus despite methodological variation (estimated or weighed food diary), underestimation of energy intake is still apparent in male adolescent participants.

Smithers, Gregory, Coward, Wright, Elsom and Wenlock (1998) found evidence to suggest the magnitude of under-reporting may differ between age groups. Smithers et al. (1998) investigated the feasibility of using a self-reported weighed food diary to analyse energy intake for the National Diet and Nutrition Survey in youth populations

(4-18 y). Energy intake calculated from the food diaries was assessed against DLW. Mean reported energy intake (8.41 MJ) and energy expenditure (10.15 MJ) demonstrated a significant overall under-reporting bias in males. However, further analysis revealed differences amongst age groups. Whilst the 11-14 y males significantly underestimated their energy intake ( $71 \pm 24\%$  of energy expenditure), 15-17 y males reported only a minor non-significant under-reporting bias ( $97 \pm 9\%$  of energy expenditure; Smithers et al., 1998). Considering the majority of evidence suggests an underestimation of energy intake when using self-reported weighed or estimated food diaries, an under-reporting bias of ~11-27% is likely within male adolescent populations (Ambler et al. 1998; Bandini et al. 1990; Bratteby et al. 1998; Livingstone et al. 1992). However, there is some evidence to suggest that the reporting bias can be reduced to only 3% (15-17 y; Smithers et al. 1998), albeit seldom within adolescent population.

#### **2.2.2.2 24-hour recall**

The 24 h recall technique is a retrospective dietary recall method, relying on participants' memory to estimate portion sizes of all food and beverages consumed during the previous day (Ashley & Bovee, 2003). The 24 h recall technique involves a short interview conducted by a trained individual to ascertain information regarding all energy intake consumption during the preceding 24 h period. Information can be gathered via two methods. A two pass methods reviews all energy intake, then probes for additional information such as brand names, cooking methods, condiments and estimated portion sizes (Ashley & Bovee, 2003). The other option is the multiple pass methods, which requires the chronological ordering of energy intake consumption to



identify gaps or missing information, in addition to items already obtain through the same practice as the two pass method (Rutishauser & Black, 2002).

Considering the issues highlighted regarding prospective methods of dietary data collection, in terms of participant burden and subsequent compliance (Livingstone & Robson, 2000), the 24 h recall technique may offer a less burdensome alternative. Advantages of this retrospective technique include convenience as it is less time-consuming, less intrusive and cheaper to administer than some prospective methods (Livingstone and Robson, 2000; Magos & Yannakoulia, 2003). Due to the somewhat simplistic administration of the 24 h (either conducted via face-to-face interviews or by telephone), it can be scheduled around training and competition schedules without interfering with participants' routine and habitual energy intake (Magos & Yannakoulia, 2003). However, a single 24 h recall has been demonstrated to be inadequate for athletes (Ballew & Killingsworth, 2002), due to the periodised training schedules resulting in the flux of load and frequency having a subsequent impact on energy requirements (Black, 2001). However, when multiple recalls are not feasible then careful consideration must be applied when selecting the most appropriate training or competition day which best reflects typical load, thus providing the most useful information (Benardot, 1996). However, scant research has used 24 h recall interviews to investigate energy intake in adolescent populations (Livingstone et al., 2004). Furthermore, no studies exist which determine the validity of 24 h recall assessment of energy intake using DLW as a quantifiable measure, within youth athletes.

### **2.2.2.3 Issues of energy intake measures in adolescent populations**

Accuracy of dietary assessment is of significant importance considering the evidence that dietary habits formed in early life have a considerable impact on long-term health status (Buttriss, 1999; Power, Heaney, Kalkwarf, Pitken, Repke, Tsang, & Schulkin, 1999). However, self-reported energy intake methods are susceptible to reporting bias, with limited studies acknowledging the magnitude and direction of such bias (Livingstone et al., 2004). Extrapolation of data from energy assessment methods lacking appropriate validation should be limited and interpreted with caution. It is therefore important to outline potential issues surrounding measurement of energy intake which may subsequently impact on accuracy of adolescent dietary evaluation (Livingstone et al., 2004).

Quantifying food portion size, with the exception of weighing food items, provides a considerable unknown reporting error (Cypel et al., 1997). This potential error is not isolated to youth populations. Indeed adults, despite possessing more sophisticated nutritional knowledge, have demonstrated difficulties when attempting to visually estimate portion size (Chambers, Godwin & Vecchio, 2000). A lack of accurate quantification may undermine energy intake findings, questioning purported conclusions and assessment of energy balance. Whilst specific training to develop portion size estimation has been shown to improve accuracy in adults (Livingstone et al., 2004), limited studies exist piloting this training in youth populations. Therefore, methods such as estimated food diaries and 24 h recall may be at risk of inaccurate misrepresentation of food consumption in adolescents. Study designs adopting such approaches may require extensive pilot testing to quantify reporting error to adjust energy intake values accordingly, with the aim of enhance the accuracy of findings.

A major concern regarding retrospective dietary assessment methods is the reliance on memory recall, compounded by evidence of recall error unsurprisingly increasing over time, with up to 30% of memory relating to food consumption potentially lost within 24 h (Fries, Green & Bowen, 1995). Whilst good memory is undoubtedly a key component in dietary recall, the role of the researcher when prompting for further information requires an understanding of the cognitive processes involved in recalling information (Livingstone et al., 2004). It is acknowledged that food consumption is seldom stored into long-term memory, instead retrieved from the ‘generic’ memory (Nelson, 1993). Livingstone et al. (2004) suggest the processes of dietary recall are comprised of determining what information is being requested, searching and evaluating such retrieved information, before deciding upon the appropriate response. Thus errors may be prevalent during each of these stages potentially due to the cognitive ability of the participant or the inability of the researcher to provide the appropriate questions to facilitate the retrieval of the required information (Livingstone et al., 2004).

In agreement with adult studies (Livingstone & Black, 2003), assessment of energy intake in adolescent populations demonstrates a positive correlation between under-reporting and increased body fat (Bandini et al. 1990). However, this finding of underestimation of energy intake is also prevalent in normal-weight adolescents (Bratteby et al., 1998; Livingstone et al. 1992). Therefore, under-reporting may be associated with aspects independent of body composition. In the case of athletic populations under-reporting has been attributed to factors such as the alteration of habitual intake during the period of dietary assessment; false reporting of food which may be perceived as more desirable and erroneous quantification or description of items

(Magkos & Yannakoulia, 2003). Misrepresentation of energy intake may lead to tenuous theories; for example, reports suggested such low unexpected energy intake values identified in athletes may be explained through metabolic efficiency (Manore & Thompson, 2000). Whilst it is possible that athletes may increase energy efficiency, subsequently impacting on energy requirements (Manore & Thompson, 2000), the contribution to the large imbalance between intake and expenditure would likely be small and insignificant (Magkos & Yannakoulia, 2003). Considering the contrasting evidence to demonstrate that under-reporting is not simply correlated with body composition, and limited explanations to fully understand the reasons adolescents are misreporting energy intake, provides further suggestion that without sufficient validation, extrapolating dietary intake data from current methods may produce limited accuracy and misleading conclusions.

Under-reporting is evident in adolescents (Ambler et al. 1998; Bandini et al. 1990; Bratteby et al. 1998; Livingstone et al. 1992), with magnitudes of reporting bias having been determined. However, it is also important to consider whether underestimation of energy intake is intentional or unintentional. Lack of participant motivation and perception of burden (Livingstone et al. 1992) have been associated with poor accuracy of dietary intake methods of assessment. Furthermore, prospective techniques of dietary assessment may lead to a conscious reduction in habitual energy intake due to burden of weighing food items, resulting in under-eating (Magkos & Yannakoulia, 2003). Participants may also use the additional scrutiny over energy intake to change eating habits to healthier food alternatives or start dieting over the period of assessment (Price, Paul, Cole & Wadsworth, 1997). Therefore, omission of items perceived as unhealthy may be intentional. Schoeller (1990) suggested that athletes may be somewhat in denial

regarding quantity of energy intake required to fuel training and competition demands and subsequently report values consistent with their non-athletic peers. In order to achieve such high energy intake requirements, athletes have been found to adopt frequent snacking strategies (Hawley & Burke, 1997), with up to nine occasions of snacking reported within a single day (Jensen, Zaltas & Whittam, 1992). Therefore, the eating pattern of adolescent athletes may be more complex due to increased frequency of recording, which can subsequently effect compliance levels (Livingstone and Robson, 2000) as well as increase the difficulty of remembering large amounts of food items during retrospective recalls. This complexity coupled with the additional burden of having to weigh and record each item may suggest alternative methods are required to offer additional prompts to reduce the potential of missing items of energy intake.

The development of validation techniques to quantify the reporting bias associated with dietary assessment, although important, provides limited information on which nutrients are under or over-reported. Livingstone and Black (2003) suggested adults' energy intake bias is predominantly selective when reporting macro and micronutrients, particular foods or meal patterns. Interestingly, a study by Kersting, Sichert-Hellert, Alexy, Manz and Schoch (1998) assessing energy intake in adolescents, identified that participants who under-reported tended to omit snacks and sugar-based food items when compared to their counterparts deemed to have accurate food records. While limited data exists providing insights into both the nature and subsequent implications of misreporting in adolescent populations, dietary data should be interpreted with caution until the magnitude and nature of misreporting is clearly identified (Livingstone et al., 2004).

#### **2.2.2.4 Combined methods of energy intake assessment**

Considering the evidence of under-reporting in both prospective (Ambler et al. 1998; Bandini et al. 1990; Bratteby et al. 1998; Livingstone et al. 1992) and retrospective (Johnson, Driscoll & Goran, 1996; Lindquist, Cummings & Goran, 2000; Montgomery Reilly, Jackson, Kelly, Slater, Paton, & Grant, 2005; Reilly, Montgomery, Jackson, MacRitchie, & Armstrong, 2001) dietary data collection methods, it has been suggested that incorporating a combined approach utilising both self-reported weighed food diaries and 24 h recall interviews can increase the accuracy of energy intake in youth populations (Rumbold et al., 2011a; Livingstone & Robson, 2000). The combined approach may help eradicate issues associated with self-reported energy intake by obtaining details relating to quantity of intake from the food diaries while using the 24 h recall interview to identify any missing items which may contribute to the under-reporting bias (Livingstone & Robson, 2000).

Rumbold et al. (2011a) investigated the accuracy of this combined method by exploring the agreement between researcher observed and self-reported energy intake in female adolescent netballers (14–16 y). Following training and instruction on completion of both methods of dietary assessment, participants were required to record all energy intake for a 24 h period (12 hours in a lab and 12 hours at home). Although this was within a laboratory setting, a range of food and drink items were made available *ad libitum* to represent real-world conditions, furthermore items were based on previously determined habitual food intake, increasing the ecological validity of the design. In addition to the self-reported weighed food diary, a 24 h recall was conducted the following morning to supplement the dietary analysis. Results indicated a slight bias towards over-reporting of  $0.46 \text{ MJ}\cdot\text{day}^{-1}$  (~4%). These findings are in contrast to

previous published data of significant under-reporting in adolescent populations (Ambler et al. 1998; Bandini et al. 1990; Bratteby et al. 1998; Livingstone et al. 1992). Rumbold et al. (2011a) concluded that on a group level (0 to 0.92 MJ·day<sup>-1</sup>) the combined dietary data collection method is an effective approach to quantify energy intake in adolescent female netballers.

Combining dietary intake assessment methods may present an opportunity to collect more accurate information on habitual energy intake in adolescents. Whilst, caution is required when extrapolating to other population groups, such as highly-trained, male counterparts, evidence of reducing the extent of misreporting in adolescent athletic groups is an important development in research (Rumbold et al. 2011a).

### **2.3 Dietary habits of Academy soccer players**

The majority of research into soccer-specific nutrition has mainly been explored in adult professional soccer (Caldarone et al., 1990; Maughan, 1997; Reilly, 1994). Investigations in to dietary practices have reported energy consumption ranges of 5.21-16.51 MJ·day<sup>-1</sup> and 8.51-16.21 MJ·day<sup>-1</sup> respectively for two professional top-level clubs (Maughan, 1997). In addition, Maughan (1997) found that carbohydrate, protein and fat contribution to total energy intake was 51.4%, 15.9% and 31.5% respectively in team A and 48.4%, 14.3% and 35% respectively in team B. A separate study examining nutritional intake of adult professional soccer players also presented similar findings; mean daily energy intake of 13.09 MJ for an international player (Reilly, 1994). Furthermore, Caldarone et al. (1990) found similar results reporting findings of 12.83 ± 2.38 MJ·day<sup>-1</sup> in top level adult Italian soccer players. It would however, be misleading to extrapolate these findings to the Academy soccer player considering the distinct

differences identified from training and match-play demands (Harley et al., 2010, Goto et al., 2015; Wrigley et al., 2012). In the relatively limited amount of studies investigating nutritional intake of Academy soccer players, researchers have reported equivocal findings (Boisseau et al., 2002; Boisseau, Vermorel & Rance, 2007; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Naughton et al., 2016; Rico-Sanz et al., 1998; Ruiz et al., 2005; Russell & Pennock, 2011). The contrasting findings could be explained due to the incorporation of inconsistent methodologies, making it difficult to compare results directly. However, the findings of the current dietary habits identified within Academy soccer populations will be discussed with regards to energy balance, diet composition and energy deficit implications.

### **2.3.1 Energy balance**

Rico-Sanz et al. (1998) conducted one of the first studies to assess the dietary intake of Academy soccer players. Players ( $n = 8$ ,  $17 \pm 2$  y) completed a self-reported (estimated) food diary over a 12-day period, which was compared to total energy expenditure (conversion equations based on information derived from self-reported activity records). Players were found to be in a slight positive energy balance (mean energy intake =  $16.54 \pm 4.48$  MJ v energy expenditure =  $16.04 \pm 2.39$  MJ), as recommended during adolescence (Meyer et al. 2007; Malina et al. 2004). Although, without a daily breakdown documenting type of training or match-day, analysis of fluctuations in energy balance cannot be determined during a typical training week. Subsequently, similar studies by Boisseau et al. (2002) and Iglesias-Gutierrez et al. (2005) demonstrated comparable findings in Academy players. No significant difference was identified in energy intake ( $9.82 \pm 0.88$  MJ) when compared to energy expenditure ( $9.10$



$\pm 0.3$  MJ) (Boisseau et al., 2002), although results indicated a positive energy balance, supporting previous findings in a similar population (Rico-Sanz et al., 1998). Additionally, Iglesias-Gutierrez et al. (2005) supported the notion of positive energy balance, demonstrating a mean daily energy intake of 12.57 MJ in comparison to expenditure values of 12.49 MJ. However, match-day intake and expenditure was excluded, which may have affected the mean values reported. Furthermore, subjective reports of energy expenditure were used to identify energy balance, questioning the accuracy of these findings.

In contrast, Leblanc et al. (2002) highlighted significant negative energy balance in elite-level French soccer players ( $n = 180$ ; age 13-16 y). The U14, U15 and U16 age groups reported daily intake ranges of  $9.85 \pm 1.91$  to  $10.93 \pm 1.38$  MJ,  $11.54 \pm 2.42$  to  $14.22 \pm 3.48$  MJ and  $10.13 \pm 1.54$  to  $12.69 \pm 1.63$  MJ respectively. Whilst energy expenditure measurements were not collected, Leblanc et al. (2002) suggested that players were in a significant negative energy balance when comparing intake to recommended dietary allowances for boys aged 13-19 y ( $15.99$ - $21.71$  MJ·d<sup>-1</sup>; Hickson Duke, Risser, Johnson, Palmer, & Stockton, 1987). These findings of negative energy balance are contrasting to Rico-Sanz et al. (1998), purporting lower energy intake amounts, albeit assessing different age ranges. However, due to the requirements of the national training centre all players were weekly boarders in Leblanc et al. (2002) study, resulting in all meals being supplied, with only weekend energy intake, whilst at home, enabling *ad libitum* consumption, thus questioning the ecological validity of the free-living design. In contrast to Leblanc et al. (2002), Ruiz et al. (2005) found no significant differences between absolute energy intakes across the same three age groups. However, Ruiz et al. (2005) did support the notion of significant negative energy

balance, with mean energy intake for the U14s, U15s and U16s were  $14.47 \pm 1.29$  MJ·day<sup>-1</sup>;  $14.31 \pm 0.76$  MJ·day<sup>-1</sup>;  $14.56 \pm 0.93$  MJ·day<sup>-1</sup> respectively, albeit no direct measure of energy expenditure was conducted. Additionally, without a measure of maturation status conducted, a discussion regarding optimal diet for stage of development and differentiated dietary practices between such players is not possible.

Caccialanza et al. (2007) was one of the first studies to recognise the issue of under-reporting bias associated with energy intake assessment in youth soccer populations. The aim of the study was twofold, firstly to assess the dietary practices of Academy soccer players and secondly to quantify the degree of under-reporting associated with the energy intake technique. Players from an Italian Serie A soccer Academy (n = 75; age 15-17 y) were required to complete a 4-day estimated food diary within a free-living environment on two separate occasions. Under-reporting was assessed using the ratio of reported estimated energy intake to estimated energy expenditure using the method adopted by Livingstone et al. (1992). Estimated mean daily energy intake was  $10.72 \pm 2.66$  and  $11.05 \pm 2.57$  MJ for the two data collection periods. Whilst mean energy intake values appear lower than previously reported (Iglesias-Gutierrez et al., 2005; Rico-Sanz et al., 1998; Ruiz et al., 2005), this may be explained due to the under-reporting error identified. Mean daily energy intake was significantly lower than mean estimated energy expenditure on both occasions ( $p < 0.001$ ). Mean bias was  $3.73 \pm 3.07$  and  $3.56 \pm 2.94$  MJ respectively. Findings reported by Caccialanza et al. (2007) may question the validity of the previous studies results, which adopted similar energy intake methods. However, the measurement of energy expenditure was estimated, without using objective assessment tools, which may affect the level of under-reporting bias identified.

Studies investigating dietary practices of Academy soccer players have primarily been conducted outside of the UK, which may provide limited insight into the habitual energy intake routines of UK players considering the requirements of the EPPP. However, Russell and Pennock (2011) designed the first study to examine the dietary regimes of UK-based Academy soccer players. Players ( $n = 10$ ; age 16-18 y) maintained an estimated food diary over a 7-day period within a free-living environment, with energy expenditure estimated for the same period using conversion equations. Mean daily energy intake was  $11.85 \pm 0.69$  MJ in comparison to estimated mean daily expenditure of  $15.15 \pm 0.26$  MJ. Thus players were reported to be in a significant negative energy balance ( $p < 0.001$ ). Russell and Pennock concluded that dietary practices are inadequate to sustain the demands of training and competition, with a mean daily energy deficit of  $3.3 \pm 0.73$  MJ reported. However, energy expenditure estimations were not based on direct, objective field-based methods and self-report bias associated with energy intake was also not considered. Similar investigations aiming to quantify energy intake over a 7-day period in UK Academy soccer players, have produced conflicting results (Naughton et al., 2016). Whilst no measure of energy expenditure was incorporated limiting the ability to accurately assess energy balance, results identified mean daily energy intake values of  $7.97 \pm 1.81$ ,  $8.07 \pm 1.33$  and  $8.2 \pm 1.63$  MJ for U13-14, U15/16 and U18 respectively. These findings demonstrated a significantly lower intake than identified in all previous studies assessing this population (Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Rico-Sanz et al., 1998; Ruiz et al., 2005; Russell & Pennock, 2011), however again, self-report bias was not considered.

Nutritional intake requires an individualised approach, considering a multitude of factors to effectively augment performance. Although studies investigating energy balance in Academy soccer players have provided equivocal findings, the majority are in agreement that dietary practices are inadequate to sustain the demands of training and match-play (Leblanc et al., 2002; Ruiz et al., 2005; Russell & Pennock, 2011). In an attempt to quantify the energy deficit of UK Academy soccer players, Russell and Pennock (2011) highlighted a mean daily deficit of  $3.3 \pm 0.73$  MJ. It is accepted that chronic periods of sub-optimal energy intake, coinciding with sustained periods of high training volumes may impair growth and maturation, whilst also experiencing acute performance detriments (Meyer et al., 2007; Petrie et al., 2004; Thompson, 1998). Thus identifying youth soccer populations as potentially at risk of such detriments, which have been outlined in detail in section 2.1.1.

Information is lacking in the literature to determine where the greatest energy deficits are occurring throughout the week. Although studies outline mean energy expenditure values and daily deficits (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Naughton et al., 2016; Rico-Sanz et al., 1998; Ruiz et al., 2005; Russell & Pennock, 2011), these studies do not provide a breakdown of the difference between training days. Furthermore, such methods used to determine energy intake (estimated food diaries) have previously been questioned due to the associated self-reporting bias and lack of accuracy in youth populations (Livingstone et al., 2000). Additionally, assumptions of energy balance were made without using objective methods of assessing energy expenditure or in some cases no measures of expenditure were provided. Conclusion of inadequate nutritional intake is difficult to determine as studies fail to address the issue of under-reporting bias,

therefore lacking clarity on whether players are consuming insufficient energy intake or if inaccurate accounts of dietary habits have been provided. Due to the equivocal findings resulting from inconsistent methodologies, clarity of information regarding dietary practices in Academy soccer players is limited. Accurate and objective measures of energy balance is warranted to fully understand the energy cost of training and match-play to determine if dietary practises are sufficient to both optimise performance but more importantly to offset and detrimental effects of chronic sub-optimal energy intake.

### **2.3.2 Diet composition**

The composition of a soccer players' diet is important considering performance detriments and the causes of match-related fatigue have been partly attributed to the depletion of liver and muscle glycogen (Krustrup et al. 2006), modulated by pre-exercise nutritional status (Anderson et al. 2016). Recommendations of periodised nutritional intake may be advised to account for training intensity and volume depending upon the type of training day (Burke, 2010). However, despite training fluctuations, diets high in carbohydrate enable an increased muscle glycogen concentration, subsequently delaying the onset of fatigue and sustaining performance levels (Alghannam, Jedrzejewski, Tweddle, Gribble, Bilzon, Thompson, Tsintzas & Betts, 2016; Burke, Hawley, Wong, & Jeukendrup, 2011).

The macronutrient breakdown of daily dietary practices in Academy soccer players demonstrate ranges of 45-56% (carbohydrate), 14-18% (protein) and 29-39% (fat) (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Naughton et al., 2016; Rico-Sanz et al., 1998; Ruiz et al., 2005; Russell &

Pennock, 2011). Due to the lack of nutritional guidelines for Academy soccer players, comparisons with adult populations provide the only insight in to the appropriateness of such dietary practices, despite differences in energy needs. However, whilst contributions to energy intake values may seem similar to adult professional soccer players; 51%, 16% and 32% for carbohydrate, protein and fat respectively (Maughan, 1997), total energy intake is predominantly reported as sub-optimal (Leblanc et al., 2002; Ruiz et al., 2005; Russell & Pennock, 2011) in Academy soccer populations.

Whilst traditionally, it was well accepted that a diet high in carbohydrate was required for all athletes, recent literature have criticised this approach (Desbrow, McCormack, Burke, Cox, Fallon, Hislop, Logan, Marino, Sawyer, Shaw, Star, Vidgen & Leveritt, 2014). Emerging studies suggest an individualised approach is warranted, based upon consumption of carbohydrates in relation to training load, with guidelines accounting for body mass (Burke et al., 2011). In a recent position statement focusing on nutrition for adolescent athletes, it was suggested that limited evidence supports a differentiated approach from adult counterparts (Desbrow et al., 2014). Whilst it was acknowledged that there is evidence of child-adult physiological differences (Armstrong and Welsman, 2007; Bar-or, 2001; Unnithan and Easton, 1990), collectively, despite the impact of maturation on energy metabolism, there is limited evidence to distinguish carbohydrate recommendations for adolescents (Desbrow et al., 2014). Therefore, adult recommended daily intakes of 6-10 g·kg<sup>-1</sup> for athletes training 1-3 h per day were accepted as relevant for adolescents (Burke et al., 2011). However, acknowledgement of adolescent differences in training load/volume, match duration, as well as participation in multiple sports is warranted when devising guidelines (Desbrow et al., 2014). With regards to soccer specific nutrition literature, dietary carbohydrate guidance for adult

professional soccer players is an evolving topic as debate exists regarding the optimal strategy. Burke et al. (2006) proposes  $5\text{--}7\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  for moderate training, increasing to  $7\text{--}10\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  for intensive training. Academy soccer players in the UK seldom achieve such recommendations, with studies highlighting  $6.0 \pm 1.2$ ,  $4.7 \pm 1.4$  and  $3.2 \pm 1.3\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  for U13-14, U15-16 and U18 respectively (Naughton et al., 2016). Although it is also acknowledged that training with low carbohydrate availability may augment adaptive responses to exercise training (Hansen, Fischer, Plomgaard, Anderson, Saltin & Pedersen, 2005; Yeo, Paton, Garnham, Burke, Carey, & Hawley, 2008), this has not been investigated specifically within Academy soccer populations. Academy soccer players have the complex task of ensuring energy intake is sufficient to not only optimise training and match-play performance but also maintain periods of growth and maturation. Considering the low levels of carbohydrate intake, Academy soccer players are not meeting daily targets, albeit specific to adult population as thus far no available guidelines exist for Academy soccer players involved in high training volumes.

Optimal protein intake provides essential amino acids to promote activation of the protein synthesis pathway and provides substrate for lean tissue accretion (Desbrow, et al., 2014). Additionally, adolescents have increased protein needs to support growth and development of lean body mass (Petrie et al., 2004). Investigations in to protein intake of adolescent athletes have highlighted ranges of  $\sim 1.2\text{--}1.6\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  (Petrie et al., 2004), which are aligned with adult counterparts. Therefore, it is unlikely that adolescent athletes, require differentiated guidelines or protein supplementation to elevate protein needs (Desbrow et al., 2014). A recommendation of  $1.2\text{--}1.7\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  has been suggested for adult soccer players depending on training goals (Tipton &

Wolfe, 2004; Lemon, 1994). However,  $0.8 \text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  reference values have been suggested for adolescent males (Department of Health, 1991), albeit not considering the training volumes associated with demands placed upon the Academy soccer player. Findings of  $1.7 \text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  (Russell & Pennock, 2011) and  $1.6 \text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  (Naughton et al., 2016) demonstrate Academy soccer players in the UK protein consumption is within the recommended range to optimise recovery and development.

Dietary fat consumption is predominantly based upon facilitating carbohydrate intake, as opposed to a large contribution for energy metabolism (Clark, 1994) considering the high-intensity nature of soccer performance. Limited evidence exists formalising fat intake guidelines for adolescents, however, it is accepted that fat consumption should not exceed 35% of total energy intake, with saturated fats contributing no more than 10% (Desbrow et al., 2014). With regards to soccer specific intake, reports of fat consumption ranging between 29%–39% (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Naughton et al., 2016; Rico-Sanz et al., 1998; Ruiz et al., 2005; Russell & Pennock, 2011) suggest intake is slightly higher in relation to recommendations of <30% (Clark, 1994), albeit in adult populations. However, considering the negative energy balance within this population (Leblanc et al., 2002; Ruiz et al., 2005; Russell & Pennock, 2011) as well as recognising recent research reporting utilisation of fat as a fuel source to spare glycogen depletion (Hansen et al., 2005; Yeo et al., 2008), albeit equivocal, a reduction in fat intake may not be advisable.

Thus far definitive information on the nutritional requirements of Academy soccer players in the UK is lacking. Investigations adopting accurate and reliable methods of



collecting both energy intake and energy expenditure is warranted to address this gap in the literature. Considering the demands of training and match-play and the ability to sustain adequate growth and maturation, further information is required to provide guidance for this population.

## **2.4 Thesis purpose and aims**

The purpose of this chapter was: (1) provide information on the training and match-play demands bespoke to the UK Academy soccer player and identify the subsequent development and performance related consequences, (2) synthesise the issues associated with current measures of energy balance with regards to assessing energy intake and estimating energy expenditure, and (3) identify current dietary habits of Academy soccer players and highlight the inconsistencies of methodological approaches resulting in a limited understanding of dietary practices and subsequent information on energy balance in this population. Consequently, the literature review has identified the following key areas for research: (1) address the issue of inaccurate methods of assessing energy intake in free-living environments, to identify if under or over-reporting is prevalent in Academy soccer players, (2) use energy intake assessment methods, accounting for any bias, to compare against objective measures of energy expenditure to investigate energy balance during a typical training week in Academy soccer, and (3) with sub-optimal dietary practices expected, examine strategies to optimise the energy intake of Academy soccer players and determine if there are any subsequent effects on soccer-specific performance.

Based on this information, the series of studies in this thesis were designed to specifically investigate the following:

- 1) Establishing the accuracy of the combined method of energy intake assessment, specifically within Academy soccer players, would enable accurate assessment of dietary practices and subsequent quantification of habitual energy intake. Therefore, the aim of chapter 3 was to explore the agreement between researcher observed energy intake and self-reported energy intake in male Academy soccer players using a combined self-reported, weighed food diary and 24 h recall method.
- 2) Following the established accuracy of the combined method of energy intake assessment, investigations into habitual dietary practices of Academy soccer players were conducted. The aims of chapter four were two fold. Firstly, the aim was to assess energy balance in male Academy soccer players over a 7-day period that included four training days, one match day and two rest days. In addition, a secondary aim was to examine type of activity day (heavy/moderate/light training, match, rest) separately to highlight any fluctuation in energy balance throughout the week, as well as examining pre-match nutritional practices. Energy intake was assessed in relation to objective measures of energy expenditure to distinguish whether or not current dietary practices were adequate to meet the demands of training and match-play.
- 3) The findings from chapter 4 identified sub-optimal nutritional practices resulting in a mean daily energy deficit. Match days produced the greatest energy deficit with pre-match intake highlighted as a particular area of concern, thus strategies are warranted to increase energy intake with the purpose of reducing the

identified energy deficit. Therefore, the aim of chapter five was to examine the effects of a prescribed (recommended pre-match meal composition) versus habitual pre-match intake on physiological responses and soccer performance measures of Academy players during a 90 min soccer match simulation. Furthermore, a sub-aim of the chapter was to assess if players could tolerate the increased pre-match energy intake consumption without experiencing abdominal discomfort.

### Chapter 3: Agreement between two methods of dietary data collection in male Academy soccer players

This work has been published in a peer-reviewed journal:

**Briggs, M. A.,** Cockburn, E., Rumbold, P. L. S., and Stevenson, E. (2015). Agreement between two methods of dietary data collection in male adolescent academy-level soccer players. *Nutrients*, 7, 5948-5960.

#### Abstract

*Introduction/Purpose:* Collecting accurate and reliable nutritional data from adolescent populations is challenging, with current methods providing significant under-reporting. Therefore, the aim of the study was to determine the accuracy of a combined dietary data collection method (self-reported weighed food diary, supplemented with a 24-h recall) when compared to researcher observed energy intake in Academy soccer players.

*Methods:* Twelve Academy players from an English Football Premier League club participated in the study. Players attended a 12 h period in the laboratory (08:00 h–20:00 h), during which food and drink items were available and were consumed *ad libitum*. Food was also provided to consume at home between 20:00 h and 08:00 h the following morning under free-living conditions. To calculate the participant reported energy intake, food and drink items were weighed and recorded in a food diary by each participant, which was supplemented with information provided through a 24-h recall interview the following morning.

*Results:* Participants systematically under-reported energy intake in comparison to that observed ( $p < 0.01$ ) but the magnitude of this bias was small and consistent (mean bias =  $-88 \text{ kcal}\cdot\text{day}^{-1}$ , 95% CI for bias =  $-146$  to  $-29 \text{ kcal}\cdot\text{day}^{-1}$ ). For random error, the 95% LOA between methods ranged between  $-1.11$  to  $0.37 \text{ MJ}\cdot\text{day}^{-1}$  ( $-256$  to  $88 \text{ kcal}\cdot\text{day}^{-1}$ ). The standard error of the estimate was low, with a typical error between measurements of 3.1%.

*Conclusion:* These data suggest that the combined dietary data collection method could be used interchangeably with the observed food intake technique in the population studied providing that appropriate adjustment is made for the systematic under reporting common to such methods.

### 3.1 Introduction

Collecting accurate and reliable nutritional data from adolescent populations is troublesome (Livingstone et al., 2004); for example, quantifying energy intake utilising self-reported, estimated food diaries within an adolescent population presents challenges, such as under-reporting and a lack of detailed information (Hill & Davies, 2001). Although research has focused on quantifying the energy intake of children (Bandini et al., 1997; Champagne et al., 1996; Champagne et al., 1998; Livingstone et al., 1992), female adolescents (Bandini et al., 1990; Bandini et al., 2003; Bratteby et al., 1998; Livingstone et al., 1992; Perks et al., 2000) and obese adolescent (Bandini et al., 1990; Singh et al., 2009) populations, limited data exists for the quantification of energy intake in highly active male adolescents. For example, Academy soccer players are training and competing up to 20 h per week (Premier League, 2015), with daily energy expenditure ranging from  $\sim 12.5\text{--}15.2 \text{ MJ}\cdot\text{day}^{-1}$  (Iglesias-Gutierrez et al., 2005; Russell & Pennock, 2011). Traditional methods of assessing energy intake within normal weight, male adolescent populations, albeit not highly trained, have included estimated and weighed food records and diet histories (Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992). Studies have investigated the validation of self-reported energy intake against doubly labelled water (DLW) measurements, demonstrating an underestimation of energy intake and fluid consumption by 18%–27% (Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992). Underestimation of energy intake in comparison to total energy expenditure is consistent within the literature, providing detailed explanations for the reporting error (Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992; Bandini et al., 1990). However, further research is required to quantify the actual reporting accuracy of energy intake in Academy soccer players, which previous studies fail to address

(Caccialanza et al., 2007; Boisseau et al., 2002; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Rico-Sanz et al., 1998; Ruiz et al., 2005; Russell & Pennock, 2011).

Contextualising the environment in which the participant is recording energy intake is of equal importance. Previous research in adolescent populations has focused on assessing energy intake, albeit in laboratory conditions, with intake recorded by observers (Bozinovski et al., 2009; Moore, Dodd, Welsman & Armstrong 2004; Tanofsky-Kraff et al., 2007). However, research representing real-world environments is imperative in understanding habitual energy intake (Livingstone et al., 2004). Recent studies have attempted to incorporate a more representative real-world design (Rumbold et al., 2011a), acknowledging a compromise between the high internal validity of laboratory-based studies, whilst attempting to provide ecological validity incorporated through more free-living designs (Blundel et al., 2010). It is important when conducting research with adolescent populations to accommodate a balance between high internal and high ecological validity, to ensure findings can be extrapolated accurately (Rumbold, St Clair Gibson, Stevenson, King, Stensel & Dodd-Reynolds 2013).

It has been suggested that introducing a combined method of dietary data collection in the form of self-reported, weighed food diaries and 24 h recall interviews can increase the accuracy of self-reported energy intake measurements in adolescent and child populations (Livingstone & Robson, 2000; Rumbold et al., 2011a). Rumbold et al. (2011a) investigated the accuracy of this combined method by exploring the agreement between researcher observed and recorded energy intake and self-reported energy intake in female adolescent netballers (14–16 y). Although this was within a laboratory setting, a range of food and drink items were made available *ad libitum* to represent real-world

conditions, as items were based on previous free-living self-reported food diaries. Results indicated a slight bias towards over-reporting of  $0.46 \text{ MJ}\cdot\text{day}^{-1}$ . These findings are in contrast to previous published data of significant under-reporting in adolescent populations (Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992). Rumbold et al. (2011a) concluded that on a group level ( $0.00$  to  $0.92 \text{ MJ}\cdot\text{day}^{-1}$ ), the combined dietary data collection method is an effective approach to quantify energy intake in adolescent female netballers. However, caution is required when extrapolating to other population groups, such as Academy soccer players, considering the high volume and intensity of training schedules.

A relatively limited number of studies have focused on nutritional recommendations for the male adolescent soccer player (Caccialanza et al., 2007; Boisseau et al., 2002; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Rico-Sanz et al., 1998; Ruiz et al., 2005; Russell & Pennock, 2011). As soccer is perceived to be one of the most popular sports worldwide (Stolen et al., 2005), this highlights the importance of providing research-informed nutritional recommendations based on growth, health, maturation and training status (Meyer et al., 2007; Petrie et al., 2004). Academy soccer players will generally have higher intake requirements due to the greater energy expenditure from training and competition (Petrie et al., 2004). This highlights the importance of accurately quantifying energy intake to ensure the energy expenditure demands of training and competition are met. Accurate methods are required for both field-based researchers and highly trained practitioners to provide evidence-based interventions and recommended nutritional practices. Therefore, the aim of the current study was to explore the agreement between researcher observed energy intake and self-reported energy intake in male adolescent Academy soccer players using a combined self-

reported, weighed food diary and 24 h recall method. It was hypothesised that the combined method of dietary data collection would demonstrate good agreement with researcher observed method, offering a more accurate alternative than previously established field-based methods.



## **3.2 Method**

### **3.2.1 Participants**

Twelve males (age:  $13.8 \pm 0.6$  y; stature:  $1.71 \pm 0.04$  m; BM:  $63.7 \pm 5.0$  kg; BMI:  $21.9 \pm 1.9$  kg·m<sup>-2</sup>) were selected for the study. Statistical power was calculated using commercially available software (GPower v3.1, Germany) and a sample size of twelve was deemed sufficient for >90% power to detect statistical differences in energy intake measures between observed and self-reported methods. The maturity offset was  $2.2 \pm 0.4$  y beyond PHV indicating that all of the players had reached their predicted PHV (positive maturity offset) and thus were of a similar maturation status (Mirwald et al., 2002). All players were actively training within a soccer Academy, which included training at least four times per week in addition to a match day. To determine if the players were restrained or unrestrained eaters, the Dutch Eating Behaviour Questionnaire (Van Strein, Frijters, Bergers, & Defares, 1986) was administered (Appendix A). All players were classified as unrestrained eaters, with the dietary restraint score ( $2.3 \pm 0.3$ ) falling into the average range for high school males (Van Strein et al., 1986). The study was approved by the Faculty of Health and Life Sciences Research Ethics Committee at Northumbria University. Information was provided prior to gaining written informed consent from the players and their parents or guardians before commencing data collection (see Appendix B for example of ethics documents).

### **3.2.2 Protocol**

Prior to the study, a series of workshop were conducted, during which the players were provided with a detailed explanation and demonstration of the food weighing and recording process. The workshop provided the players with the opportunity to practice

this technique and the 24 h recall interview in the presence of a researcher, as recommended by Livingstone et al. (1992).

Diet was assessed for each player over 24 h (12 h spent in the nutrition Laboratory at Northumbria University, 08:00 h–20:00 h, followed by 12 h spent at home between 20:00 h and 08:00 h the following morning). During the time spent in the nutrition Laboratory, players were occupied with a range of inactive tasks such as reading and homework. Players were provided with breakfast, lunch and dinner, as well as snacks *ad libitum* during the day. To replicate a real-world environment, food and drink items provided were based on a previously administered food preference questionnaire, which was administered prior to the study. This questionnaire was based on dietary information derived from self-reported, weighed food diaries and 24-hour recall interviews. This ensured that all food and drink items provided were palatable and typical of what the players consumed at home and school on a regular basis. A wide variety of foods were offered to the players at each meal in order to replicate what would typically occur in a free living situation. The macronutrient composition of the food and drink items available was 68% carbohydrate, 11% protein and 21% fat. Details of all foods provided are outlined in Table 3.1. The research team were responsible for preparing and covertly weighing all available food and drink items to the nearest gram or millilitre and producing a numerical code for each item. Players were informed all food and drink items were available *ad libitum* to replicate real-world conditions, although instructions were provided to enable players to weigh (Sartorius TE6100, Goettingen, Germany) and record all of the food and drink consumed in a food diary provided (Appendix C). To enhance energy intake accuracy, all leftover food was

weighed and recorded by the players and also covertly weighed and disposed of by the researcher.

**Table 3.1** Food and drink items made available for the players during the study

<b>Meal</b>	<b>Food and Drink Items Available</b>
	Kellogg's Frosties, Coco pops, Cornflakes, Honey loops, Coco
<b>Breakfast</b>	"Choc n Roll", Rice Krispies Multi-Grain, Rice Krispies, Weetabix, semi-skimmed or whole milk
	Ham Sandwich white/brown bread with/without butter, Chicken
<b>Lunch</b>	Sandwich white/brown bread with/without butter
	Jacket potato (with/without beans, cheese), Tomato pasta
<b>Dinner</b>	(with/without cheese), Chicken breast (with/without potatoes, carrots, tomato sauce)
	Orange cordial (no added sugar), water, pure apple juice, pure
<b>Secondary</b>	orange juice, fruit (bananas, apples, clementines), yoghurts, cereal
<b>Items</b>	bars, crisps, confectionary

For the period between 20:00 h and 08:00 h the following morning, whilst at home, players were required to only consume items taken from the laboratory and follow the same weighing process as in the laboratory. Therefore, secondary food and drink items, plus cereal and milk cartons, were available to take home for consumption (see Table 3.1). However, no players opted to take any additional items home; therefore, no further consumption was recorded between 20:00 h–08:00 h. The following morning individual face-to-face 24 h recall interviews were conducted using the two-pass method (Ashley & Bovee, 2003). This method firstly reviews the main foods and beverages consumed within the 24 h period, whilst secondly prompting players for more information such as condiments, brand names, how the foods were prepared and cooked and portion sizes if not provided in the first pass.

Energy intake for the 24 h period (12 h in the laboratory and 12 h at home; referred to as “observed” intake for the remainder of the thesis) was determined for each player by the researcher using the covert numerical coding system (as explained previously). Player 24 h energy intake was determined using information reported in the self-reported weighed food diary and any additional information provided during the 24 h recall interviews. This combined dietary data collection method has previously been used by Rumbold et al. (2011a) in a recreationally active female population of a similar age.

### **3.2.3 Estimation of energy intake**

The nutritional content of all food and drink items was obtained from food packaging and analysed to calculate the observed and player reported 24 h energy intake ( $\text{MJ}\cdot\text{day}^{-1}$ ). When information about food portions were not provided by players,

amounts were substituted using a portion size recorded in the individual's food diary which corresponded to an identical food or drink item.

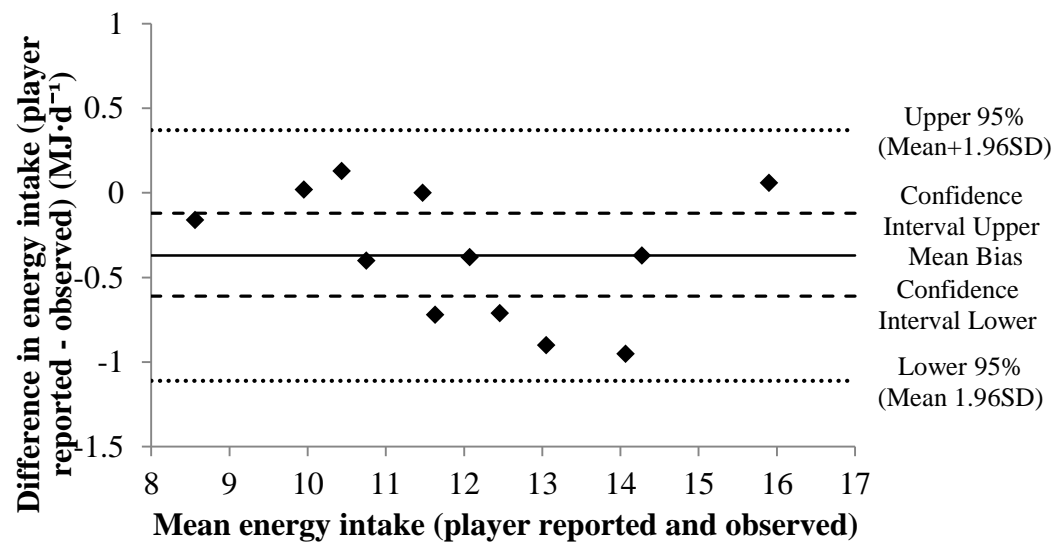
#### **3.2.4 Statistical Analysis**

All data are presented as mean  $\pm$  SD. The agreement between estimates of energy intake ( $\text{MJ}\cdot\text{day}^{-1}$ ) reported by the players (self-reported, weighed food diaries and 24 h recall interviews) and observed energy intake by the researcher was assessed using a range of statistics. Limits of agreement (LOA) using the Bland and Altman (1986) method was used to assess the relative bias (mean difference) and random error (1.96 SD of the difference) between methods, as recommended by Livingstone et al. (1992). Confidence intervals (CI: 95%) for the bias and paired samples *t*-tests were used to test for significant differences between methods. Random error was further assessed using typical error of the estimate as a coefficient of variation (CV), and linear regression (Hopkins, 2015). Statistical significance was assumed at  $p < 0.05$ .

### 3.3 Results

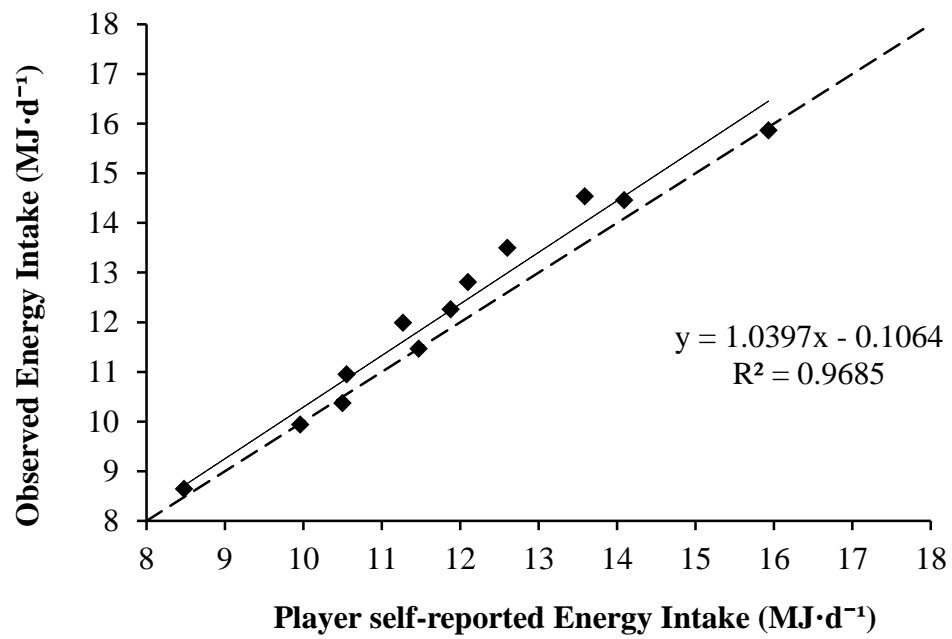
Players self-reported energy intake ( $11.87 \pm 2.01 \text{ MJ}\cdot\text{day}^{-1}$ ) was significantly under-reported in comparison to observed energy intake ( $12.23 \pm 2.12 \text{ MJ}\cdot\text{d}^{-1}$ ) with a mean bias of  $-0.37 \text{ MJ}\cdot\text{day}^{-1}$  (95% CI for bias =  $-0.61$  to  $-0.12 \text{ MJ}\cdot\text{day}^{-1}$ ) ( $t(11) 3.291$ ,  $p = 0.007$ ). The combined approach of self-reported, weighed food diary and 24 h recall therefore had a 3.0% bias towards under-reporting of energy intake when male Academy soccer players are asked to record their food and fluid intake, though the 95% CI for this bias was narrow with a range of 1.0% to 5.0%.

For random error, the 95% LOA between methods ranged between  $-1.11$  to  $0.37 \text{ MJ}\cdot\text{day}^{-1}$  (Figure 3.1). The standard error of the estimate was low, with a typical error between measurements of 3.1%. The results of the linear regression analysis (and associated calibration equation) are presented in Figure 3.2. Collectively these data demonstrate a low degree of random error between self-reported energy intake and researcher observed methods. A visual inspection of the distribution of data in Figures 3.1 and 3.2 show no indication of heteroscedasticity. A descriptive analysis of micronutrient values as a percentage of Recommended Nutrient Intake (RNI; SACN, 2011) were performed on the players with the highest and lowest total energy intake (Figure 3.3).

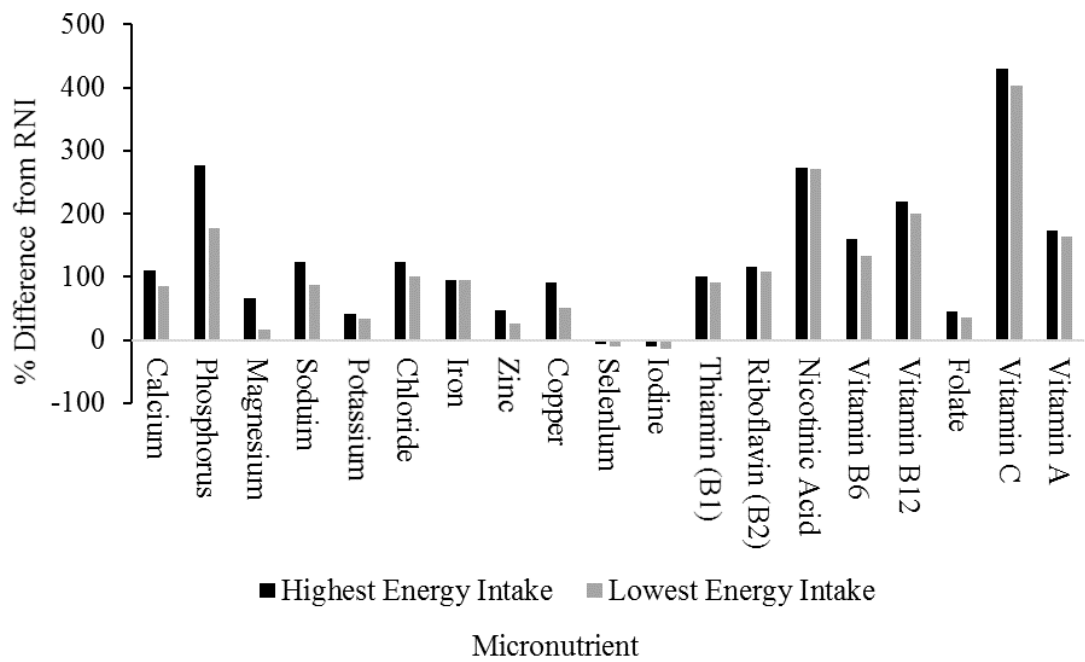


**Figure 3.1** Individual differences in energy intake (player reported energy intake – observed energy intake) versus mean of the measurements for energy intake.





**Figure 3.2** Linear regression scatter plot between player reported energy intake and observed energy intake.



**Figure 3.3.** Micronutrient contents of Academy soccer players' diets (highest v lowest individual total energy intake) expressed relative to activity corrected Recommended Nutrient Intake (RNI) values.

### 3.4 Discussion

The aim of the current study was to explore the agreement between researcher observed energy intake and self-reported energy intake in male Academy soccer players using a combined method (self-reported weighed food diary, supplemented with a 24 h recall). In agreement with the hypothesis, the findings demonstrate that the variability between methods was low (typical error of the estimate = 3.1%) and although under-reporting was observed with the combined self-report method, the magnitude of this bias was both small ( $-0.37 \text{ MJ}\cdot\text{day}^{-1}$ ) and consistent (95% CI for bias =  $-0.61$  to  $-0.12 \text{ MJ}\cdot\text{day}^{-1}$ ). Consequently, with an appropriate adjustment for under-reporting, the combined self-report method could be used as an alternative to the researcher observed method to quantify energy intake in Academy soccer players. Furthermore, it could be a valuable tool to adopt when studying such measures in a free-living environment.

Player mean self-reported energy intake ( $11.87 \pm 2.01 \text{ MJ}\cdot\text{day}^{-1}$ ) produced a significant bias of  $-0.37 \text{ MJ}\cdot\text{day}^{-1}$  toward under-reporting when compared to mean observed energy intake ( $12.23 \pm 2.12 \text{ MJ}\cdot\text{day}^{-1}$ ). However, when analysing agreement between two methods it is important to question whether the differences are meaningful. Bland and Altman (1990) suggest that it is not the statistical difference that matters, but the magnitude. While the difference between methods was significantly different, the magnitude of the difference was low, as evidenced by the narrow confidence interval for bias ( $-0.61$  to  $-0.12 \text{ MJ}\cdot\text{day}^{-1}$ ). Wang, Gortmaker, Sobol and Kuntz (2006) proposed a difference in energy intake of  $0.46\text{--}0.69 \text{ MJ}\cdot\text{d}^{-1}$  to be clinically meaningful in a weight loss context; higher than the mean bias identified in the current study ( $-0.37 \text{ MJ}\cdot\text{d}^{-1}$ ), suggesting the under-reporting would not likely impact on energy balance. Importantly for future studies, the degree of random error between methods was also low, with a

typical error of the estimate of 3.1%, with 95% LOA ranging from  $-1.11$  to  $0.37$   $\text{MJ}\cdot\text{day}^{-1}$ . Therefore, it is suggested that future studies may adopt the self-report method for determining energy intake within this population, with a small adjustment for the significant, but likely small, under-reporting. If future study findings required an adjustment, this would be achieved using the calibration equation provided by the linear regression analysis in Figure 3.2;  $y = 1.0397x - 0.1064$  where  $y$  = researcher observed energy intake and  $x$  = participants self-reported energy intake. To illustrate, for the average self-report energy intake measured in this study ( $11.87 \text{ MJ}\cdot\text{day}^{-1}$ ) would be adjusted to  $12.23 \text{ MJ}\cdot\text{day}^{-1}$  to account for the under-reporting using the calibration equation. Using this method will allow researchers and practitioners to accurately investigate energy intake in free-living, field-based environments and as such could incorporate more accurate nutritional interventions to optimise performance.

Although no previous research has attempted to quantify the accuracy of energy intake within the population of Academy soccer players, the finding of significant under-reporting is in agreement with the majority of previously published studies investigating energy intake methods in adolescent males (Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992). Despite studies adopting differing methods of collecting dietary energy intake, results present unequivocal evidence of significant under-reporting when validated against DLW;  $-20\%$ ;  $-22\%$ ;  $-18\%$  and  $-22\%$  respectively (Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992). Whilst the current study is in agreement with previous studies with regards to identifying a significant under-reporting of energy intake, the considerably lower  $-3\%$  error highlights a substantial improvement when a combined dietary data collection method is adopted.

The low level of bias and close agreement demonstrated in the current study can be explained by the players' high level of engagement. Livingstone et al. (1992) discussed the effect of age on validity of energy intake, suggesting the magnitude of under-reporting increases as children enter adolescence. However, educational workshops were conducted with the players providing a detailed explanation and demonstration of the food weighing and recording process, increasing player's engagement and confidence with the collection method. Furthermore, athletes have been found to display traits of higher inherent motivation levels (Gould, 1982; Reiss, Wiltz, Sherman, 2001), which may account for the higher level of compliance and engagement in the combined collection method within the current population sample, due to their willingness to develop, learn and impress Academy staff. Players were also administered the Dutch Eating Behaviour Questionnaire (Van Strein et al., 1986) prior to data collection. All twelve players were classified as unrestrained eaters, with the mean dietary restraint score ( $2.28 \pm 0.3$ ) falling into the average range for high school males (Van Strein et al., 1986). Higher levels of dietary restraint are more likely to coincide with under-reporting, as this was not evident, as well as all players recording a healthy body mass index ( $21.9 \pm 1.9 \text{ kg/m}^2$ ); it is likely that this also contributed to the small bias of the self-reported energy intake.

One possible reason to account for the small under-reporting evident in the present study could be the nature of how athletes consume nutrients. Frequent snacking is extremely common amongst the athlete population to accomplish the high energy intake requirements of high-level sport (Hawley et al., 1997), with as many as nine occasions of snacking demonstrated over a single day period (Jensen et al., 1992). Therefore, the

eating pattern of adolescent athletes may be more complex due to increased frequency of recording, which can subsequently increase burden and effect compliance levels (Livingstone & Robson, 2000) as well as increase the difficulty of remembering large amounts of food items during 24 h recall. The mean observed energy intake in the current study was  $12.23 \pm 2.12 \text{ MJ}\cdot\text{day}^{-1}$  however,  $35\% \pm 5\%$  of mean energy intake comprised of secondary items, which can be classified as snacking ( $4.28 \pm 1.06 \text{ MJ}\cdot\text{day}^{-1}$ ). This finding is supported by previous studies that identified contribution of snacks to total energy intake in high-level athletes range from 17%–22% (Ziegler, Jonnalagadda, Nelson, 2002) and 30%–37% (Van Erp-Baart, Saris & Binkhorst 1989). Analysis of the self-reported energy intake identified that a number of secondary items were missed which equated to  $0.33 \text{ MJ}\cdot\text{day}^{-1}$ . This finding clarifies 90% of the under-reporting error ( $-0.37 \text{ MJ}\cdot\text{day}^{-1}$ ), with the remaining 10% ( $0.04 \text{ MJ}\cdot\text{day}^{-1}$ ) attributed to inaccuracy of weighing food items. This is an important consideration to acknowledge that actual reporting accuracy was not the issue; moreover, it was the ability of the player to record the consistent snacking throughout the day.

The mean observed energy intake ( $12.23 \pm 2.12 \text{ MJ}\cdot\text{day}^{-1}$ ) is slightly higher in comparison to the Estimated Average Requirements (SACN, 2011). Recommendations are  $10.8 \text{ MJ}\cdot\text{d}^{-1}$  and  $11.7 \text{ MJ}\cdot\text{d}^{-1}$  respectively for active male 13 y and 14 y olds, based on Physical Activity Levels (PALs) of 1.85 (SACN, 2011). It is important to recognise that although the recommendations (SACN, 2011) take in to consideration physical activity and growth, the increased physical activity levels experienced on a daily basis by the current study sample are considerably higher (Russell & Pennock, 2011). When comparing the results to free-living studies investigating nutritional intake of Academy soccer players, researchers have all reported sub-optimal energy intakes based on

estimated energy expenditure (Iglesias-Gutierrez et al., 2005; Ruiz et al., 2005; Russell & Pennock, 2011), even when intake is in excess of mean observed energy intake in the current study. Energy intake findings of  $14.3 \pm 0.8 \text{ MJ}\cdot\text{day}^{-1}$  (Ruiz et al., 2005);  $12.6 \text{ MJ}\cdot\text{day}^{-1}$  (Iglesias-Gutierrez et al., 2005);  $11.9 \pm 0.7 \text{ MJ}\cdot\text{day}^{-1}$  (Russell & Pennock, 2011) have all been identified, which demonstrate the current study values represent habitual energy intake in this population. The macronutrient breakdown of mean observed energy intake equated to carbohydrates ( $59\% \pm 3\%$ ), proteins ( $15\% \pm 3\%$ ) and fats ( $26\% \pm 3\%$ ). This finding is also in direct support of previous research with Academy soccer players as Russell and Pennock (2011) identified macronutrient contributions to total energy intake as  $56\% \pm 1\%$ ,  $16\% \pm 1\%$  and  $31\% \pm 1\%$  for carbohydrates, proteins and fats, respectively. Therefore, the composition of energy intake in the present study is similar to that of habitual, free-living energy intake studies within a similar population (Russell & Pennock, 2011), supporting the study's ecologically valid design. Furthermore, a descriptive analysis of micronutrient values as a percentage of Recommended Nutrient Intake (RNI; SACN, 2011) were performed on the players with the highest and lowest total energy intake (Figure 3.3). Relatively few studies have addressed the micronutrient content of diets of Academy soccer players (Boisseau et al., 2002; Iglesias-Gutierrez et al., 2005; Russell & Pennock, 2011). However, in agreement with the limited amount of previous findings, the majority of vitamins and minerals either met or exceeded activity corrected RNI values from dietary intake alone, demonstrating that dietary practices of Academy players, are adequate to fulfil their micronutrient requirements.

Rumbold et al. (2011a) recommended that studies assessing energy balance or devising exercise interventions, which require recording of energy intake should endeavour to

establish the accuracy of the energy intake method, specific to the sample population. Whilst acknowledging the combined method requires high participant and researcher compliance, which may demand a relatively high time cost; the current study provides a benchmark for researchers and practitioners to use the combined method of energy intake when collecting such data within Academy soccer players in free-living environments. It is acknowledged that the two methods report a significant difference; however, the magnitude of the difference is still considerably lower than previously published methods with male adolescents (Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992) and a suitable adjustment to self-report estimates of energy intake can be confidently applied given the narrowness of both the estimate of the bias score and of the random error between methods. Further research is required to utilise this combined method to assess energy balance in male Academy soccer players in a free-living environment over longer time scales. This will help to inform nutritional interventions to support the training and physical development of this population.



### **3.5 Conclusion**

In conclusion, the combined method of self-report, weighed food diary and 24 h recall demonstrated a low random error between methods and although a statistically significant under-reporting was observed, the magnitude of this bias was small. Applying an appropriate adjustment for under-reporting to the combined method could provide a more accurate alternative to current energy intake collection methods, providing both researchers and practitioners with a valuable tool to quantify energy intake in Academy soccer players, in a free-living environment. Such accurate information on habitual energy intake is warranted as currently limited information exists on dietary practices of Academy soccer players in the UK. Information would likely be important for coaches and practitioners interested in assessing if energy intake is sufficient to meet the demands of training and match-play.

## **Chapter 4: Assessment of energy intake and energy expenditure of male Academy soccer players during a competitive week**

This work has been published in a peer-reviewed journal:

**Briggs, M. A.**, Cockburn, E., Rumbold, P. L. S., Rae, G., Stevenson, E. J., & Russell, M. (2015). Assessment of energy intake and energy expenditure of male adolescent academy-level soccer players during a competitive week. *Nutrients* 7, 8392-8401.

### **Abstract**

*Introduction/Purpose:* There is limited information quantifying the dietary habits of adolescent Academy soccer players, engaging in high weekly training volumes. Therefore, the aim of this study was to investigate the energy intake and expenditure of professional adolescent Academy soccer players during a competitive week.

*Methods:* Over a seven day period that included four training days, two rest days and a match day, energy intake (self-reported weighed food diary and 24-h recall) and expenditure (tri-axial accelerometry) were recorded in 10 male players from a professional English Premier League club.

*Results:* The mean macronutrient composition of the dietary intake was  $318 \pm 24 \text{ g} \cdot \text{day}^{-1}$  ( $5.6 \pm 0.4 \text{ g} \cdot \text{kg}^{-1} \text{ BM}$ ) carbohydrate,  $86 \pm 10 \text{ g} \cdot \text{day}^{-1}$  ( $1.5 \pm 0.2 \text{ g} \cdot \text{kg}^{-1} \text{ BM}$ ) protein and  $70 \pm 7 \text{ g} \cdot \text{day}^{-1}$  ( $1.2 \pm 0.1 \text{ g} \cdot \text{kg}^{-1} \text{ BM}$ ) fats, representing  $55\% \pm 3\%$ ,  $16\% \pm 1\%$ , and  $29\% \pm 2\%$  of mean daily energy intake respectively. A mean daily energy deficit of  $-1302 \pm 1662 \text{ kJ}$  ( $p = 0.035$ ) was observed between energy intake ( $9395 \pm 1344 \text{ kJ}$ ) and energy expenditure ( $10679 \pm 1026 \text{ kJ}$ ). Match days ( $-2278 \pm 2307 \text{ kJ}$ ,  $p = 0.012$ ) and heavy training days ( $-2114 \pm 2257 \text{ kJ}$ ,  $p = 0.016$ ) elicited the greatest deficits between intake and expenditure.

*Conclusion:* The mean daily energy intake of professional adolescent Academy soccer players was lower than the energy expended during a competitive week. The magnitudes of these deficits were greatest on match and heavy training days. These findings may have both short and long-term implications on the performance and physical development of adolescent soccer players.

## **4.1 Introduction**

Soccer is typically classified as a high-intensity, intermittent team sport comprised of two 45 min halves (Stolen et al., 2005). During a 90 min match, distances of 7–9 km have been reported for adolescents representing professional soccer Academies (Harley et al., 2010; Goto et al., 2015). In adult players of similar standard, match distances typically range between 9 and 13 km (Bangsbo et al., 2006; Russell, Sparkes, Northeast, Cook, Love, Bracken & Kilduff, 2014; Russell et al., 2015). Similar match distances may insinuate comparable workloads between youth and adult populations. However, utilising adult data to predict adolescent athletes' energy expenditure has been criticised and may not be directly comparable, due to the increased energy cost of exercise (Bar-Or, 2001). Energy balance is integral for adolescents to sustain optimal growth and development (Giovannini et al., 2000; Spear, 2002), with additional nutritional intake required to offset the increased energy cost of high-level training and competition (Petrie et al., 2004).

Research investigating soccer-specific nutritional intakes has been carried out in adult professional soccer (Calderone et al., 1990; Clark, 1994; Hargreaves, 1994; Martin, Lambeth & Scott, 2006; Maughan, 1997; Reilly, 1994). However, a relatively limited amount of studies have investigated the nutritional intake of adolescent Academy soccer players (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Ruiz et al., 2005). The findings of these studies, which have primarily investigated the habits of players from outside of the UK, have typically reported sub-optimal energy intake relative to estimates of energy expenditure (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002). In the only study to date to investigate dietary and activity regimes of

adolescent soccer players in the UK, it was reported that dietary practices are inadequate to sustain the demands of training and competition, with a mean daily energy deficit of  $-3.3 \pm 0.73$  MJ reported (Russell & Pennock, 2011). Although energy expenditure estimations utilised field-based methods, these equations were dependent upon subjective accounts of activity volume, recorded in self-reported training diaries. (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Ruiz et al., 2005; Russell & Pennock, 2011). While studies have outlined mean weekly energy deficit values (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Ruiz et al., 2005; Russell & Pennock, 2011), these studies do not provide a breakdown of the difference between days, to understand if fluctuations in energy balance occur. Furthermore, considering the demands of Academy soccer match-play (Harley et al., 2010; Goto et al., 2015), limited information exists quantifying pre-match dietary practices of Academy soccer players (Leblanc et al., 2002; Ruiz et al., 2005).

Assessing energy balance is reliant on the comparison of accurate methods of both energy intake and energy expenditure. Although DLW is deemed the gold standard when assessing energy expenditure (Plasqui et al., 2013), its inability to determine the energy cost of each training day suggests it may not be a feasible option for field-based researchers and practitioners who require information on fluctuations in energy balance. An alternative to this approach may be to use accelerometers, which have been demonstrated to elicit valid and reliable measures of physical activity in youth within free-living environments (De Vries et al., 2006; Santos-Lozano et al., 2013; Trost et al., 2011). There are currently no studies, which have utilised accelerometry to assess energy expenditure, whilst also accounting for the potential under-reporting error of

energy intake methods, within a full training and competition week in male adolescent Premier League Academy soccer players in the UK.

Academy soccer players in the UK engage in mandatory training volumes of up to 20 h per week in accordance with the newly adopted Elite EPPP (Premier League, 2015), with additional demands (school P.E.; county and/or national representation and other sporting commitments) independent of Academy training, comprising training loads which are not comparable to full-time scholar soccer players. In order to better understand the dietary and activity habits of this population and to distinguish whether or not current dietary practices are adequate to meet the demands of training and match play and also growth and development, the aim of this study was to assess energy balance in male Academy soccer players over a 7-day period. A secondary aim was to examine type of activity day (heavy/moderate/light training, match, rest) separately to highlight any fluctuation in energy balance throughout the week, as well as examining pre-match nutritional practices. Based on previous studies, it was hypothesised that daily energy intake would be significantly less than energy expenditure, with greatest deficits being on match and heavy training days.

## **4.2 Method**

### **4.2.1 Participants**

Ten male players (age:  $15.4 \pm 0.3$  y; stature:  $1.70 \pm 0.06$  m; BM:  $57.8 \pm 7.8$  kg and BMI:  $19.84 \pm 1.58$  kg·m<sup>-2</sup>) who played for a Premier League soccer Academy participated in the study. Statistical power was calculated using commercially available software (GPower v3.1, Germany) and a sample size of ten was deemed sufficient for >80% power to detect statistical differences between energy intake and expenditure overall (80%), and differentiating between type of training day (heavy 91% and match day 89%). The maturity offset was  $3.6 \pm 0.5$  y beyond PHV indicating that all of the players had reached their predicted PHV (positive maturity offset) and thus were of a similar maturation status (Mirwald et al., 2002). All players were actively engaged in full training and competition, which over the course of the study consisted of four training days (two training sessions per day was classified as a heavy day and one session per day was classified as a moderate day), a match day and two non-training recovery days within a 7-day period. Data collection period was during the second half of the competitive season (March), whereby players were consistently engaged in 20 h of active training per week. The study was approved by the Faculty of Health and Life Sciences Research Ethics Committee at Northumbria University. Information was provided prior to gaining written informed consent from the players and their parents or guardians before commencing data collection (see Appendix B for example of ethics documents).

### **4.2.2 Dietary Assessment**

Energy intake was recorded over a 7-day period during the competitive season, using the combined method of self-reported weighed food diary, supplemented with 24 h

recall (chapter 3). The combined method investigated in chapter 3 demonstrated an increased accuracy, with a smaller under-reporting bias (~3%), compared to previously investigated isolated methods of energy intake collection within adolescent male populations (18-27%; Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992). The accuracy of the combined method was conducted with the same cohort of players used within the current study, however, the time frame between studies was ~14 months. Furthermore, whilst the design of chapter 3 was created purposefully to mimic habitual activities, albeit within a laboratory setting, this was during a rest day. Therefore, it was deemed appropriate to engage players in a re-familiarisation pilot period prior to data collection to refresh players' memory of the combined method, whilst also gaining an insight in to any practical issues of applying this method within the Academy setting. The re-familiarisation session was conducted over a 6 h period whilst at the Academy on a moderate training day. This period consisted of 1 x 90 min training session, alongside classroom based educational work and sedentary periods of free time. The combined dietary data collection was compared to the observed method using the same covert coding process outlined in chapter 3 as well as also mimicking the *ad libitum* energy intake design of chapter 3. Mean self-reported energy intake demonstrated a slight under-reporting bias of -0.40 MJ·d<sup>-1</sup>. The results of the re-familiarisation pilot session demonstrated similar levels of accuracy outlined in chapter 3 (-0.37 MJ·d<sup>-1</sup>), providing evidence that the combined method investigated in chapter 3 can be confidently applied to free-living environments, specific to the Academy player.

Seven day dietary data collection was seen as optimal to gain a sufficient amount of information whilst maintaining high compliance (Bingham, 1987), and is indicative of

previous studies (Boisseau et al., 2002; Caccialanza et al., 2007; Russell & Pennock, 2011). Each player was provided with a food diary (Appendix D) and was asked to detail their weighed food intake, time of food consumption, preparation and cooking methods, and brand names. Provision of electronic portable scales (Salter 1036 BKSSDR, UK) facilitated weighing of all food items consumed. Prior to data collection, a series of practical workshops were delivered to all players by the lead researcher in order to ensure that participants were familiar with the study procedures relating to energy intake. To coincide with the self-reported food diary each player engaged in a 24 h recall interview on each day of the data collection period. Interviews were carried out using the two-pass method (Ashley & Bovee, 2003) whereby the overall eating events of the previous 24 h were reviewed to identify the main foods and beverages consumed. Secondly, the players were prompted for more information such as condiments, brand names, additional food or drink items, how the foods were prepared and cooked and portion sizes if not provided in the food diaries.

Food diaries were cross-referenced with the respective 24 h recalls, supplementing any missing or additional information. Commercially available software was used to analyse energy intake (Microdiet version 2.8.5, Downlee Systems Limited, High Peak, UK). To ensure consistency, a single researcher, who was responsible for delivering the data collection familiarisation workshops to the participants, performed all dietary analysis, as recommended by Deakin (2000). Total energy intake values were adjusted to accommodate for an under-reporting bias using a correction factor (Equation [1]) as previously identified in chapter 3.

$$\text{Energy Intake: } y = 1.0397x - 0.1064 \text{ (where } y = \text{adjusted energy intake and } x = \text{players self-reported energy intake).} \quad [1]$$



### **4.2.3 Energy Expenditure Estimation**

Energy expenditure was calculated using accelerometry methods (ActiGraph GT3X+; ActiGraph, Pensacola, FL, USA) that demonstrate valid and reliable measures of physical activity and sedentary time in youth populations (De Vries et al., 2006; Santos-Lozano et al., 2013; Trost et al., 2011). This accelerometer also demonstrates high levels of inter-instrument reliability (ICC values: 0.97 to 1.00 for raw outputs and 0.97 to 0.99 for derived outputs, within free-living environments; Jarrett et al., 2015). The accelerometer was positioned above the anterior spine of the iliac crest in line with the anterior axillary line of the dominant hip as per the manufacturer's recommendations. The acceleration output was digitised by a 12-bit analogue-to-digital convertor at a user specific rate of 30 Hz. Players were instructed to wear the device for 24 h for each of the 7 days except during exposure to water-based activities (e.g., swimming and bathing). MET intensity thresholds were adopted based on previous calibration studies (Trost et al., 2011) (Table 4.1). In addition, cut points devised by Evenson et al. (2008) were used as they exhibit significantly better accuracy than other published cut points (Trost et al., 2011) (Table 4.1). Furthermore, the equation (Freedson et al., 2005) used to convert the raw data activity counts to a measure of energy expenditure has previously been deemed a valid and accurate method in free-living, active youth populations (Santos-Lozano et al., 2013).

**Table 4.1** MET Intensity Threshold and Cut Points

	<b>MET Intensity Thresholds</b>	<b>Cut Points (Activity Counts)</b>
<b>Sedentary Activity (SED)</b>	<1.5 METs	≤100
<b>Light Physical Activity (LPA)</b>	≥1.5 and <4 METs	>100 and <2296
<b>Moderate Physical Activity (MPA)</b>	≥4 and <6 METs	≥2296 and <4012
<b>Vigorous physical Activity (VPA)</b>	≥6 METs	≥4012

Relevant METs and cut points were inserted to the ActiLife 6 Data Analysis Software (ActiGraph, Pensacola, FL, USA) accordingly, prior to energy expenditure calculations. In many research designs displaying energy expenditure in relation to METs is appropriate, however when comparing with energy intake, data expressed as MJ is more relevant and directly comparable. To calculate energy expenditure in MJ, daily MET values were derived from the raw data accelerations and input in to a modified version of the equation devised by Ridley et al. (2008) (Equation [2]), using Schofield's (1985) prediction equation to estimate adolescent RMR (Equation [3]).

$$\text{Energy Expenditure (MJ)} = \text{MET value} \times \text{adolescent RMR (MJ} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}) \times \text{kg body weight} \times \text{number of minutes activity performed} \quad [2]$$

$$\text{Resting Metabolic Rate (RMR)} = 17.686 \times \text{kg body weight} + 658.2 \quad [3]$$

#### 4.2.4 Statistical Analysis

Dietary intake data was considered reliable at <20% when using the percentage of relative standard error ( $\text{SEM} \div \text{Mean}$ ; Russell & Pennock, 2011). Seven day means for total energy intake (MJ), total energy expenditure (MJ), energy deficit (MJ) and macronutrients (% total energy intake, g,  $\text{g} \cdot \text{kg}^{-1}$ ) were determined. Once confirmed by normality and variance assessments, a paired samples *t*-test was used to analyse differences in mean 7-day energy balance (energy intake vs energy expenditure) and also differences in energy balance for different types of training/recovery days (heavy, moderate, rest) and match day. A one way (within-participants factor: energy deficit) repeated measures analysis of variance (ANOVA) was used to examine if energy deficit differed between days (heavy, moderate, rest and match day). A separate one way (within-participants factor: macronutrient intake) repeated measures ANOVA was used to examine if carbohydrate, protein and fat differed between days (heavy, moderate, rest

and match day). Mauchly's test was consulted and Greenhouse-Geisser correction was applied if the assumption of sphericity was violated. Significant main effects were further investigated using multiple pairwise comparisons with Bonferroni confidence interval adjustment. A descriptive analysis was performed on pre-match energy intake to quantify habitual practice, as well as micronutrient values as a percentage of Recommended Nutrient Intake. All data are presented as mean  $\pm$  SD, with level of significance set at  $p \leq 0.05$ , using SPSS (Version 21; SPSS Inc., Chicago, IL, USA) for all analysis.

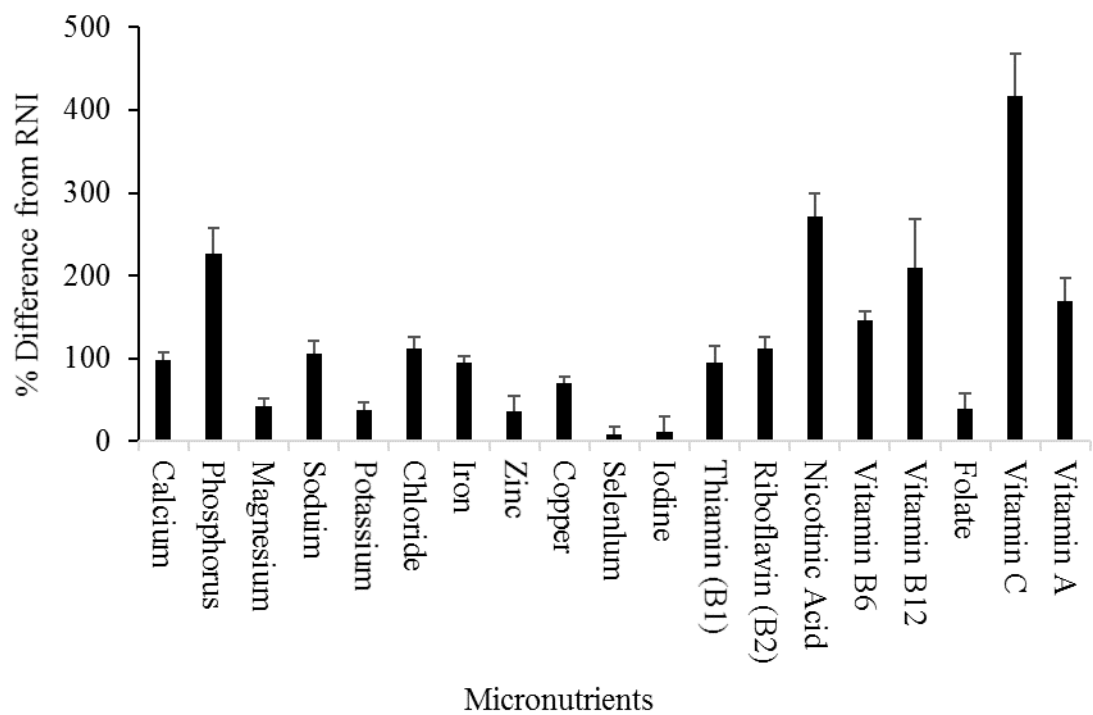
## **4.3 Results**

### **4.3.1 Macronutrients and Micronutrients**

Estimates of nutritional intake are considered reliable as relative standard error did not exceed 8% for any of the analysed macronutrients. The mean daily macronutrient intakes, with a breakdown in relation to type of activity day are expressed in Table 4.2. The ANOVA revealed no significant main effect for carbohydrate ( $F_{(3,27)} = 1.671$ ,  $p = 0.197$ ), protein ( $F_{(3,27)} = 0.883$ ,  $p = 0.462$ ) and fat ( $F_{(3,27)} = 1.963$ ,  $p = 0.143$ ) over the different types of training/match days. A descriptive analysis of micronutrient values performed on the players with the highest and lowest total energy intake (Figure 4.1), demonstrated all micronutrient either met or exceeded RNIs.

**Table 4.2** Mean macronutrient intakes of Academy soccer player's diets differentiated by type of activity day (mean  $\pm$  SD).

Macronutrient	Heavy	Moderate	Rest	Match	Mean
<i>Protein</i>					
Per day ( $\text{g}\cdot\text{day}^{-1}$ )	93 $\pm$ 29	82 $\pm$ 27	96 $\pm$ 22	86 $\pm$ 26	86 $\pm$ 10
Per unit BM ( $\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ )	1.6 $\pm$ 0.5	1.4 $\pm$ 0.6	1.7 $\pm$ 0.5	1.5 $\pm$ 0.5	1.5 $\pm$ 0.2
Total protein energy ratio (%)	17 $\pm$ 6	16 $\pm$ 4	19 $\pm$ 6	17 $\pm$ 4	16 $\pm$ 1
<i>Carbohydrate</i>					
Per day ( $\text{g}\cdot\text{day}^{-1}$ )	337 $\pm$ 109	321 $\pm$ 76	281 $\pm$ 51	314 $\pm$ 97	318 $\pm$ 24
Per unit BM ( $\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ )	6.0 $\pm$ 2.3	5.6 $\pm$ 1.6	5.0 $\pm$ 1.3	5.5 $\pm$ 2.0	5.6 $\pm$ 0.4
Of which are sugars ( $\text{g}\cdot\text{day}^{-1}$ )	155 $\pm$ 71	150 $\pm$ 53	103 $\pm$ 38	109 $\pm$ 56	136 $\pm$ 24
Total carbohydrate energy ratio (%)	55 $\pm$ 7	58 $\pm$ 8	49 $\pm$ 7	55 $\pm$ 8	55 $\pm$ 3
<i>Fats</i>					
Per day ( $\text{g}\cdot\text{day}^{-1}$ )	73 $\pm$ 24	66 $\pm$ 26	80 $\pm$ 19	66 $\pm$ 18	70 $\pm$ 7
Per unit BM ( $\text{g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ )	1.3 $\pm$ 0.4	1.1 $\pm$ 0.5	1.4 $\pm$ 0.3	1.1 $\pm$ 0.2	1.2 $\pm$ 0.1
Of which are saturates ( $\text{g}\cdot\text{day}^{-1}$ )	28 $\pm$ 11	26 $\pm$ 10	27 $\pm$ 7	21 $\pm$ 8	26 $\pm$ 3
Total fats energy ratio (%)	28 $\pm$ 6	27 $\pm$ 8	33 $\pm$ 6	28 $\pm$ 6	29 $\pm$ 2

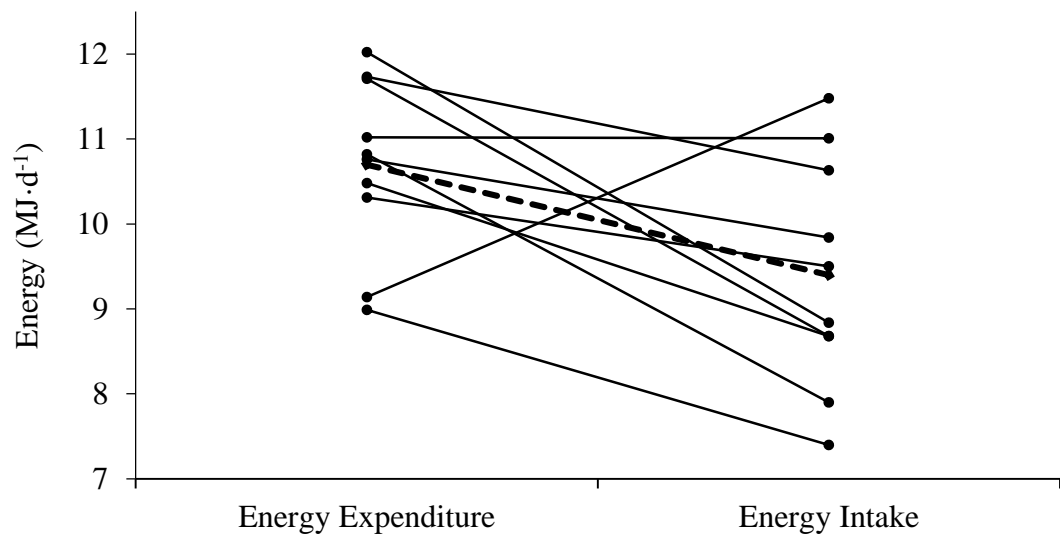


**Figure 4.1.** Mean  $\pm$  SD micronutrient contents of Academy soccer players' diets expressed relative to activity corrected Recommended Nutrient Intake (RNI) values.

### **4.3.2 Energy Balance**

Mean daily energy intake ( $9.4 \pm 1.34$  MJ) was significantly lower than mean daily energy expenditure ( $10.68 \pm 1.03$  MJ) ( $p = 0.035$ ). This resulted in a mean daily energy deficit of  $-1.3 \pm 1.66$  MJ. Figure 4.2 illustrates the daily energy intake and expenditure data for each individual.

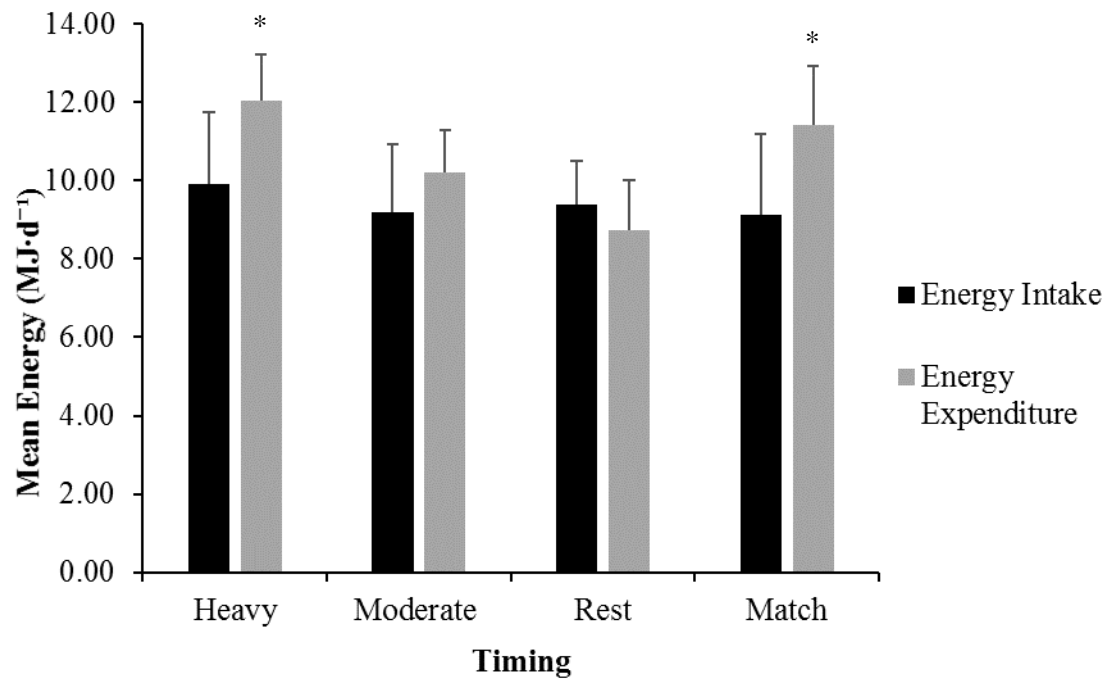




**Figure 4.2** Individualised data for estimated daily energy intake (MJ·d<sup>-1</sup>) and expenditure (MJ·d<sup>-1</sup>) for each player and the group mean (bold dashed line).

### 4.3.3 Energy Cost of Activities

Figure 4.3 illustrates the mean daily energy intake and expenditure data based on the type of training day. A significant difference was observed between mean energy intake and energy expenditure on heavy training days ( $-2.11 \pm 2.26$  MJ) ( $p = 0.016$ ) and match day ( $-2.28 \pm 2.31$  MJ) ( $p = 0.012$ ). Although an energy deficit was also observed on a moderate training day ( $-1.03 \pm 2.02$  MJ) this was not statistically significant ( $p = 0.141$ ). Rest day was the only exception, demonstrating a mean positive energy balance ( $0.64 \pm 1.2$  MJ); yet this value was similar to energy expenditure ( $p = 0.125$ ). The ratio of mean energy intake to mean energy expenditure was  $89\% \pm 16\%$ .



**Figure 4.3** Mean Energy Intake (MJ) compared to Mean Energy Expenditure (MJ) for type of training. \*Significant difference between mean energy intake and mean energy expenditure at the corresponding time-point at  $p < 0.05$  level.

The ANOVA revealed a significant main effect ( $F_{(3,27)} = 6.682$ ,  $p = 0.002$ ), with *post hoc* comparisons identifying significant differences in energy balance between heavy training days and rest day ( $-2.76 \pm 0.75$  MJ;  $p = 0.029$ ), and also between a match day and rest day ( $-2.92 \pm 0.75$  MJ;  $p = 0.003$ ).

#### **4.3.4 Pre-match energy intake**

Pre-match energy intake provides mean values of  $1.16 \pm 0.13$  MJ consumed ~2-3 h before kick-off. Consumption was comprised of  $41 \pm 2$  g,  $10 \pm 4$  g and  $8 \pm 2$  g of carbohydrate, protein and fat respectively, resulting in a macronutrient percentage breakdown of  $60 \pm 6\%$ ,  $15 \pm 4\%$  and  $25 \pm 4\%$ .

#### 4.4 Discussion

The primary aim of the study was to assess energy balance in male Academy soccer players. In agreement with the hypothesis, the findings demonstrate that over a 7-day period players were in a negative energy balance, with energy intake being insufficient to meet the demands of training and competition. Mean daily energy intake was significantly lower than mean daily energy expenditure, providing a daily energy deficit. Additionally, the type of training had a direct impact on the degree of energy deficit, highlighting that heavy training days and match days are a particular threat to energy balance. Furthermore, analysis of pre-match dietary practices highlights likely sub-optimal energy intake. Such information is likely of use to practitioners and players who should consider adjusting energy intake accordingly.

Whilst energy balance assessment of UK Academy soccer players has previously been conducted, this is the first study to utilise accelerometry to assess energy expenditure, whilst also accounting for under-reporting error in energy intake. Although magnitudes of deficits differ, evidence of negative energy balance reflects observations from similar populations competing outside of the UK (Caccialanza et al., 2007; Leblanc et al., 2002; Ruiz et al., 2005). In an attempt to quantify the magnitude of the mean energy deficit ( $-1.3 \pm 1.66 \text{ MJ}\cdot\text{day}^{-1}$ ), the findings of the present study provided a considerably lower deficit when compared to previous authors (e.g.,  $-3.73 \pm 3.07 \text{ MJ}\cdot\text{day}^{-1}$  Caccialanza et al., 2007;  $-3.3 \pm 0.73 \text{ MJ}\cdot\text{day}^{-1}$ ; Russell & Pennock, 2011). However, caution must be exercised when attempting to apply direct comparisons due to methodological differences between study designs (Garcia-Roves, Garcia-Zapico, Patterson & Iglesias-Gutierrez, 2014) and the absence of post body mass measurement. Furthermore, it is also important to acknowledge that total energy intake values were adjusted to

accommodate for any under-reporting bias (as previously identified within this population in chapter 3) using a correction factor (Equation [1]). Mean daily energy intake was adjusted from  $9.08 \pm 1.37$  MJ to  $9.4 \pm 1.34$  MJ resulting in mean daily energy deficits decreasing from  $-1.62 \pm 1.73$  MJ to  $-1.3 \pm 1.66$  MJ. However, regardless of the adjustment, the mean daily energy deficit is still considerable lower than previous studies (Caccialanza et al., 2007; Russell & Pennock, 2011). The greater deficit in the previous studies may be inflated due to using an estimated method of measuring energy expenditure ( $14.45 \pm 1.09$  MJ·day<sup>-1</sup>; Caccialanza et al., 2007 and  $15.15 \pm 0.26$  MJ·day<sup>-1</sup>; Russell & Pennock, 2011), in comparison to the current study's findings ( $10.68 \pm 1.03$  MJ·day<sup>-1</sup>), which used accelerometry as a more sensitive measure of energy expenditure.

To contextualise the energy deficit ( $-1.3 \pm 1.66$  MJ·day<sup>-1</sup>) in relation to weight loss, this would equate to a mean weekly weight loss of  $0.04 \pm 0.05$  kg per player, using previously published equations (McArdle, Katch & Katch, 1999). Energy deficit coinciding with heavy training over a sustained period may cause detriments to health, impacting on optimal growth and development (Meyer et al., 2007; Petrie et al., 2004), in addition to performance detriments and increased risk of injury (Thompson, 1998). However due to external factors, participants were unavailable for body mass measurement during the immediate post-data collection period to determine if weight loss was evident, therefore estimations of potential weight loss should be interpreted with caution. Figure 4.2 demonstrates that players were consistently in a negative energy balance with only one participant reporting energy intake values above energy expenditure. A descriptive analysis of the individual data highlights variability in mean energy intake and expenditure values, however there is no relationship apparent linking

body mass or playing position with higher or lower energy deficits. However, despite players being in a negative energy balance, analysis of micronutrient content of players' mean energy intake revealed that all players either met or exceeded RNI values (SCAN, 2011). This is aligned with previous research investigating dietary habits of Academy soccer players (Boisseau et al., 2002; Iglesias-Gutierrez et al., 2005; Russell & Pennock, 2011), suggesting, despite seemingly sub-optimal dietary practices to fuel training and match-play demands, micronutrient intake is not adversely effected.

Information is lacking in the literature to determine where the greatest energy deficits are occurring throughout the week. Although studies outline mean energy expenditure values (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Ruiz et al., 2005, Russell & Pennock, 2011), these studies do not provide a breakdown of the difference between days. Within the current study a significant weekly deficit was observed, however only heavy training ( $-2.11 \pm 2.26$  MJ) ( $p < 0.05$ ) and match day ( $-2.28 \pm 2.31$  MJ) ( $p < 0.05$ ) induced a significant energy deficit relative to energy expenditure. The deficits identified may have implications as Wang et al. (2006) proposed a difference in energy intake of  $0.46\text{--}0.69$  MJ $\cdot\text{day}^{-1}$  to be clinically meaningful in a weight loss context. Furthermore, whilst moderate training days induced an energy deficit deemed not statistically significant ( $-1.03 \pm 2.02$  MJ;  $p = 0.141$ ), this would still be above the clinically meaningful threshold outlined by Wang et al. (2006). However, weight loss could not be confirmed due to the inability to measure post-data collection body mass. In addition, macronutrient intake was not significantly different between days. Findings may suggest that macronutrient consumption and total energy intake is relatively stable across the week, therefore the issue is that players are not adjusting intake to account for the intensity of training. This

finding supports previous research, albeit in Professional Rugby League, whereby players' energy intake was not adjusted for type of training day, in addition, energy derived from carbohydrate remained stable throughout the week (Tooley, Bitcon, Briggs, West & Russell, 2015). Recommendations of periodised nutritional intake may be advised to account for training intensity and volume (Burke, 2010). Energy intake should reflect the type of training day, either increasing or decreasing total consumption accordingly, to ensure a slight positive energy balance is achieved to not only optimise performance (Petrie et al., 2004) but to sustain optimal growth and development (Giovannini et al., 2000; Spear, 2002).

In the limited amount of studies assessing the habitual energy intake of Academy soccer players, pre-match consumption is seldom specifically documented. Only studies by Ruiz et al. (2005) and Leblanc et al. (2002) provided a breakdown of nutritional practices prior to match-play in youth elite Spanish Academy and French international level soccer players respectively. Dietary analysis demonstrated significantly higher values than observed in the current study ( $1.16 \pm 0.13$  MJ), reporting pre-match energy intake of 2.32 MJ (U14), 2.29 MJ (U15), and 2.91 MJ (U16) (Ruiz et al., 2005); and 2.49, 3.56 and 3.05 MJ for U14, U15 and U16 respectively (Leblanc et al., 2002). Whilst Leblanc et al. (2002) did not provide a macronutrient breakdown of intake composition, Ruiz et al. (2005) observed relatively wide ranging values of 30-87 g, 3-19 g and 19-30 g of carbohydrate, protein and fat respectively, which predominantly exceed values reported in the current study. In the UK Academy soccer matches generally kick-off early in the day (11:00 h), thus limited time separates waking and the onset of exercise. Whilst there may be a multitude of reasons to explain the sub-optimal energy intake, the timings associated with UK Academy match-play may likely explain



the failure of this population to replicate previously reported pre-match energy consumption (Leblanc et al. 2002; Ruiz et al. 2005), whereby match-play adheres to more traditional kick-off timings (~15:00 h).

Although not sports-specific, recommendations suggest that optimised exercise performance is facilitated by a meal containing 1-4 g·kg<sup>-1</sup> (~70-280 g; ~1.2-4.7 MJ for 70 kg athlete) of carbohydrate consumed >60 min before commencing activity (AND, DC & ACSM, 2016). However, for youth soccer players whereby the time between waking and the onset of exercise is limited (i.e. morning kick-off at 11:00 h), such values are seldom achieved (Naughton et al., 2016). Moreover, implications of consuming increased energy intake prior to match-play may raise issues of gastrointestinal discomfort and gut fullness, questioning the feasibility of such recommendations in practice. Thus, a small meal (~1.68-2.09 MJ) primarily consisting of carbohydrate has also been advised prior to exercise (ASCM, 2015). Considering results in the current study demonstrate mean habitual pre-match intakes of  $1.16 \pm 0.13$  MJ consisting of 41 g carbohydrates, 10 g proteins and 8 g fats, based on the current recommendations, pre-match energy intake is likely sub-optimal. Therefore, further investigations are required to determine if increasing habitual pre-match energy intake has an effect on both physiological and soccer-specific performance during match-play and also if this can be tolerated to aid in the reduction of the significant energy deficit associated with match-days.

Burke et al. (2006) proposes 5–7 g·kg<sup>-1</sup>·day<sup>-1</sup> for moderate training, increasing to 7–10 g·kg<sup>-1</sup>·day<sup>-1</sup> for intensive training. The current study's mean daily carbohydrate intake finding of  $55\% \pm 3\%$ , equating to  $5.6 \pm 0.4$  g·kg<sup>-1</sup>·day<sup>-1</sup>, comprised mainly of starchy

foods such as breads, cereals and pasta, demonstrate carbohydrate contribution to total daily energy intake to likely be sub-optimal, especially during heavy training sessions and match days (Table 4.2). This finding supports previous published research within this population with carbohydrate intake ranging from 45% to 56% (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Ruiz et al., 2005, Russell & Pennock, 2011). Diets high in carbohydrate enable an increased muscle glycogen concentration, subsequently delaying the onset of fatigue and sustaining performance levels (Alghannam et al., 2016; Burke et al., 2011), although, it is acknowledged that training with low carbohydrate availability may augment adaptive responses to exercise training (Hansen et al., 2005; Yeo et al., 2008). However, restricting carbohydrate consumption for Academy soccer players may not be appropriate considering the significant energy deficit identified. Furthermore, soccer specific studies have identified optimal carbohydrate intake to improve total match distance (Souglis et al., 2013) and ability to perform at high-intensity (Kingsley, Penas-Ruiz, Terry & Russell, 2014).

Proteins are essential in recovery and to support gains in lean mass (Tipton & Wolfe, 2004) and maintenance following muscle-damaging exercise (Tipton, Elliott, Cree, Aarsland, Sanford, & Wolfe, 2007). In the limited amount of nitrogen balance studies in Academy soccer players, a recommendation of  $1.4\text{--}1.7\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  (Boisseau et al., 2002), has been suggested which aligns with adult counterparts ( $1.2\text{--}1.7\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$ ) (Lemon, 1994; Tipton & Wolfe, 2004). The current study's findings of  $1.5 \pm 0.2\text{ g}\cdot\text{kg}^{-1}\cdot\text{day}^{-1}$  proposes protein intake is within the recommended range to optimise recovery and development, which was consumed mostly from poultry and dairy foods. This finding is not surprising with previous research reporting young athletes

demonstrate adequate protein intakes, despite being in negative energy balance (Bass & Inge, 2006). Optimal protein intake provides essential amino acids to support growth and development of lean body mass (Petrie et al., 2004). However, whilst acknowledging adequate protein intakes may be achieved with sub-optimal energy intake, caution is required, as protein may be used as a substrate for energy, impacting on the ability to synthesise lean tissue.

Younger athletes have a greater reliance on fat as a fuel source during exercise (Bar-Or, 2001), however there is currently no data recommending adolescent athletes consume a higher fat intake than adults. Given the high-intensity nature of soccer, fat recommendations are based upon facilitating carbohydrate intake, as opposed to contribution for energy metabolism (Clark, 1994). Soccer-specific research suggests a fat intake of <30% (Clark, 1994). Studies assessing fat intake in Academy soccer players have reported intakes of 29%–38% (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Ruiz et al., 2005, Russell & Pennock, 2011), which are borderline or above recommendations. The current study's mean fat intake ( $29\% \pm 2\%$ ) may explain the limited consumption of optimal levels of carbohydrate, due to fat intake approaching the top limit of recommended consumption. Furthermore, the quality of fats is important to consider with recommendations of <10% of total energy intake derived from saturated fatty acids (Garcia-Roves et al., 2014). However, the current study found saturated fat values of  $26\% \pm 3\%$ . Considering the significant energy deficit within the current sample of players as well as recognising recent research reporting utilisation of fat as a fuel source to spare glycogen depletion (Hansen et al., 2005; Yeo et al., 2008), albeit equivocal, a reduction in fat intake may not be advisable. Moreover, a reduction in saturated fatty acids may provide opportunity

for consumption of unsaturated fats or higher intakes of carbohydrate, especially on match day to sustain performance levels.

It is acknowledged that all methods of measuring dietary intake have inherent limitations and may be affected by errors of precision and validity (Black, 2001). However, the current study is the first to adopt the combined method of a self-report weighed food diary, supplemented with daily 24 h recall, which has previously been deemed accurate in Academy soccer players (chapter 3) and other adolescent populations engaged in regular exercise (Rumbold et al., 2011a). The current study utilised the combined method and applied the correction equation to adjust energy intake data to accommodate for a slight under-reporting bias. Whilst making blanket adjustments to players' energy intake may have limitations. For example, the correction equation is based on mean group data that is subsequently being applied to individual data, which may or may not be under-reported, consequently increasing energy intake values. However, in this instance the combined dietary data collection tool had previously been investigated with this exact cohort of soccer players (Chapter 3). Furthermore, the findings of chapter 3 identified that this cohort of players are likely to under-report energy intake as 95% confidence intervals were -0.61 to -0.12 MJ·d<sup>-1</sup>, demonstrating a consistent under-reporting range. Therefore, despite the differences in overall daily energy intake values reported between chapters 3 and 4, energy intake values are considered reliable since the accuracy of the combined data collection method has previously been quantified in both chapter 3 and also during re-familiarisation pilot work conducted prior to chapter 4 in a habitual training environment, displaying similar under-reporting bias's (0.37 v 0.40 MJ·d<sup>-1</sup>). Furthermore, a series of educational workshops were conducted with the players leading

up to the data collection period, providing a detailed explanation and demonstration of the food weighing and recording process, increasing player's engagement and confidence with the collection method. The workshops were designed in light of previously published studies (Livingstone et al., 2004), which highlight increased detail and compliance when structured training is provided. This may account for the high quality and level of detail provided within the food diaries as well as the high level of compliance and engagement in throughout the study.

The current study also represents high ecological validity through the use of a free-living experimental design. Previous studies which have assessed energy intake and expenditure within formalised training centres (Leblanc et al., 2002; Rico-Sanz, 1998) may increase internal validity exerting greater control, but exclude influences of habitual family and school environment. Furthermore, whilst it is accepted that the data collection period may only provide a limited insight in to a nine month long competitive season, a 7-day energy intake collection period used within the current study is seen as optimal to increase reliability and validity whilst minimising the burden of longitudinal collection periods (Bingham, 1982). In addition, the incorporation of the EPPP (Premier League, 2015) stipulating compulsory training volumes of 20 h per week for Academy soccer players ensure that there is little differentiation in training volume within the competitive periodisation phase.

Measures of energy expenditure are diverse in the literature (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Ruiz et al., 2005, Russell & Pennock, 2011), with some studies failing to produce a quantification of energy cost whilst attempting to provide conclusions of optimal dietary practices

(Ruiz et al., 2005). The inconsistent approaches provide difficulties in accurately comparing the energy demands placed upon Academy soccer players. Techniques such as DLW and indirect calorimetry, although accurate (Plasqui et al., 2013), are complex, expensive and not applicable to identify fluctuations in training intensity and volume. The current study utilised accelerometers, which have been demonstrated to elicit valid and reliable measures of physical activity and sedentary time in youth (De Vries et al., 2006), providing an objective quantification of energy expenditure within a free-living environment. Whilst it is accepted that energy expenditure measured by accelerometry produces high correlation with indirect calorimetry (McMinn et al., 2013; Jarrett et al., 2015), there is no absolute agreement, therefore limitations do need to be acknowledged when adopting such methods. However, a quantification of the difference in absolute agreement between energy expenditure estimated by the GT3X+ accelerometer (using Freedson et al., (2005) conversion equation; also used within in the current study) and indirect calorimetry have previously been investigated. Results highlighted a non-significant underestimation of  $-0.05 \text{ kcal} \cdot \text{min}^{-1}$ ,  $p > 0.05$  (Santos-Lozano et al., 2013). Thus suggesting minimal absolute change in energy expenditure values, when used in free-living environments within adolescent populations.

#### **4.5 Conclusion**

In conclusion, over a 7-day period male adolescent Academy soccer players were in a negative energy balance. This may have longer-term implications impacting on the ability to sustain the demands of training and competition as well as maintaining optimal growth and development. In particular, heavy training and match days are of concern, with players not adjusting energy intake to combat the increased energy cost. Findings support previous research from outside of the UK, although demonstrating a lower, yet significant, mean daily energy deficit. Furthermore, pre-match dietary practices are likely sub-optimal, which may present acute implications for soccer match-play. Future investigations in to strategies to reduce energy deficits and fuel soccer-match play are warranted.

## Chapter 5: The effects of an increased calorie breakfast consumed prior to simulated match-play in Academy soccer players

This work is currently under-review in a peer-reviewed journal:

**Briggs, M. A.,** Harper, L. D., McNamee, G., Cockburn, E., Rumbold, P. L. S., Stevenson, E. J., & Russell, M. (2017). The physiological and performance effects of an increased calorie breakfast consumed prior to simulated match-play in Academy soccer players. *European Journal of Sport Science*. In Press.

### Abstract

*Introduction/Purpose:* Dietary analysis of Academy soccer players' highlights that total energy and carbohydrate intakes are less than optimal; especially, on match-days. As UK Academy matches predominantly kick-off at ~11:00 h, breakfast is likely the last pre-exercise meal and thus may provide an intervention opportunity on match-day. Accordingly, the physiological and performance effects of an increased calorie breakfast consumed ~135-min before soccer-specific exercise were investigated. *Methods:* English Premier League Academy soccer players ( $n=7$ ) repeated a 90-min soccer-match-simulation on two occasions after consumption of habitual ( $B_{hab}$ ; ~1100 kJ) or increased ( $B_{inc}$ ; ~2100 kJ) energy breakfasts standardised for macronutrient contributions (~60% carbohydrates, ~15% proteins and ~25% fats). Countermovement jump height, sprint velocities (15-m and 30-m), 30-m repeated sprint maintenance, gut fullness, abdominal discomfort and soccer dribbling performances were measured. Blood samples were taken at rest, pre-exercise, half-time and every 15-min during exercise.

*Results:* Although dribbling precision ( $p = 0.522$ ;  $29.9 \pm 5.5$  cm) and success ( $p = 0.505$ ;  $94 \pm 8\%$ ) were unchanged throughout all time-points, mean dribbling speed was faster ( $4.3 \pm 5.7\%$ ) in  $B_{inc}$  relative to  $B_{hab}$  ( $p = 0.023$ ;  $2.84$  vs  $2.75$  m·s<sup>-1</sup>). Greater feelings of gut fullness ( $67 \pm 17\%$ ,  $p = 0.001$ ) were observed in  $B_{inc}$  without changes in abdominal discomfort ( $p = 0.595$ ). All other physical performance measures and blood lactate and glucose concentrations were comparable between trials (all  $p > 0.05$ ).



*Conclusions:* Findings demonstrate that Academy soccer players were able to increase pre-match energy intake without experiencing abdominal discomfort; thus, likely contributing to the amelioration of energy deficits on match-days. Furthermore, whilst  $B_{inc}$  produced limited benefits to physical performance, increased dribbling speed was identified, which may be of benefit to match-play.

## 5.1 Introduction

The demands of Academy soccer include a requirement to cover distances of ~7-9 km (Goto et al., 2015), perform explosive bouts of skill-based work (Stolen et al., 2005) and run at high intensities for up to  $375 \pm 120$  m per half (Russell et al., 2015). However, given the importance of optimised nutritional intake on the day of competition for team sports players (Williams & Serratos, 2006), it is surprising that the dietary practices of Academy soccer players (specifically higher age Youth Development phase ~U15-U16 and lower age Professional Development phase ~U18) seldom meet recommended values (Russell & Pennock, 2011). With regards to total energy intake, consistent observations highlight less than optimal practices when food is consumed *ad libitum* in free-living conditions (chapter 4; Russell & Pennock, 2011). Notably, energy deficits of  $2.28 \pm 2.31$  MJ·d<sup>-1</sup> have been reported on match days (chapter 4), with a mean habitual breakfast intake of  $1.17 \pm 0.13$  MJ (Chapter 4).

Whilst a periodised approach to nutrition is advised to compensate for multiple matches played within close proximity and fluctuating daily training volumes (Anderson et al. 2016), a pre-exercise meal containing ~1.2-4.7 MJ of primarily carbohydrates (1-4 g·kg<sup>-1</sup>; 70-280 g for a 70 kg athlete) is recommended to be consumed >60 min before activity commences (AND, DC & ACSM, 2016). However, in the case of the UK-based Academy soccer player, competitive matches generally kick-off earlier in the day when compared to their senior counterparts (e.g., 11:00 h vs. 15:00 h). Thus, limited time separates waking and the onset of exercise. Whilst there may be a multitude of reasons to explain the sub-optimal energy intake, the timings associated with Academy match-play may likely explain the failure of this population to adhere to pre-exercise nutritional recommendations. Notably, habitual breakfast intake fails to meet adult pre-

exercise recommendations (i.e.,  $1.17 \pm 0.13$  MJ (chapter 4); 40-65 g of carbohydrate (Naughton et al. 2016).

As liver and muscle glycogen depletion is attributed as one of the main mechanisms of fatigue in soccer (Krustrup et al., 2006), modified breakfast intake may provide an intervention opportunity on match-day. In the context of morning events, a small pre-exercise meal (~1.7-2.1 MJ) primarily consisting of carbohydrate has also been recommended 2-3 h before exercise commences (ACSM, 2015). The rationale for modified breakfast intake is further substantiated by data linking the omission of breakfast to impaired exercise performance thereafter (Clayton, Barutcu, Machin, Stensel & James, 2015) and studies examining the modulation of pre-exercise nutritional status (Anderson et al., 2016) and overnight fasting (Burke, 2007) on endogenous energy storage.

In adult populations, investigations into the effects of a high carbohydrate diet on subsequent soccer performance have been performed. Souglis et al. (2013) observed improved match performance (i.e., total match distances, including increased distance covered in all running intensities performed) when players commenced competition after consuming  $8 \text{ g}\cdot\text{kg}^{-1}$  BM of carbohydrate for the 3.5 days prior to the game. While it is evident that the days preceding competition provide an opportunity to positively impact upon performance, match-day itself also allows practitioners to optimise pre-competition practices (Russell et al., 2015). However, limited data exists investigating strategies to optimise pre-exercise energy intake in adolescent athletes (Phillips et al., 2010; Phillips et al., 2012), with no studies recruiting Academy soccer players.

Considering the observations of sub-optimal nutritional practices in Academy players (chapter 4; Russell & Pennock, 2011), an investigation is therefore warranted to determine the efficacy of increasing habitual energy intake in the form of a breakfast intervention in Academy soccer players. Accordingly, the aim of the study was to examine the effects of a prescribed (recommended meal composition; ACSM, 2015) versus habitual breakfast on physiological responses and soccer performance measures of Academy players during a 90 min soccer match simulation. Furthermore, a sub-aim of the chapter was to assess if players could tolerate the increased pre-match energy intake consumption without experiencing abdominal discomfort. It was hypothesised that the increased calorie breakfast would influence physiological and soccer performance responses, without having a detrimental effect on abdominal discomfort.

## **5.2 Method**

### **5.2.1 Participants**

Seven male soccer players (age:  $16 \pm 0.6$  y; stature:  $1.75 \pm 0.04$  m; BM:  $69.4 \pm 5.2$  kg; BMI:  $22.6 \pm 1.5$  kg·m<sup>-2</sup>; estimated  $\dot{V}O_{2\max}$ :  $56 \pm 3$  ml·kg<sup>-1</sup>·min<sup>-1</sup>) playing for an English Premier League Academy participated in the study. Statistical power was calculated using commercially available software (GPower v3.1, Germany) and a sample size of seven was deemed sufficient for >80% power to detect statistical differences in blood glucose, dribbling precision and gut fullness. The maturity offset was  $3.8 \pm 0.8$  y beyond PHV indicating that all of the participants had reached their predicted PHV (positive maturity offset) and thus were of a similar maturation status (Mirwald et al., 2002). All players were actively engaged in full Academy training and competition for ~20 h per week. The study was approved by the Faculty of Health and Life Sciences Research Ethics Committee at Northumbria University. Information was provided prior to gaining written informed consent from the players and their parents or guardians before commencing data collection (see Appendix B for example of ethics documents).

### **5.2.2 Protocol**

The study used a randomised, counterbalanced and cross over design, to minimise any order effects. All players completed an initial full protocol familiarisation (to further reduce effects of trial order) and estimation of  $\dot{V}O_{2\max}$  (Yo-Yo Intermittent Recovery Test; Bangsbo, Iaia & Krstrup, 2008), to ensure speeds of SMS were relative to aerobic capacity. Familiarisation also included all physical measures such as countermovement jump height (CMJ) and 30 m repeated sprint maintenance (RSM). Players were required to attend two trials. Trials were separated by  $9 \pm 4$  days to ensure trial day was preceded by a training day of comparable intensity. Each trial was

performed within 24 h of a 45 min tactical-specific training session held on the previous day. Players were asked to replicate free-living dietary intake, whilst also refraining from consumption of caffeine and supplementations in the 24 h preceding each trial. Players were required to consume the same energy intake prior to both trials; a statement supported by comparable (all  $p > 0.05$ ) pre-trial energy intakes ( $B_{inc}$   $8.5 \pm 0.7$ ;  $B_{hab}$   $8.9 \pm 0.3$  MJ·d<sup>-1</sup>) and macronutrient contributions (carbohydrates, proteins, fats:  $3.03 \pm 0.14$ ,  $1.83 \pm 0.17$ ,  $1.13 \pm 0.27$  and  $3.53 \pm 0.31$ ,  $1.99 \pm 0.31$ ,  $0.96 \pm 0.34$  g·kg<sup>-1</sup>,  $B_{inc}$  and  $B_{hab}$  respectively) for the 24 h prior to testing. Players were required to attend the training ground at 08:00 h (i.e., ~180 min before commencing exercise) following an overnight fast. Body mass and stature (Seca GmbH & Co., Germany) were then measured prior to a resting fingertip capillary blood sample and mid-flow urine sample being obtained.

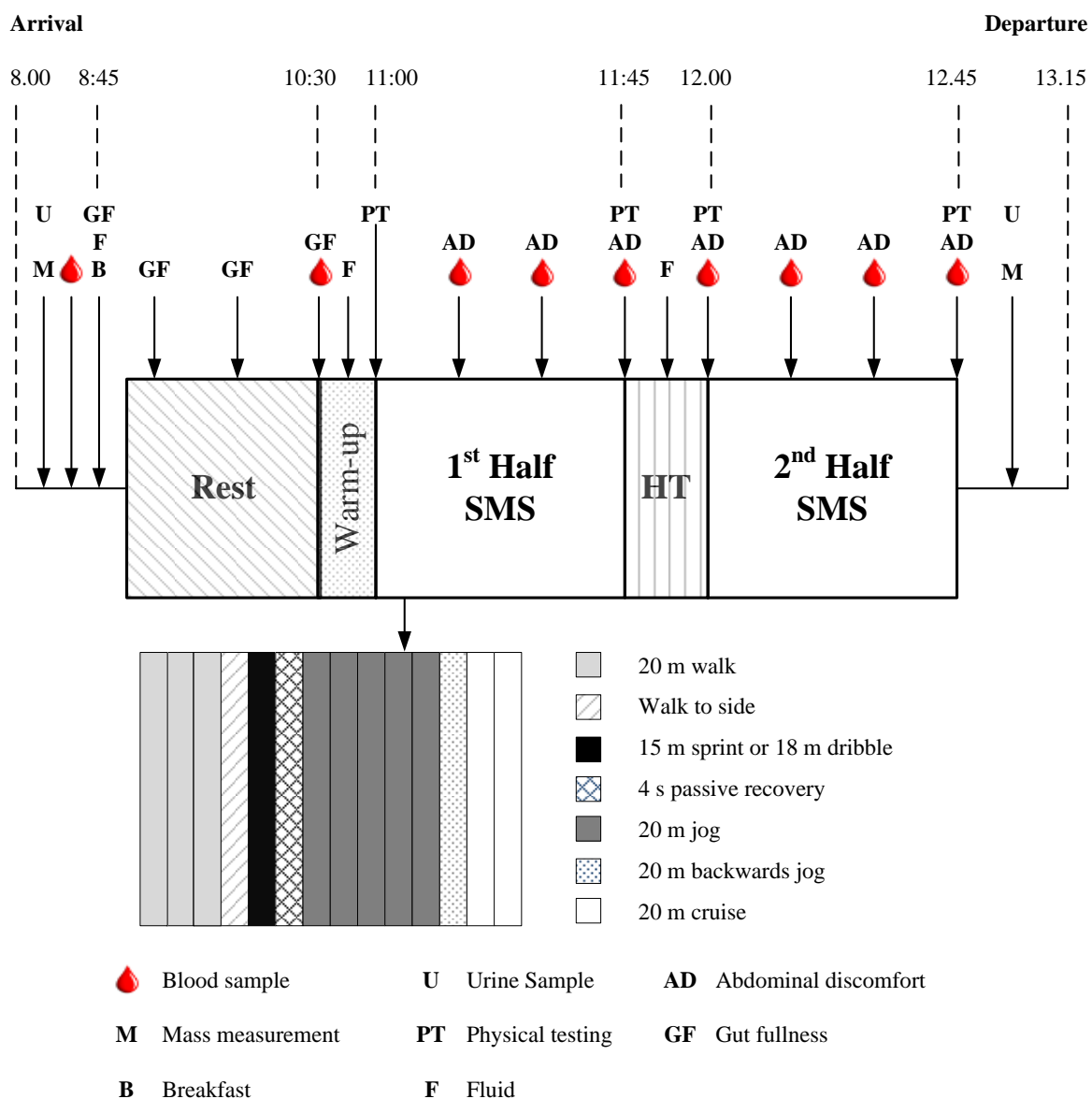
At ~08:45 h, players consumed an increased calorie breakfast ( $B_{inc}$ : 2.08 MJ, 77 g carbohydrate, 14 g protein and 12 g fat) that adhered to recommendations specific to morning exercise (ACSM, 2015), or a habitual breakfast ( $B_{hab}$ : 1.12 MJ, 39 g carbohydrate, 10 g protein and 8 g fat). Findings derived from chapter 4 investigating free-living dietary habits of Academy soccer players supported the habitual pre-exercise energy intakes used in this study ( $B_{hab}$ ) and replicated previously published data with respect to pre-exercise carbohydrate intake (Naughton et al., 2016). Furthermore, all trial day timings with regards to arrival at Academy, breakfast consumption, warm-up, in addition to type and timing of all fluid intake were all aligned with habitual practices of match-day procedures in order to increase the ecological validity of the design. Whilst the total energy intake increased approximately two-fold between trials, this was primarily achieved via manipulation of absolute carbohydrate content as relative

macronutrient contributions to the total energy yield remained similar for carbohydrates (i.e., 61% vs. 59%), proteins (14% vs. 15%), and fats (25% vs. 26%) for  $B_{inc}$  and  $B_{hab}$  respectively. Furthermore, the macronutrient composition for habitual breakfast intake was reflective of that observed during a free-living environment in chapter 4. After having been pre-weighed by the research team, breakfasts consisted of cereal (Kellogg's Rice Krispies and semi-skimmed milk) and/or buttered toast (Asda, medium sliced white bread and Flora Pro-Active butter) and were provided with 500 mL of a fluid-electrolyte beverage (Mineral Water, Highland Spring, UK). In terms of exact breakfast intake, these were either 2 x toast and butter ( $B_{hab}$ ) or 3 x toast and butter plus cereal and milk ( $B_{inc}$ ). In order to meet the  $B_{inc}$  recommended intake with just toast would have required 5 x toast which was deemed to be not appropriate. However, both food types were aligned with habitual pre-match energy intake derived from analysis of food diaries in chapter 4. After consuming the entire amount of food, players remained in a rested state for ~90 min; upon which a pre-exercise blood sample was taken. A standardised warm-up (consisting of soccer-specific dynamic movements, stretches and skills; ~10 min) was performed, during which players were required to consume an additional 200 ml of fluid-electrolytes. Measures of physical performance including CMJ and 30 m RSM were tested prior to a modified version of the Soccer Match Simulation (SMS) commencing (Russell, Rees, Benton & Kingsley, 2011a).

The SMS is comprised of two 45 min bouts of soccer-specific exercise, with 15 min of passive recovery replicating half-time (HT). During HT players consumed 500 mL of fluid-electrolytes. Assessments of soccer dribbling (Russell, Benton & Kingsley, 2010) and 15 m sprinting were performed alternatively during each cycle of the protocol. The SMS protocol designed by Russell et al. (2011a) is similar to the protocol devised by

Nicholas, Nuttall and Williams (2000), but has been subsequently adapted to include additional components that further replicate the demands of soccer match-play, such as dribbling. Movements were dictated by audio signals from CDs that specifically relate to all participants. More specifically, exercise was made up of 4.5 min blocks that consist of three repeated cycles of three 20 m walks, one walk to the side (~1 m), an alternating 15 m sprint or an 18 m dribble test, a 4 s passive recovery period, five 20 m jogs at a speed corresponding to 40%  $\dot{V}O_{2\max}$ , one 20 m backwards jog at 40%  $\dot{V}O_{2\max}$  and two 20 m strides at 85%  $\dot{V}O_{2\max}$ . A 2 min recovery period followed all blocks of exercise. Fourteen blocks of intermittent exercise (consisting of 2 halves of 7 blocks) and skill testing were completed during each main trial and participants covered a total distance of approximately 10.1 km while performing ~33 maximal sprints and ~21 dribbles during the protocol. The repeatability of the SMS, and responses to this exercise protocol for all components of the SMS have been previously been determined, including physiological (CV: 2.6%), metabolic (CV: 16.1%) and performance responses (CV: 2.1%) (Harper et al., 2016; Russell et al., 2011b). A timeline schematic of trial day procedures is outlined in Figure 5.1.

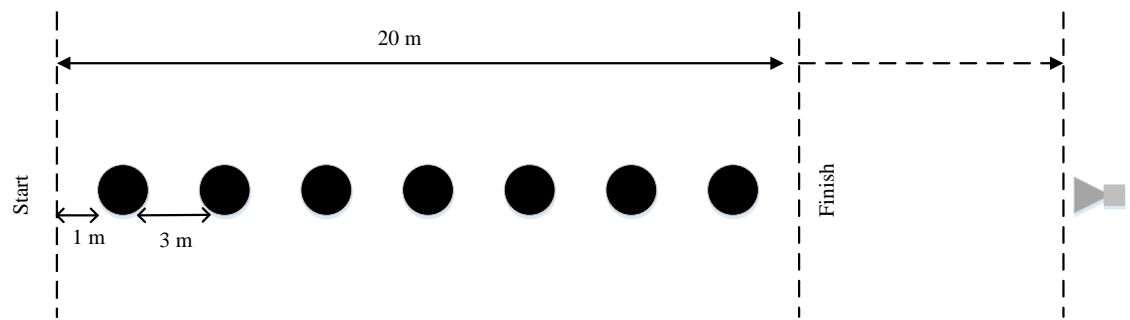




**Figure 5.1** Schematic of trial day procedures.

Participant CMJ height and 30 m RSM were tested at four time points (pre-exercise; post-first half; pre-second half; post-second half), each requiring three CMJ's separated with 10 s of passive recovery and three 30 m sprints with 25 s of active recovery (light jogging). In both performance tests the mean value of the three attempts was used for analysis. CMJ height was determined using an optical measuring system (OptoJump Next, Microgate Corp, Italy). Players began each repetition from a standing position and performed a preparatory crouching action (at a consistent, self-determined level) before explosively jumping out of the dip for maximal height. Hands were isolated at the hips for the entire movement to eliminate any influence of arm swing. For RSM testing, players commenced each repetition from a standing start at a distance of 0.3 m behind the first timing gate (Brower Timing, Utah) and verbal encouragement was provided throughout each attempt.

Integrated 15 m sprints and 18 m dribbles (assessed for precision, percentage success and average speed) were recorded throughout the SMS. Players were required to dribble the ball as fast and as accurately as possible between cones spaced every 3 m as per Russell et al. (2011a). The layout of the 18 m dribbling test included in the intermittent exercise blocks of the SMS is similar to that employed by McGregor et al. (1999) with start and finish lines placed 20 m apart (Figure 5.2). Cones 2 through 7 were placed 3 m away from the preceding cone, and cones 1 and 7 are 1 m away from each end of the course. All dribbles were video recorded (50 Hz; 103 DCR-HC96E; Sony Ltd, UK) and digitization processes (Kinovea version 0.8.15; Kinovea Org., France) derived speed (time taken to successfully complete the distance) and precision (distance of the ball from each cone) data.



**Figure 5.2** Layout of the dribbling test

Fingertip capillary blood samples (170  $\mu$ l) were taken at rest, pre-exercise, HT and at the end of each 15 min period of the protocol. Blood samples were analysed for variables associated with exercise intensity and fatigue (i.e., blood glucose and lactate concentrations via GEM Premier 3000; Instrumentation Laboratory, UK; CV's: 0.6-2.2%) (Beneteau-Burnat, Bocque, Lorin, Martin, & Vaubourdolle, 2004). Urine and plasma osmolality (Advanced Model 121 3300 Micro-Osmometer; Advanced Instruments Inc., USA; CV: 1.5%) and urine corrected mass changes were determined and the rating of perceived exertion (RPE; Borg, 1973) (Appendix E) was recorded every 15 min. Environmental conditions were measured during exercise (Technoline WS-9032; Technotrade GmbH, Germany). Heart rate was continuously recorded (Polar S610; Polar, Finland), with gut fullness (paper-based 100mm Visual Analogue Scale (VAS) (Appendix F), ranging from 'not full at all' to 'very full') recorded immediately after breakfast, 30 min post, 60 min post and 90 min post/immediately prior to exercise. Abdominal discomfort (based on a self-perceived subjective rating 0-10; 'no discomfort' to 'worst possible discomfort') (Appendix G) was determined at the end of each 15 min block of the protocol. Post exercise body mass was also recorded in addition to a mid-flow urine sample.

### **5.2.3 Statistical Analysis**

For parametric data expressed over multiple time-points, two-way repeated measures analysis of variance (within-participant factors: treatment x time) were performed (once confirmed by normality and variance assessments), which included dribbling (precision, speed and success), sprint velocities (15 and 30 m), CMJ height, 30 m RSM, RPE, heart rate (HR), gut fullness, abdominal discomfort and blood glucose and lactate concentrations. Mauchly's test was consulted and Greenhouse-Geisser correction was

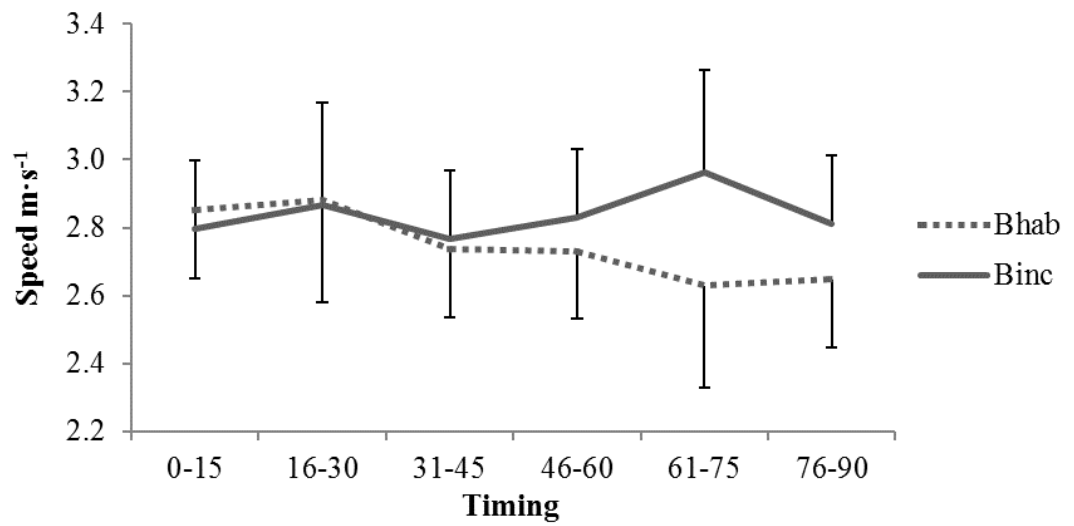
applied if the assumption of sphericity was violated. Significant main effects were further investigated using multiple pairwise comparisons with LSD confidence interval adjustment (95% Confidence Intervals; CI). Partial eta-squared ( $\eta^2$ ) values were calculated and Cohen's  $d$  effect size examined between-trial differences. A paired samples  $t$ -test was used to analyse differences in mean body mass pre and post-exercise. For  $\eta^2$  and effect size data, thresholds of 0.2, 0.5, and 0.8 were considered small, medium and large, respectively (Fritz, Morris & Richler, 2012). All data are presented as mean  $\pm$  SD, with level of significance set at  $p \leq 0.05$  using SPSS (Version 22; SPSS Inc., USA) for all analyses.

### 5.3 Results

Pre-exercise hydration was similar amongst players between each trial ( $B_{hab}$   $310 \pm 5$ ;  $B_{inc}$   $315 \pm 6$  mOsmol $\cdot$ kg $^{-1}$ ,  $p = 0.936$ ). Ambient temperature ( $18.5 \pm 1.5^{\circ}\text{C}$ ), humidity ( $74 \pm 7\%$ ) and barometric pressure ( $1017 \pm 3$  mmHg) were also consistent between trials ( $p > 0.05$ ).

Compared to  $B_{hab}$ , gut fullness was greater ( $F_{(1,7)} = 7.262$ ,  $p = 0.027$ ,  $\eta^2 = 0.548$ ) immediately ( $60 \pm 15$  vs.  $19 \pm 15$ ,  $p = 0.002$ ,  $d = 2.8$ , CI: 22-60), 30 min ( $58 \pm 13$  vs.  $18 \pm 13$ ,  $p = 0.001$ ,  $d = 3$ , CI: 23-58), 60 min ( $46 \pm 11$  vs.  $15 \pm 13$ ,  $p = 0.003$ ,  $d = 2.5$ , CI: 15-47) and 90 min after ingestion and immediately pre-exercise ( $40 \pm 11$  vs.  $13 \pm 10$ ,  $p = 0.001$ ,  $d = 2.6$ , CI: 15-38) during  $B_{inc}$ . Abdominal discomfort was similar between trials ( $F_{(5,30)} = 0.746$ ,  $p = 0.595$ ,  $\eta^2 = 0.111$ ).

Mean dribbling precision ( $F_{(2,10)} = 0.856$ ,  $p = 0.433$ ,  $\eta^2 = 0.125$ ) and success ( $F_{(2,10)} = 0.666$ ,  $p = 0.505$ ,  $\eta^2 = 0.100$ ) was comparable between trials whereas mean dribbling speed was faster ( $-4.3 \pm 5.7\%$ ) in  $B_{inc}$  ( $F_{(5,30)} = 3.072$ ,  $p = 0.023$ ,  $\eta^2 = 0.339$ ) (Figure 5.3). Post hoc comparisons were unable to isolate these specific differences but dribbling speed was  $13.3 \pm 10.1\%$  and  $7.1 \pm 10.2\%$  greater at 61-75 min and 76-90 min respectively during  $B_{inc}$ .



**Figure 5.3** Dribbling speed throughout each trial (mean  $\pm$  SD).

Breakfast did not influence 15-m ( $F_{(2,12)} = 0.668$ ,  $p = 0.534$ ,  $\eta^2 = 0.100$ ) or 30 m sprint velocities ( $F_{(3,18)} = 0.136$ ,  $p = 0.938$ ,  $\eta^2 = 0.022$ ). Similarly, 30 m RSM ( $F_{(3,18)} = 0.072$ ,  $p = 0.974$ ,  $\eta^2 = 0.012$ ) and CMJ ( $F_{(3,18)} = 0.946$ ,  $p = 0.439$ ,  $\eta^2 = 0.136$ ) performance was similar between trials. However, an exercise effect was observed in all these variables (all  $p < 0.05$ ; medium effect size). Sprint velocities over 15 m were significantly reduced in the periods 31-45 min ( $5.72 \pm 0.43 \text{ m}\cdot\text{s}^{-1}$ ), 46-60 ( $5.64 \pm 0.47 \text{ m}\cdot\text{s}^{-1}$ ) and 76-90 min ( $5.59 \pm 0.63 \text{ m}\cdot\text{s}^{-1}$ ) (all  $p < 0.05$ ), when compared to 0-15 min ( $5.94 \pm 0.53 \text{ m}\cdot\text{s}^{-1}$ ). Sprint velocity over 30 m and 30 m RSM both demonstrated decrements in performance at post 1<sup>st</sup> half, pre 2<sup>nd</sup> half and post 2<sup>nd</sup> half when compared to pre-exercise (all  $p < 0.01$ ; see Table 5.1). Likewise, CMJ height was reduced ( $p < 0.05$ ) pre 2<sup>nd</sup> half ( $32.5 \pm 3.5 \text{ cm}$ ) when compared to pre-exercise ( $35.3 \pm 2.9 \text{ cm}$ ; Table 5.1).



**Table 5.1** Performance variables as a function of timing and trial

Variable	Trial	Pre-exercise	Post-exercise	Timing	
				Pre-2 <sup>nd</sup> Half	Post-2 <sup>nd</sup> Half
<b>30 m Sprint Velocities (m·s<sup>-1</sup>)</b>	<i>B<sub>inc</sub></i>	6.95 ± 0.25	6.80 ± 0.23	6.61 ± 0.33	6.70 ± 0.31
	<i>B<sub>hab</sub></i>	7.09 ± 0.16	6.88 ± 0.20	6.61 ± 0.23	6.76 ± 0.30
<b>30 m RSM (%)</b>	<i>B<sub>inc</sub></i>	99 ± 1	96 ± 4	93 ± 7	94 ± 4
	<i>B<sub>hab</sub></i>	98 ± 2	97 ± 3	94 ± 7	95 ± 3
<b>CMJ Height (cm)</b>	<i>B<sub>inc</sub></i>	35.0 ± 2.9	34.3 ± 2.7	32.8 ± 3.1	33.7 ± 2.7
	<i>B<sub>hab</sub></i>	35.7 ± 2.8	34.5 ± 5.2	32.0 ± 4.1	34.7 ± 4.3

RSM = Repeated Sprint Maintenance, CMJ = Countermovement Jump, *B<sub>inc</sub>* = Intervention Trial, *B<sub>hab</sub>* = Habitual intake trial. Data presented as mean ± SD.

Heart rate was similar between trials ( $F_{(5,30)} = 2.353$ ,  $p = 0.065$ ,  $\eta^2 = 0.282$ ), with no trial effect identified ( $F_{(1,9)} = 1.294$ ,  $p = 0.307$ ,  $\eta^2 = 0.177$ ). Likewise, RPE was not influenced by trial ( $F_{(5,30)} = 0.691$ ,  $p = 0.634$ ,  $\eta^2 = 0.103$ ), despite increases at 46-60 min ( $13 \pm 3$ ), 61-75 min ( $14 \pm 3$ ) and 76-90 min ( $15 \pm 3$ ), when compared to 0-15 min ( $11 \pm 3$ ) values (all  $p < 0.01$ ). Mean differences in body mass pre and post-exercise were not influenced by trial ( $t_{(6)} = -0.337$ ,  $p = 0.747$ ). Mean body mass changes (pre: 69.6 kg, post: 68.9 kg) equated to a mean difference of 0.75 kg in  $B_{hab}$ , similar to  $B_{inc}$  (pre: 70.5 kg, post: 69.8 kg, mean difference: 0.70 kg).

Blood lactate ( $F_{(2,11)} = 0.728$ ,  $P=0.495$ ,  $\eta^2 = 0.108$ ) and blood glucose ( $F_{(3,19)} = 2.983$ ,  $P=0.055$ ,  $\eta^2 = 0.332$ ) concentrations were not statistically different between trials. Exercise effects were observed in both of these variables ( $F_{(2,10)} = 9.618$ ,  $p = 0.007$ ,  $\eta^2 = 0.616$ ;  $F_{(3,19)} = 10.563$ ,  $p = 0.0001$ ,  $\eta^2 = 0.638$ , respectively). Blood lactate was significantly higher during 0-15 min ( $p = 0.009$ ), 31-45 min ( $p = 0.006$ ), HT ( $p = 0.0001$ ), 46-60 min ( $p = 0.018$ ), 61-75 min ( $p = 0.008$ ), 76-90 min ( $p = 0.045$ ) in comparison to pre-exercise concentrations (Table 5.2). Blood glucose was significantly reduced (all  $p < 0.05$ ) at 45 min ( $-6.9 \pm 7.3\%$ ), HT ( $-10.9 \pm 6.4\%$ ), 60 min ( $-11.6 \pm 7.9\%$ ), 75 min ( $-12.6 \pm 7.5\%$ ), and 90 min ( $-11.2 \pm 9.6\%$ ) in comparison to 15 min (Table 5.2).

**Table 5.2** Blood metabolite data as a function of timing and trial

Variable	Trial	Timing (min unless stated)								
		Rest	Pre-exercise	15	30	45	HT	60	75	90
<b>Lactate</b> (mmol·l <sup>-1</sup> )	<i>B<sub>inc</sub></i>	0.7 ± 0.1	1.4 ± 0.5	5.1 ± 3.4	3.7 ± 3.8	4.9 ± 3.6	3.1 ± 1.1	3.9 ± 3.6	4.1 ± 2.9	3.4 ± 2.9
	<i>B<sub>hab</sub></i>	0.9 ± 0.3	1.2 ± 0.4	3.4 ± 1.1	2.8 ± 0.7	3.3 ± 0.5	2.6 ± 0.6	3.3 ± 1.2	2.9 ± 0.5	2.2 ± 0.3
<b>Glucose</b> (mmol·l <sup>-1</sup> )	<i>B<sub>inc</sub></i>	5.0 ± 0.7	5.7 ± 0.7	5.1 ± 0.5	4.7 ± 0.6	4.8 ± 0.5	4.5 ± 0.6	4.3 ± 0.4	4.2 ± 0.2	4.5 ± 0.5
	<i>B<sub>hab</sub></i>	4.9 ± 0.3	5.0 ± 0.5	5.1 ± 0.3	4.8 ± 0.3	4.7 ± 0.2	4.6 ± 0.3	4.7 ± 0.3	4.7 ± 0.7	4.5 ± 0.6

*B<sub>inc</sub>* = Intervention Trial, *B<sub>hab</sub>* = Habitual intake trial. HT = Half-Time. Data presented as mean ± SD.

## 5.4 Discussion

The primary aim of the study was to examine the effects of increasing pre-exercise energy intake (via manipulation of absolute carbohydrate content) on physiological responses and soccer performance measures of Academy players during a 90 min soccer match simulation. Furthermore, a sub-aim of the chapter was to assess if players could tolerate the increased pre-match energy intake consumption without experiencing abdominal discomfort to aid in the reduction in the previously identified energy deficit. Although dribbling precision and success were unchanged, dribbling speed was improved in  $B_{inc}$  relative to  $B_{hab}$  in line with the hypothesis. Unsurprisingly, greater feelings of gut fullness were observed in  $B_{inc}$  but not at the expense of changes in abdominal discomfort.  $B_{inc}$  provided an additional  $\sim 1$  MJ compared to  $B_{hab}$ , which equated to  $\sim 50\%$  of the match day energy deficit (chapter 4). Although limited physical benefits and no physiological benefits were observed, modified breakfast intake may offer an intervention opportunity on match day that likely contributes to attenuating the daily energy deficits previously identified in this population (Chapter 4).

When compared to  $B_{hab}$ , mean dribbling speed was  $4.3 \pm 5.7\%$  faster than  $B_{inc}$ . Although post hoc comparisons were unable to detect differences between particular time-points, dribbling speeds were  $13.3 \pm 10\%$  and  $7.1 \pm 10\%$  greater at 61-75 min and 76-90 min respectively during  $B_{inc}$ . Interestingly, more successful Academy players are associated with conducting movement patterns at higher speeds (Harley et al., 2010; Goto et al., 2015), therefore an increased dribbling speed may have positive implications for match-play, especially during phases of the game related to higher fatigue (Krustrup et al., 2006; Mohr et al., 2003a). Match-day carbohydrate ingestion has previously been demonstrated to improve soccer-skills in adolescents (Russell et al.,

2012), albeit not isolated to breakfast intake. Russell et al. (2012) demonstrated that carbohydrate provision attenuated declining shooting performance and shot speed, however no influence was identified in dribbling precision, success or speed. The current study's findings are in agreement with the intervention having no influence on mean dribbling precision or mean dribbling success.

Enhancing carbohydrate availability has been demonstrated to improve central nervous system function and attenuate the loss of motor skill performance, as Bandelow et al. (2011) reported that higher blood glucose concentrations were associated with faster visual discrimination, faster fine-motor speed and faster psycho-motor speed after soccer match-play. However, the influence of carbohydrate on soccer skill performance during simulated or actual match-play has produced equivocal findings, as Zeederberg et al. (1996) reported no measurable benefits on motor skill performance during soccer match-play after ingesting a 6.9% glucose-polymer beverage. Whilst limited studies have investigated whole food breakfast interventions on soccer-specific performance, it is plausible that increasing exogenous carbohydrate, pre-exercise, might enhance skill performance by preserving central nervous system integrity (Ross & Leveritt, 2001), considering glucose is the principle energy source for cerebral metabolism, with the brain being dependent upon a continuous supply of blood glucose (Duelli, et al., 2001). However, it is important to note that there were no significant differences in blood glucose concentration between trials. Furthermore, blood glucose concentration did not fall below  $3.5 \text{ mmol}\cdot\text{L}^{-1}$ , during match-play, which has been used as a threshold to define hypoglycaemia (DeMarco, et al. 1999). Thus, may not fully explain the increased dribbling speed during  $B_{inc}$ .

The  $B_{inc}$  breakfast (2.08 MJ, 77 g carbohydrate, 14 g protein and 12 g fat) contained a carbohydrate intake equivalent to  $1.11 \text{ g}\cdot\text{kg}^{-1} \text{ BM}$  which is higher than prescribed in studies with similar populations ( $0.78 \text{ g}\cdot\text{kg}^{-1} \text{ BM}$ ) (Phillips et al., 2010; Phillips et al., 2012). Despite methodological variation regarding the timing of pre-match energy intake, current findings support the notion of limited effects of pre-exercise carbohydrate consumption on maximal sprint performance (Phillips et al., 2010; Phillips et al., 2012). The SMS required ~33 maximal sprints interspersed with both high and low-intensity running to mimic movement patterns associated with soccer match-play. However, whilst sprint performance appears maintained when multiple 15-m sprints are separated by 30 s passive recovery (Balsom, Seger, Sjodin, & Ekblom, 1992), such activity patterns are not congruent with the SMS protocol and indeed match-play itself.

The lack of improvement in CMJ height during  $B_{inc}$  is not uncommon as previous research involving adolescent athletes has highlighted a reduction in peak power output when participants do not engage in passive recovery between multiple bouts (Thevenet Tardieu-Berger, Berthoin, & Prioux, 2007). Despite the higher calorie intake and increased carbohydrate content during  $B_{inc}$ , blood glucose concentrations were not significantly enhanced ( $p = 0.055$ ); although a trend towards significance and a small effect ( $\eta^2 = 0.332$ ) was found (Table 5.2). In addition, blood lactate concentrations, heart rate and RPE were also similar between trials (all  $p > 0.05$ ) (Table 5.2). Therefore, the standardisation of the physiological demands between trials and the limited influence of  $B_{inc}$  to raise blood glucose concentrations, regardless of the increased carbohydrate content compared with  $B_{hab}$ , may explain similar between-trial findings for specific physical variables.

Academy soccer players have been found to display poor nutritional practices with reports of mean daily energy deficits of  $1.3 \pm 1.66 \text{ MJ}\cdot\text{d}^{-1}$  (chapter 4) and  $3.3 \pm 0.33 \text{ MJ}\cdot\text{d}^{-1}$  (Russell & Pennock, 2011). Furthermore, match day energy balance within this population is less than optimal; demonstrating mean deficits of  $2.28 \pm 2.31 \text{ MJ}\cdot\text{d}^{-1}$  (chapter 4). Despite limited evidence of performance benefits with increased energy intake during  $B_{inc}$ , the additional calorie content may be worthwhile to simultaneously reduce the energy deficits observed on match-day. Additionally, the increased calorie intake apparent in  $B_{inc}$  did not induce any abdominal discomfort versus  $B_{hab}$  ( $p = 0.595$ ). Conversely, feelings of gut fullness were increased immediately after consumption until the onset of exercise (all  $p < 0.01$ ). Whilst heightened feelings of gut fullness may induce gastrointestinal discomfort and have subsequent implications for performance (de Oliveira, Burini & Jeukendrup, 2014), abdominal discomfort was not adversely effected in this study. Enhanced gut fullness may therefore have provided an additional subjective preparatory benefit.

## 5.5 Conclusion

The study findings demonstrate that Academy soccer players were able to increase pre-match energy intake without experiencing detrimental effects of abdominal discomfort, addressing the previously identified concern of significant energy deficit on such days. This finding may be of interest to applied practitioners working with Academy soccer players who typically demonstrate less than optimal pre-match nutritional habits. Furthermore, whilst  $B_{inc}$  produced limited benefits to physical performance, increased dribbling speed was identified compared to  $B_{hab}$ , a finding which may be of benefit to match-play.



## **Chapter 6: General Discussion**

### **6.1 Thesis Aims**

The aims of the thesis were threefold: (1) identify an accurate method of energy intake assessment which quantified any self-reporting bias bespoke to Academy soccer players, (2) provide a quantification of energy intake and energy expenditure of Academy soccer players over a 'typical' training week, specifically highlighting any fluctuations in energy balance, whilst also examining pre-match nutritional practices (3) investigate strategies to optimise dietary practices of Academy soccer players, specifically examining the impact on soccer performance variables, whilst assessing if players can tolerate the increased pre-match energy intake.

Chapter 3 explored the accuracy of the combined method of energy intake assessment. Findings demonstrated the variability compared to observed methods was low and although a statistically significant under-reporting was identified, the magnitude of this bias was small. Consequently, with an appropriate adjustment for under-reporting, the combined method could be used as an alternative method to quantify energy intake in free-living Academy soccer players.

Chapter 4 assessed energy balance in male Academy soccer players. Mean daily energy intake was significantly lower than mean daily energy expenditure, highlighting sub-optimal dietary practices. Additionally, type of training had a direct impact on the degree of energy deficit. Furthermore, pre-match dietary practices are likely sub-optimal, which may present acute implications for soccer match-play.

Chapter 5 examined the effects of increasing pre-exercise energy intake (via manipulation of absolute carbohydrate content) on subsequent physiological responses and soccer performance measures of Academy players during a 90 min soccer match simulation. Furthermore, a sub-aim of the chapter was to assess if players could tolerate the increased pre-match energy intake. Findings demonstrated that Academy soccer players are able to increase pre-match energy intake without experiencing abdominal discomfort, helping reduce the previously identified concern of significant energy deficit on such days. Furthermore, whilst  $B_{inc}$  produced limited benefits to physical performance, increased dribbling speed was identified compared to  $B_{hab}$ , a finding that may be of benefit to match-play.

The present chapter will collectively discuss and appraise the findings of the experimental research in relation to the thesis aims. Reflections on key findings will also be discussed, in addition to providing insights into the practical application of such findings and subsequent direction for future research within Academy soccer.

## **6.2 Reflections on main findings**

### **6.2.1 Accuracy of energy intake assessment**

Chapter 2.2.2.3 highlighted the issues of assessing dietary habits in adolescent populations, suggesting the quantification of energy intake utilising self-reported methods presents challenges, such as under-reporting and a lack of detailed information (Hill & Davies, 2001). Currently, limited data exists examining energy intake methods in highly active male adolescents such as Academy soccer players. Although investigations of normal weight, male adolescent populations have been conducted, (Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al.,

1992); highlighting significant under-reporting (-18-22%), these do not represent the daily routines of Academy soccer players. Therefore, such information provides limited insight in to Academy soccer players due to distinct differences in training and competition schedules and subsequent eating patterns. Therefore, to ensure accurate dietary information was collected from Academy soccer players, it was important to quantify any self-reporting bias in this population.

Subsequently, chapter 3 aimed to explore the agreement between researcher observed energy intake and self-reported energy intake using the combined method as it has been found to increase the accuracy of self-reported energy intake measurements in adolescent populations (Livingstone & Robson, 2000; Rumbold et al., 2011a). However, previous research has not examined the combined approached in Academy soccer populations, who experience increased training demands influencing energy intake requirements. The findings of chapter 3 demonstrated a small ( $-0.37 \text{ MJ} \cdot \text{day}^{-1}$ ) and consistent (95% CI for bias =  $-0.61$  to  $-0.12 \text{ MJ} \cdot \text{day}^{-1}$ ) under-reporting bias. Evidence of significant under-reporting is in agreement with earlier studies (Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992) using moderately active male adolescents, suggesting similar trends common to other self-report methods. However, the considerably lower ( $-3\%$ ) error highlights a substantial improvement when the combined method is adopted. Thus providing a more accurate alternative for practitioners and field-based researchers.

An important consideration when assessing energy intake is the nature and frequency of Academy soccer players' energy consumption. Analysis of the under-reporting error revealed that rather than inaccuracy of the weighing technique itself, missed items were

the main cause of under-reporting. Snacking equated to 90% of under-reporting error, suggesting complex eating patterns may explain the small bias evident within this population. This is a particular consideration for researchers and applied practitioners to be aware of when conducting the associated 24 h recall for future research design. Specific focus may be needed when prompting for snack items or possibly an introduction of a policy whereby wrappers/containers of all consumed snack items are to be kept and subsequently supplied with the food diaries.

One of the reasons purported for the significantly smaller bias in comparison to previous studies (Bandini et al., 1990; Bandini et al., 1999; Bratteby et al., 1998; Livingstone et al., 1992), was the interaction and rapport built with the players. Whilst previous studies using self-report methods of energy intake do allude to a workshop of some form prior to data collection, more emphasise should be placed on this aspect of preparation to initiate the relationship with the players. Players seemed to respond well to the workshops designed to educate them about the dietary data collection technique. Furthermore, by contextualising the requirement for accurate data to help inform nutritional practices ensured a strong relationship, whilst allowing players to develop a sense of interest and ownership in the research. Equally, the support of the Academy coaches helped cement the relationship with players and provide merit to the importance of such investigations, subsequently impacting on motivation and compliance levels.

An appropriate adjustment equation was devised;  $y = 1.0397x - 0.1064$  where  $y$  = researcher observed energy intake and  $x$  = players self-report to address the slight under-reporting error. However, from a practical standpoint the mean under-reporting error identified ( $-0.37 \text{ MJ}\cdot\text{d}^{-1}$ ) is not clinically meaningful in a weight loss context

(Wang et al., 2006), suggesting the under-reporting would not likely impact on energy balance over the long-term. Thus, whether researchers or practitioners opted to use the correction equation or not, the combined method could be implemented as an alternative to the researcher observed method when quantifying energy intake in male Academy soccer players.

### **6.2.2 Energy Balance**

Thus far a relatively limited amount of studies have investigated the nutritional intake of Academy soccer players (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Ruiz et al., 2005; Russell & Pennock, 2011), with most displaying limitations in the accuracy of methods employed. Despite a lack of acknowledgement for under-reporting bias, the majority typically reported sub-optimal energy intake relative to estimates of energy expenditure (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Russell & Pennock, 2011). However, estimates of energy expenditure were often based on subjective accounts of activity, raising questions over the reliability of such methods as discussed in chapter 2.2.1.1 and subsequently limiting the accuracy of reports relating to energy balance.

At the time of conducting the research, no study to date had incorporated a design using the combined method of energy intake assessment alongside objective measurements of energy expenditure. Whilst it is acknowledged that there are possibly more accurate methods of energy expenditure assessment (outlined in chapter 2.2.1.2), these lack practical application to free-living environments, impacting on habitual behaviour and/or not differentiating between activities, thus limiting the ecological validity.

Furthermore, the use of accelerometry enabled a collection period representative of both Academy training and match-play demands as well as habitual daily tasks including school and extra-curricular activities, providing a more holistic account of energy expenditure. Such information is lacking in the literature with previous studies failing to account for additional energy expenditure outside of training and match-play, resulting in misleading assumptions regarding how to optimise dietary practices in this population.

The findings of chapter 4 demonstrated that over a 7-day period players were in a negative energy balance, with energy intake being insufficient to meet the demands of training and competition. More importantly perhaps, type of training had a direct impact on the degree of energy deficit, suggesting players may not be periodising their nutritional intake effectively. Specifically, mean daily deficits of  $-1.3 \pm 1.66$  MJ were identified, however heavy training days ( $-2.11 \pm 2.26$  MJ) and match day ( $-2.28 \pm 2.31$  MJ) provided the greatest energy deficits. This is an important finding not only for the impact on soccer performance but also for adolescents whereby a slight positive energy balance is required for optimal growth and maturation (Meyer et al., 2007; Petrie et al., 2004; Thompson, 1998). Such information may be useful for coaches when periodising training structure to accommodate for potential decreases in energy following a heavy training session when players are not adequately refuelling.

Whilst previous studies have demonstrated sub-optimal energy intake, these fail to identify where the greatest deficits occur, or whether some days players may experience positive energy balance depending on the training load/intensity. Chapter 4 highlighted that energy intake was relatively stable across the week, independent of whether players

were involved in a heavy, moderate or light training session or if they were recovering from match-play. These findings provide support for educating players about the necessity to periodise nutritional practices and offer evidence for practitioners to advocate nutritional advice accordingly. For example, analysis of diet composition demonstrated that carbohydrate contribution to total daily energy intake was likely to be sub-optimal, especially during heavy training sessions and match days. Furthermore, analysis of pre-match dietary practices in chapter 4 identified inadequate energy intake. Results demonstrated mean habitual pre-match intakes of  $1.16 \pm 0.13$  MJ consisting of 41 g carbohydrates, 10 g proteins and 8 g fats. Therefore, based on the current recommendations (ACSM, 2015), pre-match energy intake is likely sub-optimal.

The results from chapter 4 are the first in the UK to provide insight in to energy balance in Academy soccer players, differentiating between type of activity. Thus providing key information for practitioners working with this population when planning or recommending nutritional practices. Furthermore, the collection period encompasses a holistic approach including commitments outside of Academy training which also subsequently increases daily energy expenditure, consequently impacting on nutritional requirements.

### **6.2.3 Strategies to optimise nutritional practices**

Based on the findings from chapter 4, a strategy to reduce energy deficits and fuel soccer-match play were examined in chapter 5. Results demonstrated that Academy soccer players are able to increase pre-match energy intake without experiencing abdominal discomfort, helping to reduce the previously identified concern of significant energy deficit on such days.  $B_{inc}$  provided an additional  $\sim 1$  MJ compared to  $B_{hab}$ , which

equated to ~50% of the match day energy deficit (chapter 4). However, pre-match energy intake (~2.1 MJ; 77 g carbohydrates, 14 g proteins and 12 g fats) produced limited benefits to physical performance, although, increased dribbling speed ( $-4.3 \pm 5.7\%$ ) was identified compared to habitual intake, a finding which may be of benefit to match-play. Whilst it is accepted that performance effects were limited, strategies of increasing energy intake in this population are warranted to prevent chronic negative energy balance occurring. The findings from chapter 5 provide a foundation for future research to develop pre-match strategies in this population to further reduce the energy deficit whilst also demonstrating greater benefits to match-play variables.

The design of chapter 5 was created specifically to mimic the timing and habits associated with pre-match routine with regards time players arrive at the Academy; time of breakfast consumption; habitual foods associated with Academy players' breakfast; time lapse between breakfast consumption and onset of exercise. The pre-match routine outlined in chapter 5 may provide information for researchers when planning study designs, especially to address the concern of conducting intervention studies in the fasted state, with limited application to the 'real world'. Furthermore, the protocol used has been validated to represent physiological responses to actual soccer match-play (Russell et al., 2011b). Therefore, increasing the ecological validity of the design to provide findings related to the context of habitual match-day practices. The habitual context against which the intervention in chapter 5 was made is likely of interest to applied practitioners and researchers considering criticisms of studies that have demonstrated performance improvements of interventions in fasted participants that are likely to be used in the fed state. As pre-exercise nutritional status modulates responses to subsequent exercise (Anderson et al., 2016) and specific interventions (Souglis et al.,



2013), it is therefore recommended that contextual information about the pre-exercise nutritional status of research participants is communicated. Failure to do so likely compromises the ecological validity of these findings to real world settings. Furthermore, results of intervention strategies consumed prior to exercise in a fasted state are likely to influence performance, yet hold limited merit when recommending such strategies in practice.

Thus far limited information is available on the pre-match-dietary practices of Academy soccer players to provide a rationale for recommended pre-exercise dietary practices. Chapter 5 advances the literature in this area, outlining tolerable increases in habitual energy intake to address the issues of significant energy deficit on such days, without detriments to abdominal discomfort impacting on soccer performance.

### **6.3 Limitations**

Specific limitations have been outlined in the individual experimental study chapters (chapter 3-5) relating the chosen methodology. However, the following section will discuss some general limitations associated with working with Academy soccer populations, whilst providing some further information for limitations previously identified.

Due to the elite nature of Academy soccer and competing demands for their time, access to this population can present challenges. As previously mentioned the EPPP recommends 20 h of contact with the Academy per week which can encapsulate a range of training methods. Moreover, each Academy is graded independently and provided with a category status of one to four, with one been considered the most elite. Category

status is subsequently paralleled with funding from the Premier League and Football Association. Whilst there are a number of factors upon which Academies are graded (e.g. strength and conditioning, sports psychology and physiology), the incorporation of sports nutrition does currently not impact the category status. Therefore, Academy directors allocate time accordingly, whilst considering the grading requisites, leaving limited priority for nutritional support. Consequently, conducting nutritional research with Academies, whilst welcomed, is challenging. This factor is reflected in the thesis, for example, whilst support has been provided to demonstrate that the 7-day assessment of energy balance was representative of a typical training week throughout the competitive season, multiple data collections at various time points throughout the season were not feasible due to access restrictions, which may have provided further insight.

The issue of access to this population also impacted on the intervention strategy implemented in chapter 5. Whilst a clear rationale emerged to devise a strategy to increase habitual pre-match energy intake, it is acknowledged that the days leading up to match day are also important. Souglis et al. (2013) observed improved match performance (i.e., total match distances, including increased distance covered in all running intensities performed) when players commenced competition after consuming 8 g·kg<sup>-1</sup> BM of carbohydrate for the 3.5 days prior to the game. However, to prescribe a diet with adequate control during this period was not possible due to player availability.

It is accepted that adolescence is a critical period for growth and maturation, which could be influenced by chronic periods of negative energy balance (Meyer, et al. 2007; Petrie, et al., 2004; Thompson, 1998). Yet due to the acute nature of the study designs,

no longitudinal data was able to be measured to support this assumption. Therefore, whilst information is highlighted to acknowledge the detrimental impact negative energy balance may have both short and long term, evidence of this nature could not be determined.

Methodological issues such as not accounting for under-reporting bias and using subjective measures of energy expenditure estimation were evident in previous studies investigating energy balance in Academy players. Therefore, when planning the data collections stages of this research project, a great deal of consideration was given to which methods were appropriate to gain the most accurate information in adolescent, highly active, free-living populations. It was acknowledged that the estimation of energy expenditure by accelerometry is not as precise as DLW, which is considered the 'gold standard'; however the context of the research and the information required highlighted accelerometry as the most effective method of estimating energy expenditure. It is accepted that the measurement of physical activity by accelerometry, and subsequent conversion to energy expenditure results in lower accuracy, typically observed as a slight underestimation (Rowlands, 2007; Santos-Lozano et al., 2013). Specifically, in a validation study, Santos-Lozano et al (2013) quantified a non-significant under-estimation bias of  $-0.05 \text{ kcal}\cdot\text{min}^{-1}$  when compared to indirect calorimetry. However, when contextualising this figure over a 24 h period, it equates to 72 kcal, which is lower than 110 kcal purported to be clinically meaningful in an energy balance context (Wang et al., 2006). Thus suggesting that the minor under-estimation bias would have limited 'real-world' impact. Furthermore, by utilising accelerometry it was possible to differentiate between type of training/match day and identify fluctuations in energy balance, an aspect which would not be possible with DLW. A

major advantage of this was to understand the importance of periodised nutritional practices for Academy soccer players and identify specifically where the greatest energy deficits were occurring.

#### **6.4 Future direction for research and practice**

It is important to acknowledge that the intervention strategy implemented in chapter 5, whilst augmenting dribbling speed without impacting on abdominal discomfort, produced limited performance benefits. Pre-match intake is essential for subsequent exercise performance (Anderson et al., 2016) as liver and muscle glycogen depletion is attributed as one of the main mechanisms of fatigue in soccer (Krustrup et al., 2006). However, if habitual diet is sub-optimal during the days preceding match-play then simply focusing on pre-match intake may have limited effects on performance. Future research should investigate the performance effects of optimising dietary practices of the Academy soccer play both in the days leading up to match-play and pre-exercise. Previous studies have prescribed such nutritional practices (Souglis et al., 2013), albeit using adult populations. Players consumed either a high ( $8 \text{ g}\cdot\text{kg}^{-1} \text{ BM}$ ) or low ( $3 \text{ g}\cdot\text{kg}^{-1} \text{ BM}$ ) carbohydrate diet 3.5 days prior to match-play. However, this was post season, in which players were involved in relatively light training, not reflecting the training schedule of Academy soccer players. Such information may provide greater insight for optimal nutritional practices during demanding training and competitive schedules.

This far dietary assessment of Academy soccer players has been conducted over 3-7 days (Boisseau et al., 2002; Caccialanza et al., 2007; Iglesias-Gutierrez et al., 2005; Leblanc et al., 2002; Ruiz et al., 2005; Russell & Pennock, 2011). Whilst this may provide an accurate representation of habitual intake, future studies may seek to extend

this period or opt to assess energy intake during multiple time points in the season to identify potential fluctuations. Evidence in chapter 4 highlights a lack of periodised nutritional practice, which is necessary for fluctuating training volumes, however, this may exist throughout other parts of the season.

Bass and Inge (2006) suggest chronic inadequate energy intake in adolescent athletes may result in detrimental effects on aspects of growth and maturation. Whilst chapter 4 identified a significant daily energy deficit resulting in negative energy balance, the impact of this was beyond the scope of the thesis. A longitudinal study tracking player development may provide further insight in to the effects of the negative energy balance identified. Previous research (Theintz, Howard, Weiss & Sizonenko, 1993), attempted to observe the impact of intensive training in gymnasts and swimmers highlighting a delay in linear growth. However, such different training regimes offer little information on Academy soccer players. Moreover, limited information was presented on dietary practices during periods of intensive training. Thus highlighting the need to fully understand the energy requirements to support such developments (Unnithan & Gouloupoulou, 2004), as seldom information currently exists.

## **6.5 Main Conclusions**

Based on the findings of the studies conducted within the present thesis, the following conclusions can be made:

- When using a combined method of dietary data collection (self-reported weighed food diary and 24 h recall), Academy soccer players provided an accurate account of their energy intake.

- Although accurate, Academy soccer players do systematically under-reported energy intake in comparison to that observed but the magnitude of this bias was small and consistent (mean bias =  $-0.37 \text{ MJ}\cdot\text{day}^{-1}$ , 95% CI for bias =  $-0.61$  to  $-0.12 \text{ MJ}\cdot\text{day}^{-1}$ ).
- A correction equation has been developed for use when assessing the energy intake of Academy soccer players, which is as follows;  $y = 1.0397x - 0.1064$  where  $y$  = researcher observed energy intake and  $x$  = player self-reported energy intake.
- The combined approach offers an accurate alternative to current energy intake collection methods, providing both researchers and practitioners with a valuable tool to quantify energy intake in male Academy soccer players, within a free-living environment.
- Over a 7-day period Academy soccer players were in a negative energy balance ( $-1.3 \pm 1.66 \text{ MJ}\cdot\text{day}^{-1}$ ), with energy intake being insufficient to meet the demands of training and competition.
- Heavy training ( $-2.11 \pm 2.26 \text{ MJ}$ ) and match days ( $-2.28 \pm 2.31 \text{ MJ}$ ) are a particular area of concern, inducing the greatest energy deficit relative to energy expenditure.
- Negative energy balance, identified in this population may have both short-term implications for performance and also long-term detrimental impact on growth and maturation.
- Academy soccer players display sub-optimal pre-exercise nutritional practices ( $1.16 \pm 0.13 \text{ MJ}$ ), comprising  $41 \pm 2 \text{ g}$ ,  $10 \pm 4 \text{ g}$  and  $8 \pm 2 \text{ g}$  of carbohydrate, protein and fat respectively, resulting in a macronutrient percentage breakdown of  $60 \pm 6\%$ ,  $15 \pm 4\%$  and  $25 \pm 4\%$ .

- Academy soccer players are able to increase pre-match energy intake without experiencing abdominal discomfort, addressing the previously identified concern of significant energy deficit on such days.
- Increased dribbling speed ( $-4.3 \pm 5.7\%$ ) was identified when habitual energy intake was increased, a finding which may be of benefit to match-play.
- Limited effects on physical performance were seen when increasing pre-match energy intake above habitual levels ( $\sim 1.1$  MJ v  $\sim 2.1$  MJ).

# **CHAPTER 7**

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# **CHAPTER 8**

## **APPENDICES**

## 8.1 APPENDIX A: Dutch Eating Behaviour Questionnaire-Child

### Dutch Eating Behaviour Questionnaire for Children

### Scoring sheet

#### Instructions

Below you'll find 20 questions about eating.

Please read each question carefully and tick the answer that suits you best.

Only one answer is allowed. Don't skip any answer.

There are no incorrect answers; it's your opinion that counts.

1.	Do you feel like eating whenever you see or smell good food?	No	Sometimes	Yes
2.	If you feel depressed do you get a desire for food?	No	Sometimes	Yes
3.	If you feel lonely do you get a desire for food?	No	Sometimes	Yes
4.	Do you keep an eye on exactly what you eat?	No	Sometimes	Yes
5.	Does walking past a candy store make you feel like eating?	No	Sometimes	Yes
6.	Do you intentionally eat food that helps you lose weight?	No	Sometimes	Yes
7.	Does watching others eat make you feel like eating too?	No	Sometimes	Yes
8.	If you have eaten too much do you eat less than usual the next day?	No	Sometimes	Yes
9.	Does worrying make you feel like eating?	No	Sometimes	Yes
10.	Do you find it difficult to stay away from delicious food?	No	Sometimes	Yes
11.	Do you intentionally eat less to avoid gaining weight?	No	Sometimes	Yes
12.	If things go wrong do you get a desire for food?	No	Sometimes	Yes
13.	Do you feel like eating when you walk past a snack bar or fish and chips stand?	No	Sometimes	Yes
14.	Have you ever tried not to eat in between meals to lose weight?	No	Sometimes	Yes
15.	Do you have a desire to eat when you feel restless?	No	Sometimes	Yes
16.	Have you ever tried to avoid eating after your evening meal to lose weight?	No	Sometimes	Yes
17.	Do you have a desire for food when you are afraid?	No	Sometimes	Yes
18.	Do you ever think that food will be fattening or slimming when you eat?	No	Sometimes	Yes
19.	If you feel sorry do you feel like eating?	No	Sometimes	Yes
20.	If somebody prepares food do you get an appetite?	No	Sometimes	Yes

**PLEASE CHECK, TO BE SURE THAT YOU TICKED EVERY QUESTION.**

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## 8.2 APPENDIX B: Example of ethics documents (Informed consent, participation info/debrief, cover letter etc.)

### Consent Form

Please complete section 1 & 2 prior to the start of the study.

Participant No. \_\_\_\_\_

#### Section 1 (parent/guardian)

I agree to my child.....participating in a research project investigating techniques to assess food intake on Saturday 28<sup>th</sup> April. The exact details have been explained to me in the information sheet.

I have been given the opportunity to ask any questions and discuss the procedures the study entails with the organiser of the investigation. I understand that my child will have his height, weight, seated height (for prediction of maturity offset) and food intake assessed.

I understand that my child will be required at Northumbria University City Campus, for approximately 12 hours followed by a 15-minute meeting the following day.

It is not expected that your child will experience any pain or physical discomfort and no psychological discomfort is expected. It is extremely important that we know about any special dietary requirements or food allergies/intolerances your son may have. Please indicate these on the food preference questionnaire enclosed with this letter.

Importantly by agreeing for your child to take part you will be significantly helping to investigate and increase knowledge of an area greatly lacking in research.

The results will be saved on a password protected computer in coded form and will therefore be completely confidential. Your child is free to withdraw at any time and does not have to provide a reason. It is emphasised that his relationship with the researcher and football club will be unaffected. The results of this project may be published, but the information will not be linked to any specific person. You can ask questions about the study at any time. Please do not hesitate to contact me using the details provided on the covering letter or Dr Emma Stevenson [e.stevenson@northumbria.ac.uk](mailto:e.stevenson@northumbria.ac.uk) the project supervisor, to discuss this matter or any other queries further.

Signed.....(parent/guardian)

Signed .....(researcher)

Name (Printed).....

Name (Printed).....

Date.....

Date.....

I would like to receive feedback on the overall results of the study at the email address given below. I understand that I will not receive individual feedback on my own child's results.

☐

Email address.....

#### Section 2 (Participant)

I.....agree to taking part in the study described above, which has been explained to me. I understand what is needed of me during the study and that I can withdraw from the study at any time without affecting my relationship with the football club.

Signed.....(child)

Date .....

## Cover Letter



Faculty of Health and Life Sciences  
Northumberland Building 226  
Newcastle upon Tyne  
NE1 8ST  
marc.a.briggs@northumbria.ac.uk  
Office: 0191 2437913  
Mobile: 07984 177250

Dear Parent/Guardian,

My name is Marc Briggs, I am currently conducting my PhD at Northumbria University, whilst also lecturing on the sport degree programme. I graduated University in 2008 with a first class honours degree in Sport and Exercise Science with Coaching (BSc). Throughout my time at University I have always been interested in nutrition and the effects it can have on increasing performance in football. My PhD will investigate the current dietary habits of adolescent academy and centre of excellence level soccer players in the North East of England. I believe this research is important as current nutritional information for adolescents is largely based on adult data, even though there are very obvious differences between child and adult physiology.

I am very passionate about this area having been in the same position as your son. I have represented Sunderland AFC and Darlington FC, through academy level since the age of 9 years old up until apprentice level. I understand the need for greater awareness of areas which can potentially increase performance. A good nutritional status in particular is imperative to maintaining health, but it is also a critical factor to increasing athletic performance.

I am therefore writing to you to consider this proposal and to ask your permission for your son's participation in a research study on either Tuesday 23<sup>rd</sup>–30<sup>th</sup> April or Tues 7<sup>th</sup>–14<sup>th</sup> May. The study will be conducted by CRB cleared adults. Full details are outlined in the information sheets provided, one for yourself and the other for your son. If you have any questions or would like to discuss any issues further please do not hesitate to contact me on the details provided above. There is no obligation that your son must participate and they will be at no disadvantage if they do not wish to take part.

If your child is able to participate, please sign the informed consent form (signed by both you and your son) and bring this with you to the next training session.

Thank you for your cooperation in this matter.

Yours faithfully,

A handwritten signature in blue ink, appearing to read "M. Briggs".

Marc Briggs Bsc (Hons)

## Participation Information Sheet

Marc Briggs  
Department of Sport, Exercise and Rehabilitation  
Faculty of Health and Life Sciences  
Northumbria University  
Newcastle upon Tyne  
NE1 8ST  
Mobile: 07984177250  
Email: marc.a.briggs@unn.ac.uk

### **PARTICIPANT INFORMATION SHEET**

Congratulations! You are being asked to take part in this exciting study, as you have been identified as a high-level adolescent football player. This is the first study ever study of its kind in the UK, so you should be really proud that you have been selected.

#### **Why are we doing this study?**

We know that nutrition is very important in football and it can help increase performance, but what we don't know is what is the best type and amount of foods for adolescent footballers like yourself, as the only studies that have been done previously are with adults. So once we know exactly how much energy you are using over a typical week and also the types of food and drinks you are having, it will make it easier for us to produce recommendations on what the best diet is to make you perform at top levels.

#### **What will I need to do?**

To track all of your energy you will have to wear a device called an accelerometer which looks like this:



You will wear this accelerometer around your waist for 7 days. The only time you will remove this will be when you shower. To track all of your energy intake, you will record every item of food and drink you consume into a food diary that we will give you. You will also be given a set of scales to weigh all of the food where possible. In addition to this I will also speak to you on the telephone each day to conduct what is called a 24 hour recall which simply means you let me know all of the food and drink

items that you have had on the last 24 hours, which should only take approximately 5-10mins.

#### **How long for?**

7 days

#### **When?**

23rd - 30<sup>th</sup> April or 7<sup>th</sup>- 14<sup>th</sup> May depending on which group you have been allocated

If all of this sounds good and you want to take part then that's great, just let your parent or guardian know. If you can't take part or you don't want to that is fine too. If you start the study and you don't like it and want to drop out then that is no problem either.

Thank you,  
Marc Briggs

Faculty of Health and Life Sciences  
Northumberland Building 226  
Newcastle upon Tyne  
NE1 8ST  
marc.a.briggs@northumbria.ac.uk  
Office: 0191 2437913  
Mobile: 07984 177250

Dear Parent/Guardian

Thank you for taking the time to read this information concerning the study in which your son has been asked to participate. I aim to track all of the energy intake and energy expenditure of the under 15 and under 16 academy squads. Due to the high intensity training workload it is essential that we understand exactly what these academy players are doing, as a negative energy balance can be detrimental to football performance and more importantly health, especially during this critical stage of growth and maturation. Therefore this research will hopefully provide some vital information to structure training and nutritional recommendations.

The Faculty of Health and Life Science's Ethics Committee, at Northumbria University have approved the study and all the procedures involved. Please read all the information carefully in order to decide whether you agree to your child being involved. If you decide to allow your son to participate you will be required to sign the form of consent. Your son will also be required to sign the consent form after reading the information sheet provided. If you decide that you do not want your child to be involved there will be no disadvantage to them

What will my son have to do?

Your son will be wearing an accelerometer around his waist. This is approximately the size of a watch and will be connected around his waist via an elasticated strap. This will measure all of his movements and will be concealed under his clothing. Your son will be required to wear this for 7 days and the only time this should be removed is when he is showering. Your son will simply wear this device without any interruption to his normal daily schedule. In addition your son will be required to complete a food diary to record all of the food he eats. He will need to write down all foods and fluids he consumes. Your son will be required to weigh the food items where possible to help with the accuracy of the information provided.

When will he be doing this?

The study will be over a 7 day period and your son will be allocated to one of two groups, either:

Tuesday 23<sup>rd</sup> – 30<sup>th</sup> April or

Tuesday 7<sup>th</sup> – 14<sup>th</sup> May

Once the groups have been allocated I will inform you via email.

Is there anything I need to do?

No. I am simply contacting you to make you aware of the situation and to request kindly to support this research and encourage your son to keep track of all his food and fluid intake. All information provided will be anonymous and only the researcher will know the exact details provided by your son. Individual food diaries will NOT be given to coaches at SAFC, only anonymous group information will be given.

Safety

All members of the research team have been CRB checked and cleared.

Can participation be ceased?

You and your child can change their mind at any time and decide not to continue participating. If withdrawal does occur reasons for this do not have to be declared and no disadvantages will be experienced. If you do wish to withdraw from the study please contact myself on the above details.

How do I contact you?

If you have any questions about the study please either email me on [marc.a.briggs@northumbria.ac.uk](mailto:marc.a.briggs@northumbria.ac.uk) or ring me direct on 07984177250.

Thank you for your cooperation in this matter.

Kind Regards,

A handwritten signature in blue ink, appearing to read 'M. Briggs', with a stylized flourish at the end.

Marc Briggs (BSc Hons)

## Participant Debrief Form

Marc Briggs  
Department of Sport, Exercise and Rehabilitation  
Faculty of Health and Life Sciences  
Northumbria University  
Newcastle upon Tyne  
NE1 8ST  
Mobile: 07984177250  
Email: [marc.a.briggs@unn.ac.uk](mailto:marc.a.briggs@unn.ac.uk)

Participant Debrief

Participant Number \_\_\_\_\_

### **Energy Intake and Energy Expenditure Assessment in Adolescent Academy Soccer Players**

The study was investigating the total amount of energy you consumed and also the amount of energy you used in a typical week.

Generalised findings will be made available. However if you would like individual feedback or if you have any questions regarding the experiment please contact Marc Briggs (email: [marc.a.briggs@unn.ac.uk](mailto:marc.a.briggs@unn.ac.uk) phone: **07984177250**). You are also reminded of your right to withdraw from the study at any time. If you choose to do so, please use the email address above, giving your confidential participant number code (on top of this sheet) and all your data will be deleted.

If you have any concerns or worries concerning the way in which this research has been conducted, or if you have requested but do not receive feedback from the principal investigator concerning the general outcomes of the study within a few weeks after the study is concluded, then please contact Lesley Fishwick [lesley.fishwick@northumbria.ac.uk](mailto:lesley.fishwick@northumbria.ac.uk)

Thank you for your participation.



Marc Briggs



## Parent Debrief Form

### TITLE OF PROJECT: **Energy Intake and Energy Expenditure Assessment in Adolescent Academy Soccer Players**

Principle Investigator: Marc Briggs

Researcher Email: [marc.a.briggs@northumbria.ac.uk](mailto:marc.a.briggs@northumbria.ac.uk)

Researcher Mobile: 07984177250

#### **1. What was the purpose of the project?**

There is a prevailing need to investigate the dietary habits of adolescent soccer players, as thus far no studies have specifically addressed this issue within English football. The overall aim of the thesis is to ultimately investigate what high-level adolescent soccer players are currently consuming and whether or not their diet is adequate to sustain the demands placed upon them, with regards to training, competition and health. However, before any recommendations are provided it is important to understand exactly what high-level adolescent soccer players are currently doing with regards energy intake and expenditure. Due to the high intensity training workload it is essential that we understand exactly what these academy players are doing, as a negative energy balance can be detrimental to football performance and more importantly health, especially during this critical stage of growth and maturation

#### **2. How will I find out about the results?**

Participants were presented with the opportunity to request a summary of generalised findings prior to the start of the study. If you did not tick the appropriate box on the informed consent form but would like to receive the generalised findings please email the principal investigator Marc Briggs [marc.a.briggs@northumbria.ac.uk](mailto:marc.a.briggs@northumbria.ac.uk). Furthermore, players and parents will be invited to attend a presentation of the results, early next season.

#### **3. Will I receive any individual feedback on my son?**

Individual participant feedback is also available on request, if you require this information please email the principal investigator Marc Briggs [marc.a.briggs@northumbria.ac.uk](mailto:marc.a.briggs@northumbria.ac.uk)

#### **4. What will happen to the information my son has provided?**

To ensure participant confidentiality, the consent forms and data collected will be stored separately in locked cabinets and the raw data will be analysed on a password protected computer so participant anonymity is maintained throughout the research study process. All data will be stored, used and destroyed in accordance with the Northumbria University's Ethics policies and procedures and in accordance with the Data Protection Act (1998).

#### **5. How will the results be disseminated?**

The overall results may be published in a scientific journal or may be presented at a conference, but all of the data will be generalised, and individual information will not be presented.

**6. Has my son been deceived in any way during the project?**

No

**7. If my son changes his mind and wishes to withdraw the information he has provided, how will he do this?**

You and your child can change their mind at any time and decide not to continue participating. If withdrawal does occur reasons for this do not have to be declared and no disadvantages will be experienced. If you do wish to withdraw from the study please contact principle investigator Marc Briggs [marc.a.briggs@northumbria.ac.uk](mailto:marc.a.briggs@northumbria.ac.uk)

*If you have any concerns or worries concerning the way in which this research has been conducted, or if you have requested, but did not receive feedback from the principle investigator concerning the general outcomes of the study within a few weeks after the study has concluded, then please contact Dr Lesley Fishwick (Chair of Ethics Committee) via email at [lesley.fishwick@northumbria.ac.uk](mailto:lesley.fishwick@northumbria.ac.uk)*

### 8.3 APPENDIX C: Food Diary (chapter 3)

# Food Diary



Name.....

Signature.....

Date.....



## **Instructions**

You will need to record EVERYTHING you eat and drink today in this food diary. You will need to weigh each food item before you eat it and if you have any leftovers you will also need to weigh and record this in your food diary. E.g. 2 slices of toast = 20g, if you leave some weigh the left over's which may be 5g, therefore you have eaten 15g. If any of the food items are in packaging, then please remove this before you weigh it. As well as recording the weight of all of the food items you eat, each will have a numbered sticker on it. Please make sure you write the number in your food diary in the column provided. You are free to eat food as you wish, however please make sure everything to eat it weighed and recorded in your food diary.

You will also need to measure out and drinks that you have in the drinks bottles provided.

## **Checklist:**

- Are the scales back to 0g before you start?
- Have you taken off the packaging before you weigh your food item?
- If weighing on a plate have you remembered to subtract the weight of the plate?
- Remember to weigh each item individually
- Have you measure out your drink in ml?
- Have you written down the sticker number in your diary?
- HAVE YOU MEASURED ANY LEFTOVER FOOD?

TIME	DESCRIPTION OF FOOD/DRINK	WEIGHT BEFORE (g or ml)	WEIGHT AFTER (g or ml)	STICKER NUMBER

## 8.4 APPENDIX D: Food Diary (chapter 4)



Name:

Date:

### Instructions

You will need to weigh and record **EVERYTHING** you eat and drink over the next 24 hours in this food diary. That includes Breakfast, Lunch, Dinner and any snacks and Drinks you have in between.

Every time you eat something you **MUST** right down how it was cooked (your mum and dad) can help you with this if you're not sure!

1. BOILED - was it boiled in a pan with water?
2. FRIED - was it cooked in the frying pan with oil?
3. ROASTED - was it roasted in the oven?
4. GRILLED - was it put underneath the grill and cooked?

Keep checking the list of foods on the next few pages to help you know how to describe the foods that you eat and also so you don't forget to record everything. REMEMBER; don't forget about those SNACKS... chocolate, crisps, fizzy drinks etc...

<b>Food/Drink</b>	<b>Description &amp; Preparation</b>	<b>Amount (remember you can write the g, ml or kg values if you have them!)</b>
<b>Bacon</b>	Lean or streaky? Fried or grilled rashers?	Number
<b>Baked beans</b>	Normal or reduced sugar/salt?	Tablespoons, tin size or Picture?
<b>Beef burger/Hamburger</b>	Home-made, packet or take-away? Fried, micro-waved or grilled? With bread roll?	Number
<b>Biscuits</b>	Plain, chocolate, sweet, crisp bread, cheese, wafer, home-made? What brand?	Number
<b>Bread</b>	Wholemeal, granary, white, multigrain? Currant, fruit, malt? Large or small loaf? Thick, medium or thin slices? Brand?	Number of slices
<b>Bread rolls</b>	Wholemeal, granary, white? Size? Crusty or soft? Brand? If with filling remember to record it!	Number of rolls
<b>Breakfast cereal</b>	What sort? Cornflakes, Weetabix etc? What brand?	Number, tablespoons or Picture?
<b>Bun</b>	What sort: Iced, currant, sweet or plain? Large or small? Brand?	Number
<b>Butter</b>	Ordinary or low fat spread? Brand?	Spread: thickly, average or thinly
<b>Cake - small and large</b>	What sort: Cream, iced, chocolate etc...? Brand?	Number, slices or Picture?
<b>Cheese</b>	What sort: hard, soft, spread, cream, low-fat, mature, mild? Brand?	Tablespoons or Picture?
<b>Chips</b>	Frozen, oven, microwave, crinkle-cut, chip-shop, MacDonald's etc? How cooked? In what oil? Brand?	Picture?
<b>Chocolate</b>	What sort: Milk, white, plain? Name and Brand?	Number or weight of bar
<b>Chops</b>	What sort: Lamb or Pork? Lean or fatty? Large or small? Fried, grilled, baked?	Number
<b>Coffee</b>	Include milk & sugar! Skimmed, semi, whole milk?	How much milk/sugar?
<b>Cooking oil</b>	Type, Brand?	How many teaspoons/tablespoons?

<b>Cream</b>	Half, whipping, single, double, clotted, lo-fat, fresh or substitute?	How many tablespoons?
<b>Crisps</b>	Brand name? Normal, lo-fat or lo-salt?	Packet weight
<b>Egg</b>	How was it cooked: boiled, fried, scrambled, poached, omelette etc.	Number and size
<b>Fish</b>	What sort; Fried, boiled, grilled, poached, micro waved? Pickled, smoked, salted? Batter, breadcrumbs? Tinned with oil or tomato sauce? Size? Brand where possible?	How much? Or picture?
<b>Fish fingers/cakes</b>	What sort; large, medium or small? Fried or grilled? Brand?	Number
<b>Fruit - fresh</b>	What type (eg banana, apple, and orange)? Brand (eg Bramley, Golden Delicious)?	Number
<b>Fruit - canned/stewed</b>	In fruit juice or syrup? Type of fruit? With or without sugar?	Tablespoons or tin size
<b>Fruit - juice</b>	What sort; sweetened or unsweetened? Brand?	Glasses or cups, small, medium or large
<b>Gravy</b>	Thick or thin? Instant, packet or homemade?	Tablespoons
<b>Honey</b>	Brand? Clear?	Teaspoons
<b>Ice-cream</b>	Dairy or non-dairy? Flavour, variety? Brand?	Tablespoons
<b>Jam</b>	Brand? Normal or lo-sugar?	Teaspoons
<b>Kidney</b>	Fried or stewed? Pig, lamb or ox?	Picture??
<b>Liver</b>	Fried or stewed? Pig, lamb or ox?	Picture??
<b>Margarine</b>	Soft, hard? Polyunsaturated, lo-fat, very lo-fat? Brand?	Spread thickly, average or thinly
<b>Marmalade</b>	Brand? Normal or lo-sugar?	Teaspoons? Spread thickly, average or thinly
<b>Mayonnaise</b>	Brand? Normal or lo-fat?	Teaspoons
<b>Meat</b>	What sort; lean or fatty? Fried, grilled, roast, BBQ, micro waved etc..? Any gravy? If so see GRAVY on checklist!	Slices, helping or Pictures??
<b>Milk</b>	Full cream, semi-skimmed, skimmed? Sterilized, UHT, flavoured, powdered, Soya?	Pints, glasses or cups



<b>Mince</b>	Beef or Lamb? On its own, with vegetables, gravy (see VEGETABLES and GRAVY on checklist)? Fatty or lean? Brand?	Tablespoons or Picture?
<b>Pasta, Spaghetti</b>	Canned, fresh or boiled? White or wholemeal? In sauce (see SAUCE on checklist)? Brand?	Tablespoons or Picture?
<b>Pie, Pasty, Pastry</b>	What sort: meat, vegetable, fruit etc...? Individual or a slice? What type of pastry? Brand?	Number or Picture?
<b>Peanuts</b>	Dry roasted or ordinary salted? Brand?	Packet weight
<b>Pomide</b>	How made: with all milk, $\leftrightarrow$ milk+ $\leftrightarrow$ water or cream? Type of milk (see MILK on checklist)? With sugar or honey? Brand?	Small, medium or large bowl
<b>Potatoes</b>	Baked, boiled (with or without skin?), mashed, creamed, fried, chips (see CHIPS on checklist), roast, instant? With butter, margarine etc (see BUTTER or MARGARINE on checklist)?	Tablespoons or Pictures??
<b>Pudding</b>	What sort and brand? Is it jelly, mousse, milk pudding, sponge etc? If with cream, see CREAM on checklist.	Tablespoons, slices or Pictures???
<b>Rice</b>	Brown or white? Boiled or fried? Brand? If rice pudding see PUDDING on checklist.	Tablespoons or Picture?
<b>Salad</b>	What ingredients? If with dressing, what type (eg. Oil, vinegar, mayonnaise, salad cream etc...)?	Tablespoons, slices or Picture?
<b>Sandwiches and rolls</b>	See checklist for BREAD, ROLL, BUN, BUTTER, and MARGARINE. Remember to include fillings.	
<b>Sauce - hot</b>	What sort: savoury or sweet? Thick or thin? Recipe or ingredients if possible? Brand?	Tablespoons or Picture?
<b>Sauce - cold</b>	What sort: eg. Tomato ketchup, brown sauce, soy sauce, salad cream? Brand?	Tablespoons or Picture?
<b>Sausages</b>	Pork, beef, pork & beef? Large or small? How cooked (grilled, fried)? Brand?	Number
<b>Sausage rolls</b>	Large or small? Type of pastry? Brand?	Number

Day:

Time	Description of Food	How it was cooked/prepared	Amount/Size (g)	Brand Name

## **RATING OF PERCEIVED EXERTION**

6	NO EXERTION AT ALL
7	
8	EXTREMELY LIGHT
9	VERY LIGHT
10	
11	LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD
16	
17	VERY HARD
18	
19	EXTREMELY HARD
20	MAXIMAL EXERTION

## 8.6 APPENDIX F: Visual Analogue Scale (VAS) Gut Fullness

Participant – .....

Trial – .....

**Time – Immediately post breakfast**

How full do you feel now?

not at all full \_\_\_\_\_ very full

**Time – 30 mins post**

How full do you feel now?

not at all full \_\_\_\_\_ very full

**Time – 60 mins post**

How full do you feel now?

not at all full

very full

**Time – 90 mins post**

How full do you feel now?

not at all full

very full

**8.7 APPENDIX G: Abdominal Discomfort Scale (adapted from Price et al., 2003)**

